HMNR scheme based Dynamic Route Optimization to Support Network Mobility of Mobile Network

Moon-Sang Jeong[1], Jong-Tae Park[1], and Yeong-Hun Cho[2]

[1] School of Electronic and Electrical Engineering, Kyungpook National University 1370, Sankyuk-Dong, Buk-Gu, Daegu, Korea
{ msjeong, jtpark }@ee.knu.ac.kr
[2] Department of Information and Communication, Kyungpook National University 1370, Sankyuk-Dong, Buk-Gu, Daegu, Korea
yhcho@ee.knu.ac.kr

Abstract. A lot of recent research has been focused on developing network mobility management to support the movement of a mobile network consisting of several mobile nodes. In the mobile ad-hoc network environment, network itself can be moved to another point. For the network mobility, the IETF NEMO working group proposed the basic support protocol for the network mobility to support the movement of a mobile network consisting of several mobile nodes. However, this protocol has been found to suffer from the so-called 'dog-leg problem', and despite alternative research efforts to solve this problem, there are still limitations in the efficiency for real time data transmission and intra-domain communication. Accordingly, this paper proposes a new route optimization methodology that uses unidirectional tunneling and a tree-based intra-domain routing mechanisms which can significantly reduce delay in both signaling and data transmission.

1 Introduction

As the technology related to the wireless and mobile ad-hoc network environments is rapidly being developed, it increases the necessity for research about network mobility that could support the ad-hoc mobility of not only a single mobile node but also the movement of a mobile ad-hoc network which consists of several mobile nodes [1]. The most representative work is that of the IETF (Internet Engineering Task Force) NEMO (Network Mobility) working group. The IETF NEMO working group has proposed several Internet drafts [2], [3], [4].

The NEMO basic support protocol defines a methodology for supporting network mobility by using bi-directional tunneling between the home agent and the MR(Mobile Router). It extends binding messages of Mobile IPv6 and the data transmission of a mobile network can be achieved by using the MR which is the egress interface of a mobile network. In other words, only the MR is involved in the acquisition of CoA (Care of Address) according to a handover of the mobile network. A MNN (Mobile Network Node) which is connected to the MR can maintain their home network address. The NEMO basic support protocol defines basic procedures to support network mobility of a mobile network, but excludes route optimization, multi-homing, and other issues. These issues are examined in the extended network mobility support part. In particular, the basic support protocol has a serious problem called dog-leg problem; that is, all traffic to or from the MNN of the nested mobile network passes through the HAs (Home Agents) of all preceding mobile networks. To solve this problem, various methodologies have been proposed [5], [6], [7]. However, these ideas are still inefficient for real time data transmission and they remain as the optimal route because they are based on bi-directional tunneling between the root-MR and HA of the nested mobile network. Furthermore, direct message exchange between the MNNs within the same root-MR, which is called intra-domain communication, is not supported and the root-MR can experience a very heavy load because it must maintain full paths for all nested MRs. If there are frequent movements of mobile networks, and intra-domain communication is large, these methodologies are very inefficient. Thus, most previous methods have limitations with regard to signaling overhead, concentrated traffic and load in the root-MR, and packet-header overhead due to multiple encapsulations.

Accordingly, this paper proposes a new route optimization methodology for the efficient support of network mobility based on unidirectional tunneling between the HA of a nested mobile network and the root-MR, and the use of a tree-based intra-domain routing mechanism. The use of unidirectional tunneling facilitates more optimized route construction. When using tree-based routing for intra-domain communication and binding procedures, a hierarchical mobile network routing is more efficient and faster than previous tunneling mechanism for signaling and data transmission.

2 Previous Works

The IETF NEMO working group has defined a basic protocol operation to support the network mobility of a mobile network based on Mobile IPv6. There have already been several Internet drafts related to the goals and requirements, terminology, and basic support protocol for network mobility. Network mobility is essentially defined as Nemo basic support and Nemo extended support, where the purpose of Nemo basic support is to preserve session continuity in a mobile network, while Nemo extended support provides more optimal routing for a nested mobile network [4]. The goal of the Nemo basic support protocol is to support network mobility and backward compatibility by extending Mobile IPv6. As such, its definition of the MR extends the MN of Mobile IPv6, where the MR performs internal routing and external data transmission for an MNN, which moves with the MR. Data transmission between the MNN and the CN is performed using bi-directional tunneling between the HA and the MR. All traffic passes through the HA, and IPSec is used for secure signaling between the MR and the HA [4].

