Neighbor Route Discovery for Route Optimization in Nested Mobile Networks

Masafumi Watari† Koshiro Mitsuya† Jun Murai‡
Graduate School of Media and Governance, Keio University†
Faculty of Environmental Information, Keio University‡

Network Mobility (NEMO) is needed to provide continuous network connectivity and movement transparency to nodes which moves together as a group, like in a moving vehicle. The protocol is currently being standardized at IETF with a solution called NEMO Basic Support. However, the protocol lacks features for Route Optimization, which becomes a critical problem when a mobile network attaches behind another mobile network creating a form called, Nested Mobile Networks. This paper address the problems of nested mobile networks, and propose Neighbor Route Discovery as its solution. From our experimental evaluation, we show the effects of nested mobile networks, and evaluate the effectiveness of our proposal through a prototype implementation.

1 Introduction

A vehicle consists of many sensor devices and computers built inside the vehicle, together with devices carried by passengers. The devices will be connected to the Internet to provide entertainment to passengers, and to utilize the information of each sensors. For example, the speed meter of a vehicle combined with its location information can create traffic information, built in cameras can provide live pictures of its surroundings for more detail information, and opening of the air bags can indicate accidents occurring real time and can be further used to inform the event to a rescue team.

A need for a NEtwork MObility (NEMO) [3] [4] arises where the nodes move together as a group, like in a vehicle, changing its point of attachment to the Internet. These devices will be connected to the network built inside the vehicle, and the vehicle would provide network connectivity to them [9]. A router carrying of the network is in charge of providing movement transparency to the network, and the devices attached in the network would see the network as any static network. Compared to approaches like Mobile IPv6 [1], where each host has the mobility support, NEMO only requires the router to have the mobility function. Since some sensor devices are not capable of having additional functions, NEMO is more cost efficient, preserving network resources which are valuable in mobile environments.

NEMO is currently being discussed and standardized at IETF, with a solution called the NEMO Basic Support protocol [2]. The NEMO Basic Support protocol aims to provide a generic solution to support network mobility, and as a drawback lacks consideration for "Route Optimization." Route optimization can provides better communication performance for nodes attached behind the mobile network. Route optimization is especially needed for applications which require real-time communication such as Voice over IP and video conference applications since the delay caused by the inefficient routing can be critical.

In this paper, we focus on the case where a mobile network is attached behind another mobile network called, "Nested Mobile Network" and introduce Neighbor Route Discovery (NRD) protocol to provide route optimization in nested mobile networks. NRD aims to provide route optimization in the nested mobile network by exchanging routes of the other mobile routers in the nest. NRD allows optimization with nodes attached behind the same nest, and also with nodes attached behind two distinct nests.

The rest of this paper is organized as follows: we first describe the protocol of the NEMO Basic Support and the define nested mobile networks in Section 2. We address the problems of nested mobile network and its complexity with nested correspondent nodes in Section 3. Section 4 discuss related work. We introduce NRD as a solution to provide route optimization in Section 5. We show the results of our experiment with the NEMO Basic Support and our prototype implementation in Section 6 and conclude the paper in Section 7.

2 Nested Mobile Networks

NEMO Basic Support protocol is currently being discussed at the NEMO WG at IETF to provide network mobility in IPv6 Internet. Figure 1 shows the basic overview of network mobility. The router carrying the mobile network is called the Mobile Router (MR), and provides continuous network connectivity to the mobile network nodes at-

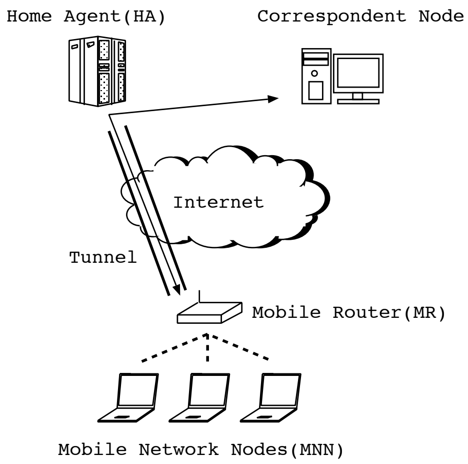

Figure 1: Overview of Network Mobility

tached behind it. Each MR is registered to a Home Agent (HA) which forwards packets destined to the mobile network to the corresponding MR. The MR and the HA always use a IP-in-IP encapsulation for all packets related to the mobile network. Whenever the MR moves to a different access network, it informs the HA with its new IP address configured on the link, called the care-of address. When a correspondent node sends packets destined to the mobile network node, the packet is intercepted at the HA, and then forwarded to the care-of address of the MR. HA also assigns each MR an unchanging IP address, called the Home Address and maintains bindings of the two addresses for each MR.

