N-NEMO: A Comprehensive Network Mobility Solution in Proxy Mobile IPv6 Network

Zhiwei Yan[1], Huachun Zhou[1] and Ilsun You[2]
[1] *Beijing Jiaotong University*
Beijing, China
{06120232, hchzhou}@bjtu.edu.cn
[2] *Korean Bible University*
Seoul, South Korea
ilsunu@gmail.com

Abstract

In this paper, we propose a Network-based NEtwork MObility supporting scheme (N-NEMO) in Proxy Mobile IPv6 (PMIPv6) network, which is an issue still up in the air for the basic PMIPv6 protocol. The N-NEMO, like PMIPv6, bases mobility support on network functionality, thus enabling conventional (i.e., not mobility-enabled) IP devices to change their point of attachment without disrupting ongoing communications. As a result, N-NEMO enables off-the-shelf IP devices to roam within the fixed infrastructure, attach to a mobile network and move with it, and also roam between fixed and mobile points of attachment while using the same IP address. Besides, a tunnel splitting scheme is used in N-NEMO to differentiate the inter-Mobility Access Gateway (MAG) mobility and intra-MAG mobility. The analyzing results show that N-NEMO reduces the signaling cost significantly and enhances the efficiency and scalability of network mobility in the PMIPv6 context.

1 Introduction

There is a growing interest in deploying high-speed wireless LANs (WLAN) on public transport vehicles to allow travelers to connect their devices to the Internet. Such an on-board mobile network (NEMO) typically consists of a high-speed mobile LAN and a Mobile Router (MR) which provides connectivity to the Internet through wireless links (e.g. WLAN, GPRS or CDMA). There are two types of interfaces in MR: the interface which connects to the Internet is called egress interface, the interface which connects to its own mobile network is called ingress interface.

A mobile network may attach inside another mobile network. The aggregated hierarchy of mobile networks is called a nested mobile network. The nodes inside the mobile network are generally called Mobile Network Node (MNN). There are two kinds of MNNs: Local Fixed Nodes (LFNs) and Visiting Mobile Nodes (VNNs). An LFN belongs to the subnet of an MR and is unable to change its point of attachment, while an VMN is temporarily attached to the MR's subnet.

In order to support the network mobility in the IPv6 architecture, the NEMO basic supporting protocol (NEMO-BSP) [1] is designed based on the basic Mobile IPv6 (MIPv6) [2]. However, the NEMO-BSP suffers from all the shortcomings of MIIPv6, such as the heavy signaling cost and long handover latency. Besides, some particular problems arise according to the NEMO-BSP, such as the sub-optimized routing and high overhead for the packet transmission in the nested NEMO.

In order to cut down the signaling overhead by network-based mobility management and avoid the mobility stack in the terminal as in MIPv6, the Network-based Local Mobility Management NetLMM functional architecture is defined in RFC 4831[3]. In this architecture, a Mobility Access Gateway (MAG), typically located at the Access Router (AR), updates a Local Mobility Anchor (LMA) with the location of an MN. Of the several alternatives considered by the NETLMM working group, the

Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, volume: 1, number: 2/3, pp. 52-70

approach that has emerged is Proxy Mobile IPv6 (PMIPv6)[4]. With PMIPv6, it is possible to support mobility for IPv6 nodes by extending MIPv6 signaling and reusing the Home Agent (HA) of MIPv6. This approach to support mobility does not require the MN to be involved in the signaling required for mobility management.

Although an MN can freely roam within the PMIPv6 domain without changing its IP address, the network-based localized mobility provided by PMIPv6 was only designed for single host. An interesting scenario, which is not supported by current PMIPv6 standard, is the network mobility. So in this paper, our aim is to propose a novel network mobility scheme in the PMIPv6 network. The remainder of this paper is organized as follows: Firstly, we briefly present overviews and related work of the network mobility support in MIPv6 and PMIPv6. Secondly, we present our N-NEMO in detail. Then the quantitative comparisons of our proposed scheme against the existing scheme are thoroughly investigated, highlighting the main desirable features and key strengths of our scheme. The concluding remarks and future work are given finally.

2 Related work

2.1 Network mobility in MIPv6 network

Based on the MIPv6, the NEMO-BSP is proposed to provide the network mobility in the MIPv6 environment. The architecture of basic NEMO-BSP is shown in Figure 1.

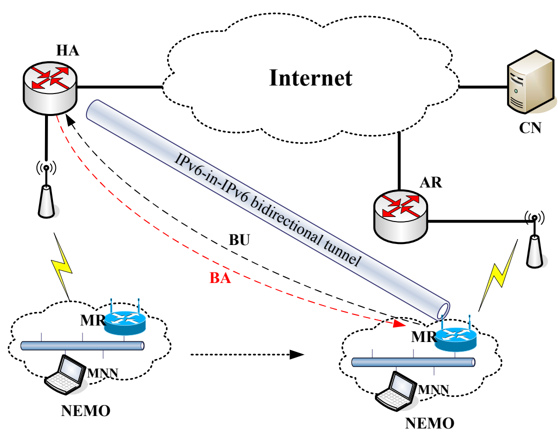

Figure 1: Architecture of NEMO-BSP

The MR manages the movement of the entire mobile network and provides continuous and uninterrupted Internet access to the MNN. The MR combines MIPv6 MN functionality with basic router functionality and manages the delivery of packets to and from the mobile network. HA is a mobility anchor point which assists MR by keeping track of the current point of network attachment, also known as Care-of Address (CoA) of MR and delivering packets destined to the Mobile Network Prefix (MNP) to the current CoA of MR.