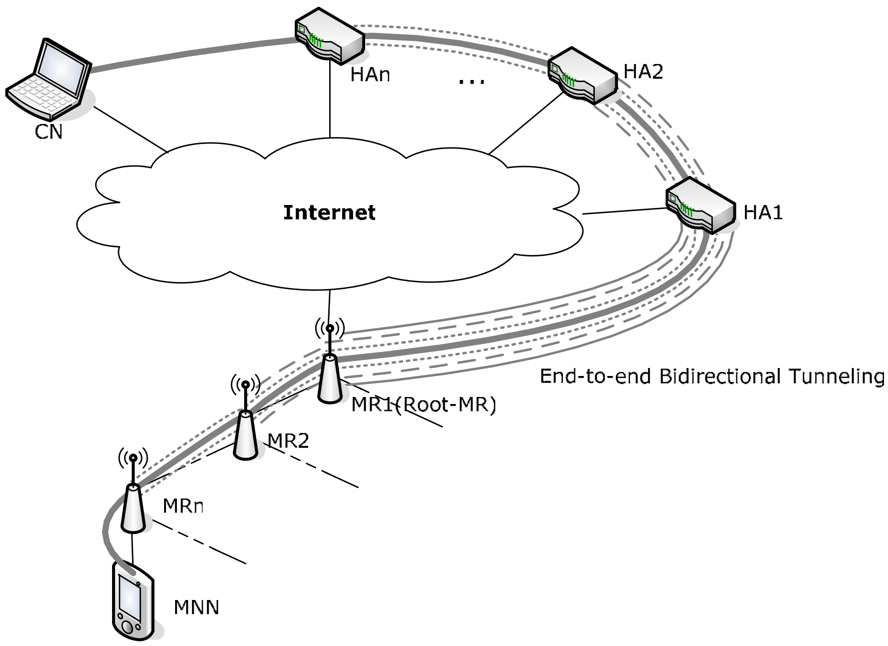


Fig. 1. Dog-leg problem in Nemo basic support protocol

In a mobile network on a visited link, a bi-directional tunnel is created between the HA and the MR for data transmission. Thus, data transmission by a mobile network is achieved using the MR, which is the egress interface of the mobile network. In other words, since only the MR is involved in the acquisition of a CoA in a mobile network handover, an MNN behind the MR can maintain its home network address. For the construction of a bi-directional tunnel, the basic support protocol extends the binding message of Mobile IPv6. The extended BU(Binding Update) message contains a network prefix instead of a home address, and the egress interface address of the MR as the CoA. Thus, by using these extensions, network mobility can be supported without changing the addresses of the MNNs in the mobile network.
The Nemo basic support protocol defines the minimal procedures and extensions required to support network mobility, as such it does not cover route optimization, multi-homing, and so on. Although these issues are being investigated under Nemo extended support, the work has not yet been completed. In the basic support protocol, the tunnel of a nested mobile network is constructed through all preceding mobile network tunnels, and all the traffic of the nested mobile network passes through the HAs of all preceding mobile networks, thereby causing a serious problem called the 'dog-leg problem'. Fig. 1 shows an example of the dog-leg problem in the basic support protocol.
Recently, a lot of research has focused on solving the dog-leg problem, including route optimization of the basic support protocol [5], [7], [9]. Several previous studies on route optimization have used bi-directional tunneling between the HA of the

nested mobile network and the root-MR, where two bi-directional tunnels are made between the HA of the nested mobile network and the root-MR, and between the root-MR and the MR of the nested mobile network. By using direct tunneling between the HA of the nested mobile network and the root-MR, the dog-leg problem is solved. Yet, an extended RA(Router Advertisement) message that includes an address of the root-MR egress interface is required to discover and notify the root-MR address to the nested MRs.

Most of previous works in route optimization have used bidirectional tunneling. The methods using bidirectional tunneling has some drawbacks for real-time data transmission. Since these methods have more complex signaling than the basic support protocol. Because if the root-MR moves along with the nested mobile network, the nested mobile network must re-establish the tunnel since the root-MR address was changed. In addition, these methods do not support intra-domain communication, because all traffic passes through either the HA of the nested mobile network or at least the root-MR. The root-MR must maintain full paths for the MRs of all nested mobile networks. If there are frequent movements of mobile networks, these methods become very inefficient due to the large signaling overhead, large data transmission delay, traffic concentration in the root-MR, and packet header overhead resulting from multiple encapsulations. Therefore, a new route optimization methodology is needed to support efficient signaling and optimized routes.