A nested mobile network is a case where a mobile network is attached behind another mobile network. For example, passengers with its own mobile network, called the Personal Area Network (PAN) may move in to a mobile network inside a vehicle creating a form of a "nest." Figure 2 shows an example of a routing in a nested mobile network. With the NEMO Basic Support protocol, each MR creates a tunnel with its HA, thus each packet is encapsulated twice before being sent to and from the nest. When the correspondent node sends packets destined to the mobile network nodes, the packet is first intercepted by HA2, and tunneled to MR2. Since MR2 is attached behind MR1, the packet is then routed to HA1 which tunnels the packet to MR1. The packet is then sent to MR2 via MR1 and finally to the MNN. The number of encapsulation and the number of forwarding to the HA depends on the nested level and the location of the

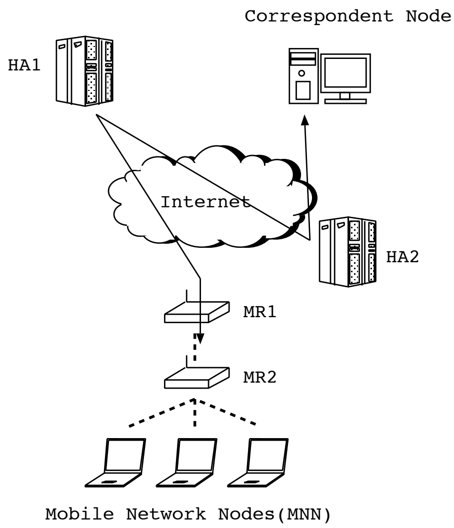

Figure 2: Nested Mobile Network

communicating nodes.

3 Problem Statement

As described in Section 2, the NEMO Basic Support protocol uses a bi-directional tunnel established between the mobile router and it's HA for all communication. Such model brings delay in packets since the path via the HA is often inefficient compared to the direct path between the two nodes. Furthermore, if the mobile network is a nested mobile network as shown in figure 2, the packets must go via each HA before being forwarded to the destination node, which causes even more delay. Such inefficient routing will pose crucial problems for real-time applications such as VoIP. It also wastes bandwidth, causing traffic congestion and even packet losses. Moreover, heavy traffic load is given to the HA regardless of the location of the two end nodes. Since all packets which are tunneled from the MR to the HA uses IPsec and also requires the HA to decapsulate each packet, heavy processing load can be expected. If a failure of the HA occurs, the communication is terminated regardless of the network condition between the mobile network node and the correspondent node.

The complexity of nested mobile network and the delay given to the packets becomes much more significant when the communication involves nested correspondent nodes. A nested correspondent node is a correspondent node which is located behind a nested mobile network. Figure 3 shows the differ-