When the MR moves away from its home network, it acquires a CoA as the MN does in MIPv6. To set up a bidirectional tunnel with the HA, the MR first sends a Binding Update (BU) message to the HA and the HA then replies with a Binding Acknowledgement (BA) message. The bi-directional tunnel between the HA and MR have endpoints with the address of the HA on one end and the CoA of the MR on the other end. When a packet is originated from a Corresponding Node (CN), it is sent through this tunnel. The MR then decapsulates this packet and forwards it to the corresponding MNN. Similarly, the packet is encapsulated at the MR end and decapsulated at the HA when it is originated from an MNN.

2.2 Proxy Mobile IPv6

PMIPv6 is intended to provide network-based IP mobility management to the MN, without requiring its participation in any IP mobility related signaling. The mobility entities in the network track the MN's movement and initiate the mobility signaling and setup the required routing state. The core functional entities in the PMIPv6 infrastructure are the LMA and the MAG. The LMA is responsible for maintaining the MN's reachability state and is the topological anchor point for the MN's Home Network Prefix (HNP). The MAG is the entity that performs the mobility management on behalf of the MN and it resides on the access link where the MN is anchored. The MAG is responsible for detecting the MN's movement to and from the access link and for initiating binding registrations to the MN's LMA.

Figure 2 shows the signaling call flow of the basic PMIPv6.

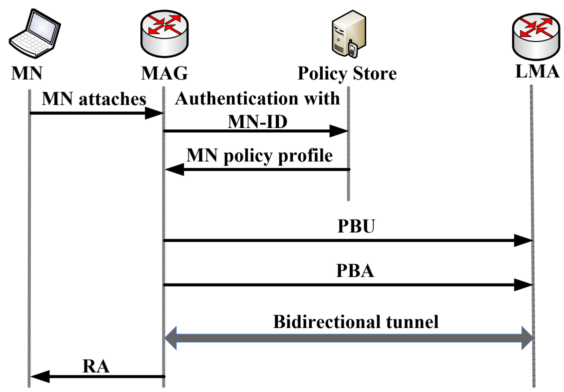

Figure 2: Signaling call flow of basic PMIPv6

Once the MN enters PMIPv6 domain and attaches to an access link, the MAG on that access link, after identifying the MN and acquiring its identity (MN-ID), will determine if the MN is authorized for the network-based mobility management service. If the authentication is successful, the MAG retrieves the policy file from the Policy Store, which is the functionality used to maintain the basic information of the MN. For updating the LMA about the current location of the MN, the MAG sends a Proxy Binding Update (PBU) message to the MN's LMA. Upon accepting this PBU message, the LMA sends back a Proxy Binding Acknowledgement (PBA) message including the MN's HNP. It also creates a binding cache entry and establishes a bidirectional tunnel to the MAG. The MAG on receiving the PBA message sets up a bi-directional tunnel to the LMA and establishes the data path for the MN's traffic. At this point, the MAG has all the required information for emulating the MN's home link and it sends Router Advertisement (RA) messages to the MN on the access link to advertise the MN's HNP as the hosted on-link-prefix.

If the MN changes its point of attachment after obtaining the initial address configuration in the PMIPv6 domain, the previous MAG on the previous link will detect the MN's detachment from the link and will signal the LMA to remove the binding and routing state for that MN. The new MAG on the new access link upon detecting the MN on its access link will signal the LMA for updating the binding state. Once that signaling is completed, the MN will continue to receive the RAs containing its HNP, making it believe it is still on the same link and it will use the same address configuration on the new access link.

2.3 Network mobility in PMIPv6 network

CJ. Bernardos describes the problem of supporting network mobility in PMIPv6 in the draft[5]. This draft briefly analyzes how the use of current standards fails in fully supporting the NEMO in the PMIPv6 network. Although current mechanisms (i.e., NEMO-BSP and PMIPv6) can be combined to provide the NEMO support, this combination does not constitute a full integration. The root reason is that the addresses used within the mobile network belong to the MNP are different from the addresses belong to the HNP used by PMIPv6. Besides, it proposes that the MR is the router providing connectivity to a set of nodes moving together and has the functionality of MAG. In this way, the AR may be an MAG or an MR. Besides, J.H. Lee analyzes the possible NEMO scenarios in PMIPv6 network and related supporting schemes in draft [6]. Then we propose the idea in draft [7] to carry the HNP information in the authentication signaling in a proxy manner for the NEMO support. Although there are some achievements for the NEMO support in PMIPv6 network, an efficient and comprehensive scheme is still needed.