3 Hierarchical Mobile Network Routing Scheme

3.1 Basic Operation of HMNR

To solve the problems as stated above, this paper proposes a HMNR(Hierarchical Mobile Network Routing) scheme consisting of intra-Nemo routing and extra-Nemo tunneling, where tree-based routing is used for intra-domain data transmission and signaling, while unidirectional tunneling is used for data transmission to or from the external network. Fig. 2 shows the operation of the HMNR scheme for route optimization. As shown in Fig. 2, an MNN behind the MR cannot receive data from the CN directly since a mobile network uses the network prefix of the home network. However, data from an MNN can be directly transmitted to the CN using a normal routing scheme. In other words, although a tunnel is required for data transmission from the HA to the MR, the other tunnel from the MR to the HA does not need to be established to optimize the route. As a result, the MNN can communicate with the CN using only a unidirectional tunnel from the HA to the MR. Similarly, route optimization for a nested mobile network can be achieved using unidirectional tunneling from the HA of the nested mobile network to the root-MR by binding the network prefix to the CoA of the root-MR. Only the root-MR can perform decapsulation of the packets from the CN.

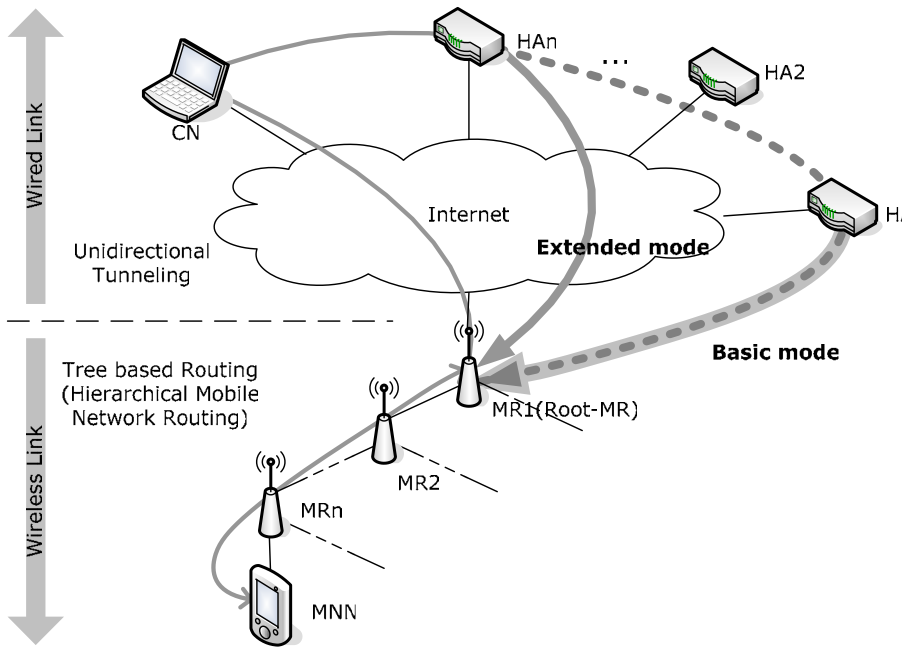


Fig. 2. HMNR Scheme for Route Optimization

The direct tunneling between the HA of the nested mobile network and the root-MR requires the additional handover procedure because the binding address of the mobile network needs to be changed for the root-MR movement along with the nested mobile network. Thus, the handovers are divided into three cases: inter-Nemo, intra-Nemo and root-MR handover. In the vehicular environments, the root-MR handover frequently occurs and it accompanies with the mass signaling for all nested mobile networks, and the root-MR suffers from the large processing load, bottleneck and the service discontinuity.

To satisfy the requirements, this paper proposes the HMNR scheme with two operating modes for the signaling efficiency and route optimization respectively: the basic mode and the extended mode. In the extended mode, the route optimization is performed by using the direct tunneling from the HA to the root-MR. On the other hands, the MR in the basic mode binds its network prefix to the HoA of the root-MR, thus the data from the CN to the MNN passes through both HAs of the MNN and of the root-MR. By using this mechanism, the MR is independent of the root-MR handover. Moreover, the route is more optimal than the one of the basic support protocol with same signaling complexity because the HMNR scheme has only two intermediate HAs regardless of the nested level of the mobile network. Each operating mode is dynamically switched by sending the BU message including the HoA or CoA of the root-MR for the binding address. Thus the MR decides the basic mode for the vehicular environment with low data traffic, and it can switch into the extended modes if the data traffic or inter-Nemo handover is increased.