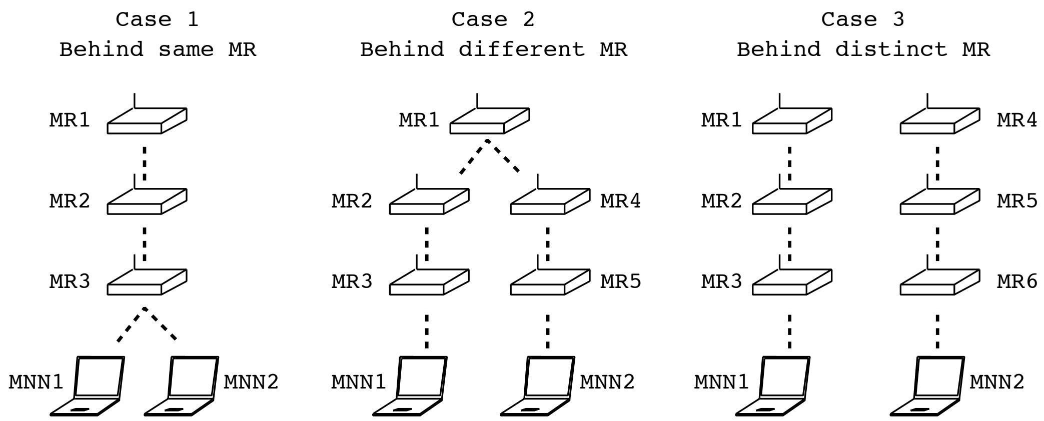

Figure 3: The different cases of Nested Correspondent Nodes

ent cases of a nested correspondent node.

Case 1 in figure 3 shows the case where both MNN1 and MNN2 is located behind the same MR. If both MNN1 and MNN2 are Local Fixed Nodes (LFNs), no special function is necessary for optimization of their communication. Similarly, if both MNN1 and MNN2 are Visiting Mobile Nodes (VMNs) and support route optimization, the flow will eventually be optimized based on the route optimization defined in Mobile IPv6. However, if one of the node is LFN and the other a VMN, Mobile IPv6 route optimization can not be performed. Therefore, VMN will establish a bi-directional tunnel with it's HA, which causes the flow to go out the nested mobile network.

Case 2 in figure 3 shows the case where the two communicating nodes are connected behind a different MR, but the MRs connected behind the same nested mobile network. If both MNNs are LFNs, then optimization within the mobile routers are needed. If both the MNNs are VMNs, then the flow will eventually be optimized based on the route optimization defined in Mobile IPv6, but still requires optimization among the mobile routers. As with case 1, if one of the node is LFN and the other a VMN, Mobile IPv6 route optimization can not be performed. Therefore, VMN will establish a bi-directional tunnel with it's HA, which causes the flow to go out the nested mobile network.

Case 3 in figure 3 shows the case where the two communicating nodes are connected behind distinct nested mobile networks. Similar with Case 2, optimization among the MRs are needed regardless of the node type of the MNNs. Additionally, it would require a scheme to discover the MRs attached behind the corresponding nest. Otherwise, packets are routed to the HAs even after optimizing the path within the nest.

4 Related Work

The NEMO Extended Support is supposed to support route optimization in mobile networks, to provide better communication performance and many proposals [5] [6] [8] have been proposed. The proposed mechanisms allow route optimization in nested mobile networks. However, they often assume the correspondent node to be located at the infrastructure, and thus the route optimization is achieved with a Mobile IPv6 correspondent node, Correspondent Router, or an IPv6 node using a bi-directional tunnel with the HA from the root-MR. Thus, route optimization is not possible with correspondent nodes that are also located behind the nested mobile network. Furthermore, the proposed schemes for route optimization uses multiple tunneling, one for each mobile router it goes through, or multiple routing headers to forward packets to the other mobile routers in the nest. Because the number of headers increases as the level of the nest becomes deeper, the overhead is simply increases by the number.

5 Neighbor Route Discovery

5.1 Protocol Overview

In this paper, we introduce Neighbor Route Discovery (NRD) for route optimization in nested mobile networks. The NRD protocol aims to achieve route optimization with minimum tunneling overhead and without any routing headers. The concept of NRD is to treat the nested mobile network as a single static network.

For example, packets destined to other mobile network nodes in the same nest are routed within the network without any extension headers, nor any tunneling. This allows a mobile network nodes to communicate in the optimized route with other mobile network nodes attached in the same nest, but behind a different mobile router, without any forwarding to and back from the HAs.

For packets destined to mobile network nodes attached behind another nested mobile network, single tunnel is used between each root-MR, and then routed within the other nested mobile network. Similarly, packets destined to correspondent nodes located at the infrastructure are tunneled directly either to the correspondent node, correspondent router, or to the HAs.

A new ICMPv6 messages called Neighbor Route Discovery is introduced, to discover routes to other mobile routers in the nest. The messages are used by each mobile router in the nest to create routes for other sub-MRs behind them.