In order to guarantee the connectivity of the MNN moving between MR and MAG, the NEMO-enabled PMIPv6 (N-PMIPv6) is proposed [8]. With N-PMIPv6, the mobility of MRs and MNNs is managed by the network. The MR extends the PMIPv6 domain by providing IPv6 prefixes belonging to this domain to attached MNNs and by forwarding the packets through the LMA. From the point of view of the MNN that attaches to an MR, this MR behaves as a fixed MAG of the N-PMIPv6 domain. To deliver IPv6 packets addressed to an MNN, LMA functionality is extended to support recursive lookups in its binding cache: in a first look up, the LMA obtains the MR to which the MNN is attached; after that, the LMA performs recursive lookups until it finds the associated fixed MAG. N-PMIPv6 bases mobility support on network functionality, thus enabling conventional IP devices to change their point of attachment without disrupting ongoing communications. However, it suffers from the following shortcomings:

1. In order to update the location, the MR fires the binding update signaling for the MNN and the two endpoints of tunnel is MR and LMA. It means when the MNN moves between different MRs but under the same MAG, the binding update to LMA also must be executed.

2. It incurs multiple tunneling encapsulations with the LMA for the packets transmitted to the MNN. So the efficiency and scalability decreases with the nested degree.

3. All the traffic has to be routed via the LMA. This results in undesirable effects, such as longer route leading to increased delay and increased overhead.

In order to support the NEMO in a more efficient and scalable way, we propose the N-NEMO in this paper. And this work is a extension of the paper in MoMoPE 2010 [9].

3 N-NEMO

The following terms are newly explained in our scheme:

1. Access Router (AR): when deploying NEMO in the PMIPv6 network, the AR may be an MR or a general MAG. For MAG, it has some additional functions compared to the MAG in the basic PMIPv6.

2. Network Mobility (NEMO): we refer to network mobility as the capacity of a set of nodes attached to a MR move together within the PMIPv6 domain. We do not consider the case of mobile networks that may roam across PMIPv6 domains, although this scenario might be also interesting.

3. HNP and MNP: every MR is allocated an HNP for its connectivity supporting as the MN does in PMIPv6. Besides, every MR manages an MNP for the connectivity of its LFNs.

4. Intra-MAG and Inter-MAG: the Intra-MAG denotes that the MR/MNN moves between different MRs under the same MAG and the communication peers are located under the same MAG. In opposite, it is inter-MAG mobility and inter-MAG communication.

3.1 N-NEMO

The proposed N-NEMO (Network-based NEMO) is based on a tunnel splitting scheme. The proposed scheme splits the tunnel into two parts: global tunnel which is established between LMA and MAG, and local tunnel which is established between MR and MAG. By using this scheme, it has greater data efficiency with less packet overheads, and decreases the latency of the packet transmission using a more optimal route for the intra-MAG communication.

3.1.1 Extended RA message

For this goal, the identity of the AR should be recognized, it means that the MR should recognize whether it connects to an MAG or another MR. Besides, the address of MAG has to be learned in order to establish the local tunnel. Then the extended RA [10] message of PMIPv6 is used. In the extended RA message, an "G" flag and a corresponding MAG option is added as shown in Figure 3.

0 1 2 3 4 5 6 7	0 1 2 3 4 5 6 7	0 1 2 3	4 5 6 7 0 1 2 3 4 5 6 7
Type	Length	Dist	Reserved
Valid Lifetime			
Address of MAG			

Figure 3: Format of the MAG option

In the newly defined MAG option, the 4 bits "Dist" is added to identify the distance between MAG and the related MR. Its default value should be set to 1. The distance must be set to 1 if the MAG is on the same link with the MR. This field can be interpreted as the number of hops between MAG and the MR.

The "G" flag is used to identify whether the AR is an MAG. If the MR receives the RA message without this option, it gets the MAG address contained in the RA message sent by MAG. Then, it relays the RA message after appending the "G" flag and MAG option. If the MR receives the RA message with this option and the "G" flag is set to "1", the MR resets the flag to "0" and inserts the MAG address in the MAG option, besides, the "Dist" should be added by 1. Accordingly, the MRs can learn the MAG address and the distance to the MAG.

3.1.2 Tunnel splitting scheme

In N-PMIPv6, LMA maintains two tunnels for one MR: one is established between LMA and the MAG; another one is established between the LMA and the MR as shown in the left part of Figure 4.

This incurs the sub-optimized route for the intra-MAG communication and the additional overhead for the packet transmission from LMA to the MNN. In the N-NEMO as shown in the right part of Figure 4, we separate the tunnel of one MR into two parts: the global tunnel between MAG and LMA is used for the inter-MAG mobility; the local tunnel between MR and MAG is used for the intra-MAG mobility.

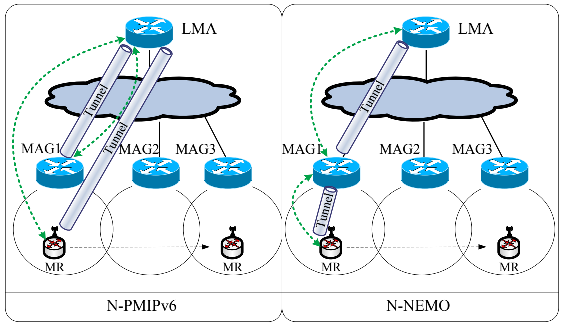

Figure 4: Tunnel splitting

0 1 2 3 4 5 6 7	0 1 2 3 4 5 6 7	0 1 2 3 4 5 6 7	0 1 2 3 4 5 6 7
		Sequence #	
A H L K M R P B	N T Dis	Lifetime	
Information of VMNs			

Figure 5: Format of LPBU message

When the MR attaches to an MAG, the PBU message is firstly sent by the MAG to the LMA as in PMIPv6, however, the MNP of the MR is carried in the PBU message. In this way, the packets sent to MR and LFNs can be transmitted by the LMA to the correct MAG. Besides, the MAG sends the RA message to the MR and the MR can maintain its connectivity because the advised prefix is always its HNP. For the MR, it has learned the address of MAG after the proxy binding update procedure. Then it sends the LPBU (Localized PBU) message to the MAG (the format of LPBU message will be described in the next subsection in detail) for the location update of VMN. When receiving this LPBU message but the MAG finds there is not binding state of the VMN, the MAG also sends the PBU message to the LMA as in PMIPv6.