3.2 Routing & Handover Procedures

Mobile networks are composed of a tree topology from the root-MR to the MRs of each nested mobile network, where only the root-MR has an egress interface for transmitting data to or from the external network. Thus, a new routing mechanism based on a tree topology is needed where the root-MR is the root of the tree and the nested MRs are the tree nodes. In a tree-based routing scheme, each MR contains a parent-MR address as a default route entry and maintains a routing table that consists of a mobile network prefix and next hop address pairs for each nested mobile network. In this case, the traffic from the root-MR to the CN is transmitted using the default route entry of the root-MR, that is, an AR(Access Router) instead of tunneling. The routing process is completed by updating the routing entry, which consists of a mobile network prefix and new MR's CoA pair, to the parent-MR, then the parent-MR updates its routing entry and resends the RU message to its parent-MR recursively. At this time, the RU message from the parent-MR has a new next hop address as the CoA of the parent-MR. If an RU message reaches the root-MR or a crossover MR that contains the same routing entry in the RU message, the routing update procedure is completed. The proposed HMNR scheme can also support intra-domain data communication without passing through the HA, because the MR maintains the routing information while providing a routing for transmitting data from MNNs. Traffic can also be transmitted to its destination without passing through the root-MR, if a crossover MR exists which contains a routing entry to the destination.

To support the binding and routing of HMNR, an RA(Router Advertisement) message extension is needed to discover the root-MR and advertise its information. The HMNR also requires a Root-MR Option, which contains the CoA and HoA of the root-MR, and an RA message with the Root-MR Option is used to advertise the addresses of the root-MR.

When a mobile network detects movement, the MR sends an RS(Router Solicitation) message to acquire a network prefix for the foreign network. If an RS message is received, the parent-MR or access router then responds to the MR with an RA message and Root-MR Option. As such, the handover procedures can be decided using an RA message. Fig. 3 shows the RA message handling procedures for supporting an inter-domain and intra-domain handover.

An inter-domain handover includes two cases where the mobile network obtains a new root-MR address: inter-Nemo handover or root-MR handover.

In the former case (*inter-Nemo handover*),

(1) The MR obtains a new CoA

(2) The MR processes a binding procedure between the HA and the root-MR using the address for the root-MR obtained by exchanging RS and extended RA messages with a Root-MR Option.

(3a) The MR sends an RU message with its own network prefix and CoA to the parent-MR for intra-Nemo data transmission.

(4a) Finally, the MR advertises the root-MR address to the nested mobile network by using an RA message with a Root-MR Option.

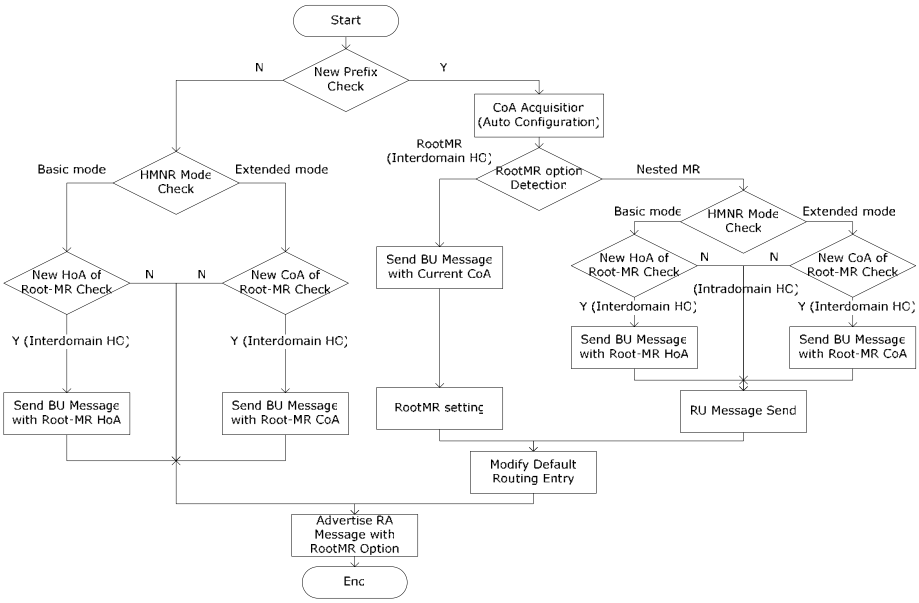


Fig. 3. RA Message Handling Procedures for supporting Inter-domain and Intra-domain Handover

(3b) Conversely, if the MR receives an RA message without a root-MR address option, this means that the MR is directly connected to the AR, in which case, the MR does not perform a routing procedure, but rather sets itself up as the root-MR

(4b) The MR advertises an RA message with its CoA to the nested mobile network.