Neighbor Route Discovery Request

The message format of the Neighbor Route Discovery Request message is defined in Figure 4. The message is sent to inform the root-MR, of the mobile network prefix it's carrying and the IP address of it's HA. The mobile network prefix field includes the prefix obtained by the MR, and its prefix length in the prefix length field. The identifier is used to match the corresponding reply message.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |     Code      |          Checksum             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Identifier          |   Reserved    |Prefix Length|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                     Mobile Network Prefix                     +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                          HA's Address                         +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4: Neighbor Route Discovery Request

Neighbor Route Discovery Reply

The message format of the Neighbor Route Discovery Reply message is defined in Figure 5. The message is sent in reply to the request message received from the sub-MR. When successfully processing the Neighbor Route Discovery Request message, it MUST return a reply message with the status code of 1. Otherwise it should return a error with the status code of 255. The identifier is used to match the corresponding request message.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |     Code      |          Checksum             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Identifier          |          Reserved             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5: Neighbor Route Discovery Reply

Nest Optimization Option

The router advertisement message sent by the MR for its mobile network should use Nest Optimization Option to inform other MRs attaching behind it for the form of a nest. The message format of the option message is defined in Figure 6. The care-of address should include the address of the root-MR. The sub-MRs receiving the messages should relay the option by adding it to their router advertisement message.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |    Length     |          Reserved             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Reserved                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                         Care-of Address                       +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6: Nest Optimization Option

5.2 Routing within a nested mobile network

The NRD assumes to trust neighbor MRs. Once the MR attaches behind another MR, it receives an extended router advertisement messages from the root-MR. The sub-MR should send a binding update to it's HA with an alternative care-of address option including the care-of address of the root-MR obtained from the extended router advertisement message. This is to inform the HA of the care-of address of the root-MR, to allow packets to be tunneled from the root-MR. The binding update messages should have a flag indicating such purpose and the HA should not use the care-of address to tunnel packets for the sub-MR.

The sub-MR then sends Neighbor Route Discovery request to the default router obtained from the router advertisement message. When the root-MR receives the request, it creates a route to the sub-MR for the prefix given in the request message. The root-MR also adds the HA address of the sub-MR in its prefix table along with the sub-MR's prefix information. The root-MR must then reply back with a Neighbor Route Discovery Reply.

Once the sub-MR receives the Neighbor Route Discovery Reply, it forwards all packets originating from it's mobile network to the root-MR. For packets which it has routers for, the root-MR routes them directly to the corresponding sub-MR. If the root-MR does not have routes for the destination, it tunnels the packet to the HA of the sub-MR according to the prefix table.

5.3 Routing to the nested mobile network

The tunnel end point for a nested mobile network should be the root-MR of the nest. Packets from correspondent nodes, correspondent routers, and other mobile networks are tunneled to the care-of address of the root-MR with a single tunnel encapsulation. When the root-MR decapsulate the tunneled packet, it can route packets using their routing table.

Any packet destined to a mobile network node will first be routed to the HA of the MR which it is attached to. Since the sub-MR receives tunneled packet from it's HA, it knows the corresponding node is not located in the same nest and should perform route optimization. The sub-MR should notify the care-of address of the root-MR to the correspondent node, correspondent router, or to the other root-MR. How to establish bindings with such nodes are explained in [7].

Outgoing packets from the nested mobile network, are tunneled from the root-MR to the correspondent node, the correspondent router, the HA of the sub-MR, or to the root-MR of another nested NEMO.