According to this scheme, when the MR/VMN moves from one MR to another MR within the same MAG, only the LPBU message to MAG is needed to update the tunnel between the attached MR and MAG. And the binding process between MAG and LMA is unnecessary.

3.1.3 Handover process

Because the tunnel splitting is used in N-NEMO, the new LPBU message is illustrated in Figure 5. The newly added “N”flag is used to differentiate the PBU and LPBU messages. When the AR is an MR and it finds the detachment of MR/VNN, it should send out the LPBU message with the non-zero value lifetime to the MAG. However, a “T” flag is added in the LPBU message which means the MAG should maintain the global tunnel for the MR temporarily. If the MR/VNN attaches to another MR under the same MAG, the LPBU message is sent to establish the new local tunnel for the MR/VNN. Otherwise, if the previous MAG does not receive the LPBU message for the MR/VNN when the lifetime expires, it should send the PBU message to LMA for deregistration. In this case, the MR/VNN hands over to another MAG.

Besides, the “Dis” is copied from the “Dist” get from RA message. And it is included in the LPBU message for the location management of the MR/VNN. Then the entries in the binding cache of MAG created/updated by LPBUs have their “Dist” value. For the handover of entire NEMO, the binding update for each VMN causes large signaling cost and latency. So the MR can update the mobility bindings of multiple VMNs attached to it with a single LPBU message. As in bulk registration scheme [11], the "B" flag is used in the LPBU message to identify that it is a bulk registration message. Besides, the "Information of VMNs" contains the information of multiple VMNs in any of the mobility signaling messages. The bulk registration mechanism allows the MAG and the LMA to extend the binding lifetime for a number of VMNs with a single transaction. In this way, the MR and MAG or the MAG and LMA maintain a set of VMNs that can be registered in bulk mode.

The handover procedure is illustrated in Figure 6.

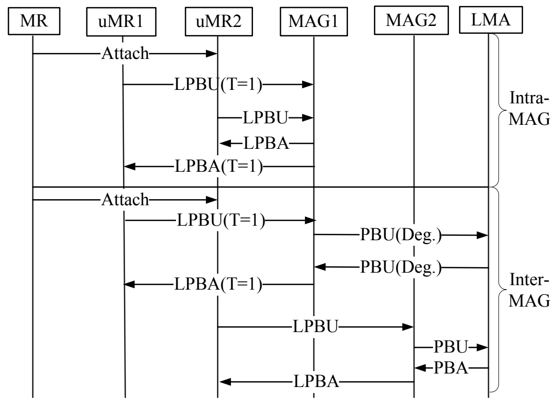

Figure 6: Handover procedure of N-NEMO

In the intra-MAG scenario, the MR moves between uMR1 and uMR2, and they are located under the same MAG (e.g., MAG1). While, in the inter-MAG scenario, the MR moves between uMR1 and uMR2, and they are located under different MAGs (e.g., uMR1 and uMR2 are located at MAG1 and MAG2 separately). The handover procedure of intra-MAG is listed as follows:

- When MR moves from uMR1 to uMR2, its detachment and attachment are detected by uMR1 and uMR2 separately.
- For the uMR1, the LPBU message with T flag is sent to the MAG1, and then the MAG1 maintains the global tunnel for MR temporarily.
- For the uMR2, the LPBU message is sent to the MAG1 for the registration of MR.
- When the MAG1 receives the LPBU from uMR2 and finds there exists the state of MR, MAG1 sends back the LPBA message to uMR2 on one hand, and sends the LPBA message with T flag to uMR1 for the deregistration on the other hand.

The handover procedure of inter-MAG is listed as follows:

- When MR moves from uMR1 to uMR2, its detachment and attachment are detected by uMR1 and uMR2 separately.
- For the uMR1, the LPBU message with T flag is sent to the MAG1, and then the MAG1 maintains the global tunnel for MR temporarily. After the timeout, the MAG1 sends the PBU message to the LMA for deregistration. Then the LPBA message with T flag is sent back to the uMR1 for the deregistration.
- For the uMR2, the LPBU message is sent to the MAG2 for the registration of MR.

- When the MAG2 receives the LPBU from uMR2 and finds there exists no state of MR, MAG2 sends PBU message to LMA for the global tunnel establishment. And then the MAG2 sends back the LPBA message to uMR2 for the local binding acknowledgement.

3.1.4 Packets routing

We propose the optimized packets routing scheme in N-NEMO. When the MR receives the packet from MNN, it encapsulates it and sends it to the MAG through the local tunnel. When the MAG receives this packet, it should judge whether this packet is inter-MAG or intra-MAG: When it finds there is no binding state of the prefix corresponding to the destination address of the packet, the MAG sends the packet to the LMA through the global tunnel; Otherwise, when the MAG finds that it maintains the state of the prefix corresponding to the destination address of the packet, the MAG decapsulates the packet and sent it to the MNN directly or through the correct local tunnel.