In the latter case (*Root-MR handover*),

(1) The preceding MR obtains a new CoA

(2) The preceding MR performs a handover procedure similar to the former case

(3) Then it advertises a new root-MR address to the nested mobile network. If a mobile network receives an RA message with a new root-MR address

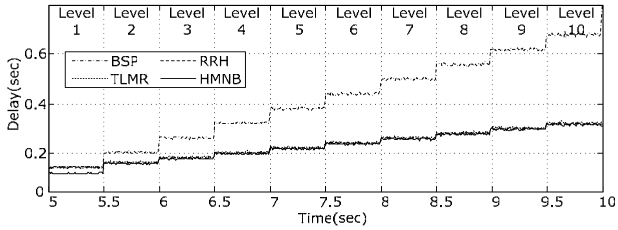
(4) If the MR uses the HMNR extended mode then, the MR reestablishes the unidirectional tunnel between the HA and the new root-MR CoA

(5) Finally, the MR advertises the root-MR address to the nested mobile network.

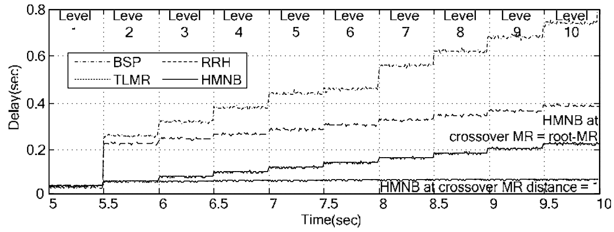
Meanwhile, an intra-Nemo handover occurs when a mobile network moves within the root-Nemo domain, that is, the root-MR address is not changed. In this case, the MR does not need to update the binding to the HA and only performs a routing procedure.

4 PERFORMANCE ANALYSIS

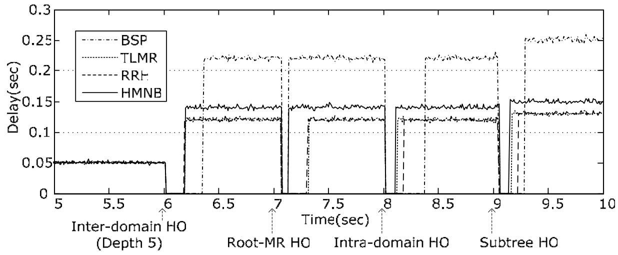
We evaluated the performance of the proposed hierarchical mobile network binding scheme by using discrete event simulation. All HAs are assumed to have the same wired link with a 10ms delay, and the mobile nodes are simulated on the following network mobility support protocols: Basic support protocol (BSP)[2], the route optimization method using bi-directional tunneling (TLMR)[4], Reverse Routing Header (RRH) scheme, and the proposed HMNB scheme.



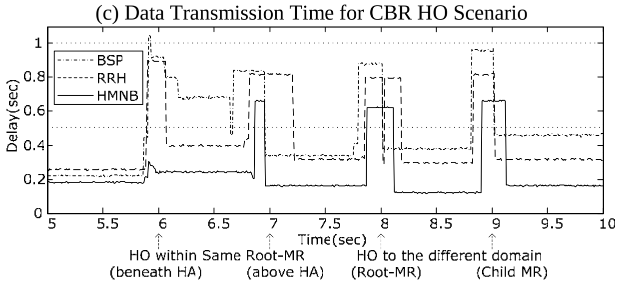
(a) Inter-domain Data Transmission Time vs. MR Level