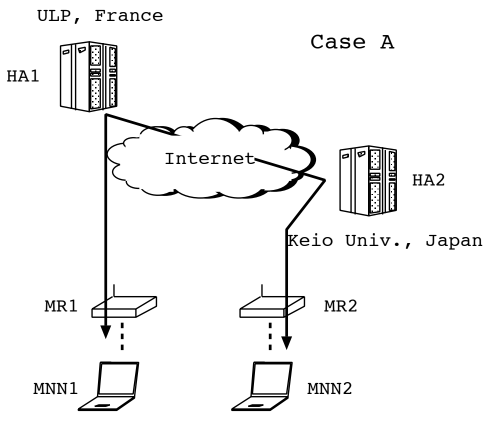

Figure 7: Generic NEMO configuration

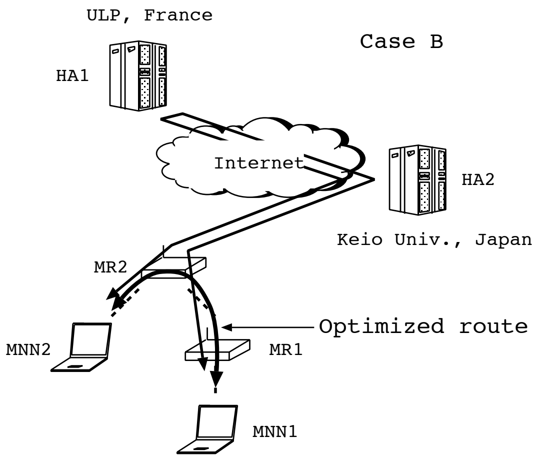

Figure 8: Nested NEMO configuration

6 Experimental Evaluation

6.1 Experimental Network

As an evaluation of our proposal, we performed an experiment to measure the communication performance using the NEMO Basic Support protocol, and then compare the results with the prototype implementation of the NRD protocol. In our scenario, we assume each person to have a PAN carrying sensor devices, PDA's or mobile phones and each are attached to the network as mobile network nodes. The PAN is supported by NEMO, and the HAs are placed at their office. When the PAN attaches behind another PAN, it would create a nested mobile network.

In Figure 7 (Case A) and Figure 8 (Case B), we show the configuration of the network used in the experiment. Each MR has its own HA, where MR1 is supported by HA1 and MR2 is supported by HA2. HA1 is placed at University Louis Pasteur (ULP) in Strasbourg, France. HA2 and both MRs are placed at K2 Campus of Keio University in Kawasaki, Japan. Figure 7 shows the case where each MR is attached to the Internet independently, and Figure 8 shows the case where MR1 is attached behind MR2, creating a nested mobile network. The arrows represent the path in which the packet

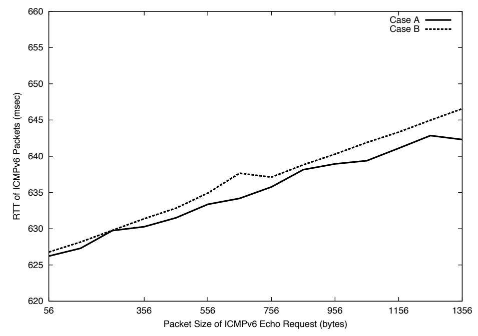

Figure 9: RTT between MNNs

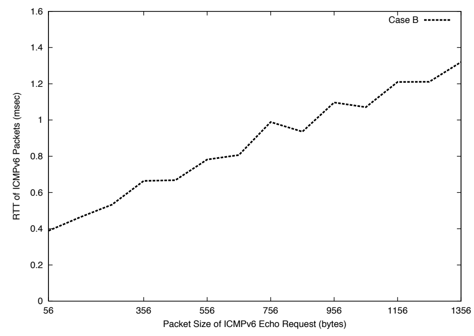

Figure 11: RTT between MNNs with NRD

takes. The NEMO implementation used was provided by the Nautilus6 Project [10] of WIDE.

6.2 Experimental Results

The experiment was based on Round Trip Time (RTT) values from the MNN1 to MNN2 using ping6. An ICMPv6 Echo Request of 56 bytes was sent from MNN1 every second for 100 times. The test was then conducted by adding 100 bytes each time up to 1356 bytes. Figure 9 shows the results in average of the 100 packets, for both Case A and Case B.