To deliver IPv6 packets addressed to an MNN attached to a MR, we extend MAG functionality to support recursive lookups in its binding state as shown in Figure 7.

ID	Prefix	AR	Dis
VNN	VMN_HNP	MR(N)	N
MR(N)	MR(N)_HNP	MR(N-1)	N-1
⋮	⋮	⋮	⋮
MR(0)	MR(0)_HNP	MAG	1

Figure 7: MAG binding state

We use the “Dis” value in the binding state used by the MAG to support recursive lookups. The entries in the binding cache created/updated by LPBU received from nested MRs have their “Dis” value. In a first lookup, the MAG obtains the MR to which the MNN is attached. After that, the MAG performs a second lookup searching for this MR in its binding state and finds the associated MR. In the recursive manner, the MAG can encapsulate the received packets towards all the related MRs until the value of “Dis” equals to “1” which corresponds to the directly attached MR. And then, nested tunnels are used to encapsulate the packets between the MAG and the MRs.

4 Example

In order to illustrate our N-NEMO and analysis its features, we explain its procedure using an example as shown in Figure 8.

As shown in Figure 8, the movement of N-NEMO is very complex and there are two kinds of scenarios: simple N-NEMO scenario and nested N-NEMO scenario. In order to present it more clearly, the following terms are used:

- MRi_MNP is the MNP of MRi, it is used by the LFNs connecting to the MRi;
- MRi_HNP is the HNP of MRi and it is allocated by the LMA;
- VMNi_HNP is the HNP of VMNi and it is allocated by the LMA just as MRi_HNP. In order to guarantee the connectivity, the MRi_HNP and VMNi_HNP should not change even the MRi and VMNi move;

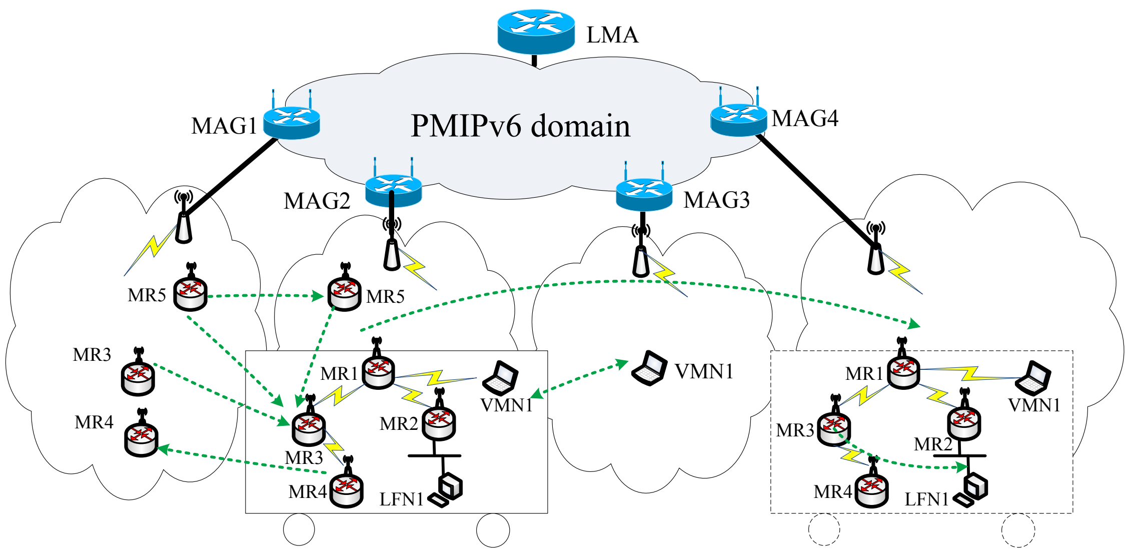

Figure 8: Example scenario of N-NEMO

- MRi_ID and VMNi_ID are the IDs of MRi and VMNi. They have the same functions as in basic PMIPv6.

4.1 Simple N-NEMO scenario

In the simple N-NEMO scenario, the MR moves between MAGs and no nested connection of NEMO happens. So there are the following kinds of handovers in this scenario.

4.1.1 Movement of MR

In this case, the MR hands over from a MAG to another MAG. As shown in Figure 8, the MR5 hands over from MAG1 to MAG2. When MAG2 detects the attachment of MR5, it sends the PBU message to the LMA with the MR5_ID. Then the LMA establish the tunnel for the MR5. Because the LMA learns that it is a tunnel for an MR, the tunnel is not only used for the packet redirection corresponding to MR5_HNP, but also used for the packet redirection corresponding to MR5_MNP. Then the MAG2 sends the RA with MR5_HNP to MR5 after it receives the PBA message from LMA. Because the MR5 receives the same HNP, the handover is transparent to the upper layer. However, the MR5 finds that the MAG changes because the MAG address in the RA message is different from the previous one. Then the MR5 sends a bulk registration to MAG2 for the VMNs in its subnet. Then the local registration triggers the MAG2 to send the bulk registration message to the LMA to establish their global tunnel.