(b) Intra-domain Data Transmission Time vs. MR Level



(c) Data Transmission Time for CBR HO Scenario



(d) Data Transmission Time for Mobile HA

Fig. 4. The performance analysis of the HMNB scheme

Fig. 4 (a) and (b) show the performance results of the inter-domain and intra-domain data transmission times for the TCP traffic, in accordance with the increase of the depth of the destination MR. In the inter-domain communication environment, the data transmission delays for the route optimization methods i.e. TLMR, RRH and HMNB schemes were smaller than those of the BSP. In the intra-domain communication environment, the data transmission delays in the RRH scheme are larger than the HMNB scheme because the traffic always passes through the HA. Moreover, the intra-domain communication times of the HMNB scheme show that the delays become smaller than other schemes, if the crossover MR is located below the root-MR. Fig. 4 (c) shows the data transmission delays and the service discontinuity times for the CBR(100 KBps) traffic with the various handover scenarios. In the case of the CBR handover scenario, the delays of the HMNB scheme are larger than those of the RRH and TLMR schemes because it uses two intermediate HAs. The service discontinuity time of HMNB scheme is, however, the smallest in the root-MR handover scenario. At the time of the root-MR handover, the HMNB and BSP schemes can accomplish the handover procedure with just the root-MR, so the discontinuity times of these schemes are the smallest. In the case of the BSP scheme, the nested depth of the MR is deeper, so the service discontinuity time becomes larger than other handover scenarios. Thus, the TLMR and RRH schemes may thus not be suitable for a vehicular environment where the root-MR mobility is usually very high. Fig. 4 (d) shows the performance results of the data transmission times for the mobile-HA scenario, according to the various handover cases. The TLMR scheme does not define any method that supports the mobile-HA. The HMNB scheme has the smallest delay time because the mobile-HA can forward the received binding message to its own HA, so that the traffic does not pass through any additional HAs. In conclusion, the HMNB scheme has minimal signaling complexity and supports an efficient route optimization mechanism for the nested mobile network.

5 CONCLUSION

In the current study, we have investigated the limitations of current and previous approaches to network mobility management. We have then proposed a new approach for the efficient route optimization in a mobile network, which is called a hierarchical mobile network routing scheme. The proposed scheme uses tree-based routing for intra-domain data transmission and signaling, and unidirectional tunneling for data transmission to or from the external network. It can provide a more optimized solution for route construction and faster signaling, and can also provide intra-domain handover and communication. In addition to these advantages, it can also support micro-mobility without any additional extension.

In summary, the proposed hierarchical mobile network routing eliminates many problems in route optimization such as large signaling delay and the lack of intra-domain communication which are drawbacks of most previous approaches to the mobility management of network groups. We have compared the characteristics of a hierarchical mobile network routing scheme with the NEMO basic support protocol and previous route optimization methods. A hierarchical mobile network routing scheme can be adopted in various mobile environments to efficiently support network mobility such as WPAN, ubiquitous computing, and VNE.

References

1. Hong-Yon Lach, Christophe Janneteau, and Alexandru Petrescu, ”Network Mobility in Beyond-3G Systems”, IEEE Communication Magazine, July 2003
2. Thierry Ernst, ”Network Mobility Support Goals and Requirements”, Internet-Draft, IETF, May 2003
3. Thierry Ernst, and Hong-Yon Lach, ”Network Mobility Support Terminology”, Internet-Draft, IETF, May 2003
4. Vijay Devarapalli, Ryuji Wakikawa, Alexandru Petrescu, and Pascal Thubert, ”NEMO Basic Support Protocol”, Internet-Draft, IETF, December 2003
5. P. Thubert, M. Molteni, and C. Ng, ”Taxonomy of Route Optimization models in the Nemo Context”, Internet-Draft, IETF, June 2003
6. H.S. Kang, K.C. Kim, S.Y. Han, K.J. Lee and J.S. Park, ”Route Optimization for Mobile Network by Using Bi-directional Between HA and TLMR”, Internet-Draft, IETF, June 2003
7. H. Ohnishi, K. Sakitani, and Y. Takagi, ”HMIP based Route Optimization method in a mobile network”, Internet-Draft, IETF, October 2003
8. Campbell, A.T., Gomez, J., Sanghyo Kim, Chieh-Yih Wan, Turanyi, Z.R., and Valko, A.G., ”Comparison of IP micromobility protocols”, IEEE Wireless Communications, Volume 9, Issue 1, February 2002
9. Hyunsik Kang, Keecheon Kim, Sunyoung Han, Kyeong-Jin Lee and Jung-Soo Park, “Route Optimization for Mobile Network by Using Bi-directional Between Home Agent and Top Level Mobile Router”, Internet-Draft, IETF, June 2003