For Case A, even though both MRs are attached on the same link, the RTT value was greater than half a second, because packets had to be routed through each HA. For Case B, the RTT values are larger than that of Case A, because the packet is tunneled twice before going out from the nested NEMO. The experiment clearly shows that further level of the nest cause more delay to packets. Furthermore, we also found that large packets causes severe packet losses. To analyze the the packet losses caused at different packet sizes, we measured

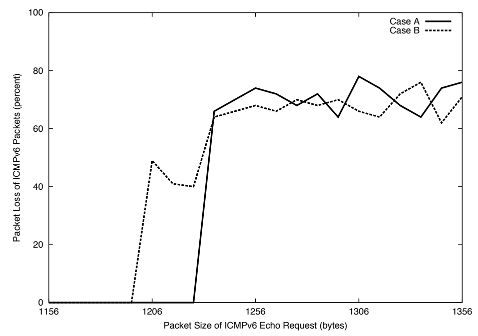

Figure 10: Packet Loss between MNNs

the loss using ping6 both Case A and Case B. The test used ICMP Echo Request messages of 1156 bytes, sent from MNN1 every second for 100 times. We then added 10 bytes each time up to 1356 bytes. Figure 10 shows the results in average of the 100 packets.

Although the values may vary depending on the network, our experiment showed the effects of what the nested mobile network causes to the packets.

We then conducted the same test using the prototype implementation of NRD under Case B. The bold arrow in Figure 8 represent the optimized path in which the packet takes for both ways using NRD. Figure 11 shows the results in average of the 100 packets starting from 56 bytes to 1356 bytes, by 100 bytes.

The effectiveness of the NRD protocol is significant, since the packets are not routed to the HAs. For packets destined in within the same nest, our scheme can provide the optimization without any routing headers or IP-in-IP encapsulation to cause fragmentation. For packets destined outside the nest, it would only require a single encapsulation, and provide far better communication performance compared to the NEMO Basic Support protocol.

7 Conclusion

In this paper, we introduced Neighbor Route Discovery (NRD) to provide route optimization in nested mobile networks. NRD aims to provide route optimization in the nested mobile network by exchanging routes of the other mobile routers in the nest. The NRD can achieve route optimization with minimum tunneling overhead and without any routing headers. From our experimental evaluation, we showed effects of the nested mobile network under the NEMO Basic Support protocol, and the effectiveness of the NRD protocol was shown with its prototype implementation.

As a future work, we continue to implement the proposed protocol to support all cases mentioned in this paper, evaluate them based on the implementation. Evaluations should include the time required for the aggregation of the routes, and for the recovery after the sub-MRs moves. Additionally, authors plan to further discuss security considerations.

Acknowledgment

Authors would like to thank University Louis Pasteur and Keio University for providing the network, and the Nautilus6 Project for the NEMO implementation.

References

[1] Johnson, David B. and Perkins, C. and Arkko, Jari. Mobility Support in IPv6, June 2004, RFC 3775

[2] V. Devarapalli, R. Wakikawa, A. Petrescu, and P.Thubert, " Network Mobility (NEMO) Basic Support Protocol" June 2004. Work in Progress, draft-ietf-nemo-basic-support-03.txt

[3] T. Ernst,"Network Mobility Support Goals and Requirements" February 2004. Work in Progress, draft-ietf-nemo-requirements-02.txt

[4] T. Ernst, and H-Y. Lach, "Network Mobility Support Terminology" February 2004. Work in Progress, draft-ietf-nemo-terminology-01.txt

[5] P. Thubert, and M. Molteni, "IPv6 Reverse Routing Header and its application to Mobile Networks" June 2004. Work in Progress, draft-thubert-nemo-reverse-routing-header-05

[6] Hosik Cho, Eun Kyoung Paik, and Yanghee Choi, "BU: Recursive Binding Update for Route Optimization in Nested Mobile Networks," IEEE VTC 2003-Fall, October 2003.

[7] R. Wakikawa and M. Watari, "Optimized Route Cache Protocol" July 2004, Work in Progress, draft-wakikawa-nemo-orc-00.txt

[8] J. P. Jeong, K. Lee, J. Park, and H. Kim, "ND-Proxy based Route and DNS Optimizations for Mobile Nodes in Mobile Network " February 2004, Work in Progress, draft-jeong-nemo-ro-ndproxy-02.txt

[9] T. Ernst, K. Uehara. *Connecting Automobiles to the Internet*, Proceeding of ITST2002, November 2002.

[10] 'Nautilus6 Project'. http://www.nautilius6.org/, July 2004.