4.1.2 Movement of VMN

In this case, the VMN hands over between MAG and MR or between MRs. As shown in Figure 8, the VMN1 connects to the MR1 and hands over to MAG3 during the session. Then the MAG3 detects the attachment and the basic PMIPv6 procedure follows.

When the VMN1 connects through the MAG3 and hands over to the MR1 during the session. The MR1 who detects the attachment of VMN1 will authentication the VMN1 through MAG2. When the authentication reply message arrives at the MR1, it will establish the local tunnel for the VMN1. After the tunnel is established successfully, the MAG2 will establish the global tunnel for the VMN1. When the global tunnel is established, the VMN1_HNP is contained in the PBA message sent from LMA to MAG2. In the similar manner, the MAG2 sends the LPBA message to MR1 and the VMN1_HNP is carried in this message. Because the MR1 advises the same HNP to VMN1, no handover in the network layer is detected by VMN1.The handover between MRs has the similar procedure as handover from MAG to MR.

4.2 Nested N-NEMO scenario

In the nested N-NEMO scenario, multiple MRs exist under the same MAG and the movements in this scenario are more complex compared with the simple scenario and there are the following kinds of handovers in this scenario.

4.2.1 MR moves from MR to MAG

For the handover of MR from MR to a different MAG, the process is similar as the handover of MR between MAGs in the simple N-NEMO scenario. For example, the MR4 hands over from MR3 to the MAG1. When detects the detachment of MR4, the MR3 sends a bulk registration message with “T” flag set to 1 to the MAG2. Then the MAG2 maintains the global tunnel for the MNNs connected through MR4 and buffers their packets temporarily. Because the MR4 moves to a new MAG, the global tunnel will be torn down and the buffered packets will be discarded when the timer expires. On the other hand, when the MAG1 detects the attachment of MR4, the procedure follows the process of MR handover between MAGs as in the simple N-NEMO scenario.

If the MR4 moves from MR3 to MAG2, the MAG2 will refresh the “Dis” option in the binding state for the corresponding MNNs and MR4. And then the MAG2 redirects the buffered and following packets to MR4.

4.2.2 MR moves from MAG to MR

For the handover of MR from MAG to MR in different MAG, the MR5 moving from MAG1 to MR3 is an example. In this case, the MAG1 firstly tears down all the local tunnels ended at MR4 and sends a bulk deregistration message to LMA to tear down the global tunnel for the MR5_HNP and the HNPs connects to the MR5, and this information can be get from the local binding state. On the other hand, the MR3 who detects the attachment will sends the LPBU message to the MAG2. When the MAG2 receives this message, it sends the PBU message to LMA to establish the global tunnel for MR5. After this, the MR3 sends the RA message with MR5_HNP and the address of MAG2 to MR5. Because MR5 receives the same prefix, the connectivity is guaranteed. However, because it receives a different MAG address, a bulk registration is triggered to establish the local tunnel for the VNNs in its subnet.

If the MR5 moves from MAG2 to MR3, the global tunnel of MR5 has not to be reestablished. Only the MR3 sends the LPBU message to MAG2 to establish the local tunnel for MR5.

4.2.3 MR moves between MRs

When the MR moves from a MR to another MR in the same MAG, only the local tunnel should be refreshed. As shown in the Figure 8, the MR3 moves from MR1 to MR2. On one hand, the MR1 sends the bulk de-registration message with the “T” set to 1 to the MAG4. The MAG4 buffers the packets for the MNNs of MR3. When the MR2 detects the attachment of MR3, the MR2 sends the LPBU message for MR3 to establish its local tunnel. Then the MR3 sends the bulk registration message for its VMNs.

Because the MAG4 receives the binding update message for the VMNs, the buffered and following packets are transmitted through the new local tunnel.

If the MR moves between MRs located at different MAGs, the procedure is similar. But the state of MR and the packets for its MNNs are discarded by the previous MAG after the timeout. On the other hand, it follows the process of MR handover from MAG to MR in different MAG.

4.2.4 VMN movement

For the VMN movement from MAG to MR, the process is the same as the case that VMN mover to MR in the simple N-NEMO. However, the detachment of VMN triggers the packets buffering by the MAG temporarily. If the VMN moves to the MR located at another MAG. The temporary state is deleted after the timeout and deregistration process is fired. Otherwise, only the local tunnel is needed to be updated from the MR to the MAG.

For the VMN movement between MRs, the process is similar with the process of the MR handover between MRs.

5 Protocol cost

In this section, we analyze the protocol cost [12] of N-PMIPv6 and N-NEMO. The protocol cost has two major components: (i) cost related to the location updates (LU), and (ii) cost related to the packet transmission (PT) [13-15]. The LU cost (C_{LU}) and PT cost (C_{PT}) are the accumulative traffic loads due to exchanging binding update messages and IP tunneling headers of data packets, respectively. Therefore, the LU cost and PT cost is calculated by the product of message length and hop distance, and their units are bytes$\times$hops. We model the LU and PT costs during an inter-session arrival time, which is defined as the time interval between the arrival of the first packet of a data session and the arrival of the first packet of the next data session [16,17]. Then, the total cost (C_T) is formulated as

$$C_T = C_{LU} + C_{PT} \tag{1}$$

5.1 System model

We adopt the network model for our performance analysis as shown in Figure 9.

For analytical simplicity, we consider a subnet tree with LMA as root. We assume that an entire subnet moves under the m level. Then the depth from MAG to MNN is m+2. In order to analyze the packet transmission cost for intra-MAG and inter-MAG communications, we assume that the corresponding node is located at the depth n in the same MAG or a different MAG. The hops between LMA and MAG is a. Besides, the following assumptions are made without loss of generality.

- The inter-session arrival time follows an exponential distribution with rate λ_I.
- The MR subnet residence time of a NEMO follows a Gamma distribution with mean $1/\mu_S$ and variance $V_(S) = 1/\mu_S^2$, and its probability density function is $f_S(t)$. $F_S(t)$ and $f_S^*(t)$ denote the cumulative distribution function and Laplace transform of $f_S(t)$, respectively. Then $f_S^*(t) = (\frac{\mu_S\lambda}{s+\mu_S\lambda})^{\lambda}$, $\lambda = \frac{1}{V_S\mu_S^2}$. Besides, the MAG residence time of a NEMO follows a Gamma distribution with mean $1/\mu_M$ and variance $V_(M) = 1/\mu_M^2$, and its probability density function is $f_M(t)$. $F_M(t)$ and $f_M^*(t)$ denote the cumulative distribution function and Laplace transform of $f_M(t)$, respectively. Then $f_M^*(t) = (\frac{\mu_M\lambda}{s+\mu_M\lambda})^{\lambda}$, $\lambda = \frac{1}{V_M\mu_M^2}$.

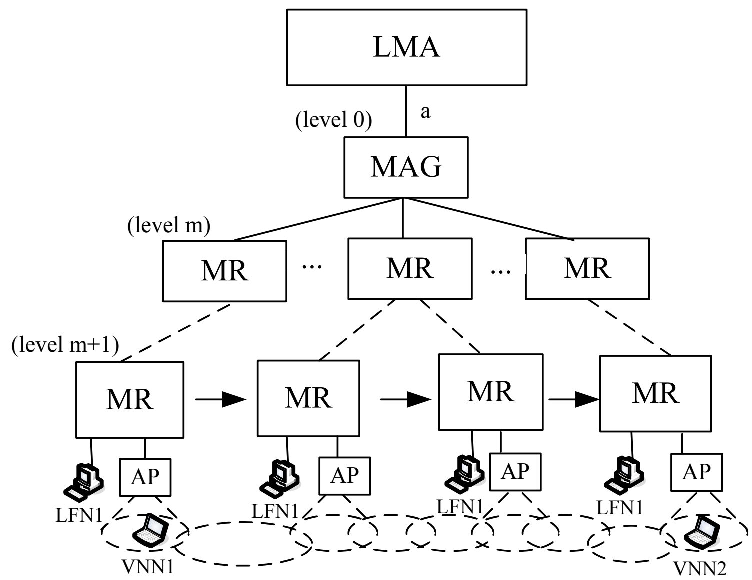

Figure 9: The network model

- Based on the fluid flow model [17], μ_S is given by $\mu_S = \frac{vL_S}{\pi A_S}$, where v is the average velocity of a NEMO and L_S denotes the perimeters of a MR subnet. Also, A_S is the area of a MR subnet. If we assume that a MAG domain consists of N subnets, then $\mu_M = \frac{\mu_s}{\sqrt{N}}$[19].

- We consider only incoming sessions to MNNs and the session arrival rate (or the amount of traffic) for each MNN is independent and identically distributed. Besides, N_L and N_V denote the number of LFN and VMN, respectively.

- We assume that the proxy binding update refresh interval is sufficiently long and thus the cost for the refreshment is not considered. Also, we focus on the location update cost incurred by handovers and therefore initial location update costs are not considered.

- Let N_S and N_M be the numbers of mobile subnet crossings and MAG subnet crossings during an inter-session arrival time. Then, $Pr(N_S = i) = \alpha(i)$ and $Pr(N_M = j) = \beta(j)$ are derived as follows [18]:

$$\alpha(i) = \begin{cases} 1 - \frac{1}{\rho_S}[1 - f_S^*(\lambda_I)] & i = 0 \\ \frac{1}{\rho_S}[1 - f_S^*(\lambda_I)]^2 [f_S^*(\lambda_I)]^{i-1} & i > 0 \end{cases} \tag{2}$$

$$\beta(j) = \begin{cases} 1 - \frac{1}{\rho_M}[1 - f_M^*(\lambda_I)] & j = 0 \\ \frac{1}{\rho_M}[1 - f_M^*(\lambda_I)]^2 [f_M^*(\lambda_I)]^{j-1} & j > 0 \end{cases} \tag{3}$$

where $\rho_S = \frac{\lambda_I}{\mu_S}$ and $\rho_M = \frac{\lambda_I}{\mu_M}$.

- The per-hop transmission costs for a binding update pair is δ_{LU}. Our analytical model accounts for transmission costs incurred by additional IP tunneling headers, not including the original packet. Besides, transmission over a wireless link is more expensive than that over a wired link [14]. To allow for this, we define a weight factor ω, for the wireless link. We assume that the size of the IPv6 header is 1×40bytes and then the transmission cost of an IP tunneling header over a 1-hop wired link to be $\omega\times1\times40$bytes , for instance, and the transmission cost of the same header over a wireless link would be .

The N-PMIPv6 has no differentiation of intra-MAG mobility and inter-MAG mobility. Therefore, the average C_{LU} is expressed as

$$C_{LU} = \sum_{i} C_{LU}(i)\cdot\alpha(i) \tag{4}$$

Let $C_{LU}(i,j)$ be the location update cost when a NEMO experiences i MR subnet crossings and j MAG subnet crossings during an inter-session arrival time. Then, the average location update cost in N-NEMO can be computed from

$$C_{LU} = \sum_{j}\sum_{i} C_{LU}(i,j)\cdot\alpha(i)\cdot\beta(j) \tag{5}$$

5.2 N-PMIPv6

In the N-PMIPv6 protocol, the MR provides transparent mobility to LFNs and VMNs within an NEMO. When an MR moves to another MR, the upper layer MR performs the location update for the attached MR through the proxy binding update procedure with LMA. Therefore, the LU cost of the N-PMIPv6 protocol is

$$C_{LU}(i) = i\cdot B_{LMA} \tag{6}$$

where B_{LMA} is the LMA binding update cost performed by the upper layer MR, which is equal to $2(m+a)\delta_{LU}$. To deliver IPv6 packets addressed to an MNN attached to a connected MR, the recursive lookups are adopted by LMA. Then all the packets sent from MNN or sent to MNN must be sent to LMA firstly, and then the LMA re-encapsulates the packets and send them to the destination. For the LFN, the last encapsulation is the upper layer MR. On the other hand, packets destined for a VMN should also be encapsulated by the MR as the last tunneling. Therefore, the VMN has a higher packet delivery cost than the LFN. Let C_{PT}^{LFN} and C_{PT}^{VMN} be the PT costs of the LFN and VMN, respectively, and they are respectively given by

$$C_{PT}^{LFN} = 40\times\{[(1+2+...+m)\times\omega+ma]+[(1+2+...+n)\times\omega+na]\} \tag{7}$$

and

$$C_{PT}^{VMN} = 40\times\{[(1+2+...+m+(m+1))\times\omega+(m+1)a]+[(1+2+...+n)\times\omega+na]\} \tag{8}$$

Accordingly, the PT cost of a session with L packets in the N-PMIPv6 is

$$C_{PT} = L\times(\frac{N_L}{N_L+N_V}\times C_{PT}^{LFN}+\frac{N_V}{N_L+N_V}\times C_{PT}^{VMN}) \tag{9}$$

5.3 N-NEMO

The key idea of N-NEMO is to separate routings inside the MAG and outside the MAG. Then the LU cost in N-NEMO is

$$C_{LU}(i,j) = (i-j)\cdot B_{MAG} + j\cdot (B_{LMA'} + B_{MAG}) \tag{10}$$

where B_{MAG} is the location update cost from the upper layer MR to the MAG, which is equal to $2m\delta_{LU}$. $B_{LMA'}$ denotes the location update cost from MAG to the LMA, which is equal to $2a\delta_{LU}$. For N-NEMO, the packets can be limited within the MAG if the two corresponding nodes are located under the same MAG. When the corresponding node is located under a different MAG, the multiple tunnels are needed within the MAG as in N-PMIPv6. However, only one tunnel is needed between MAG and LMA. So the packet transmission cost of LFN is

$$C_{PT}^{LFN} = p\times C_{Intra}^{LFN} + (1-p)\times C_{Inter}^{LFN} \tag{11}$$

where the p denotes the probability that the communication is established within the same MAG. C_{Intra}^{LFN} and C_{Intra}^{LFN} denote the intra-MAG communication cost and inter-MAG communication cost for LFN and they can be expressed as

$$C_{Intra}^{LFN} = 40\times\{[(1+2+...+m)\times\omega] + [(1+2+...+n)\times\omega]\} \tag{12}$$

and

$$C_{Inter}^{LFN} = 40\times\{[(1+2+...+m)\times\omega + a] + [(1+2+...+n)\times\omega + a]\} \tag{13}$$

Similarly, the packet transmission cost of VMN is

$$C_{PT}^{VMN} = p\times C_{Intra}^{VMN} + (1-p)\times C_{Inter}^{VMN} \tag{14}$$

C_{Intra}^{VMN} and C_{Intra}^{VMN} denote the intra-MAG communication cost and inter-MAG communication cost for VMN and they can be expressed as

$$C_{Intra}^{VMN} = 40\times\{[(1+2+...+m+(m+1))\times\omega] + [(1+2+...+n)\times\omega]\} \tag{15}$$

and

$$C_{Inter}^{VMN} = 40\times\{[(1+2+...+m+(m+1)\times\omega + a] + [(1+2+...+n)\times\omega + a]\} \tag{16}$$

Similarly, the PT cost for a session with L packets in the N-NEMO protocol is given by the Equation(9) with the above C_{PT}^{LFN} and C_{PT}^{VMN}.

6 Numerical results

In this section, we compare the performance of N-PMIPv6 and N-NEMO. The parameter settings in our analysis are listed in Figure 10[17-19].

Parameter	Value	Parameter	Value
N	49	δ_{LU}	60
L	5~20	m	1~10
p	0.5	n	5
ω	10	a	10
N_L	5	N_V	5~20
L_S	40m	A_S	100m^2

Figure 10: Related parameters

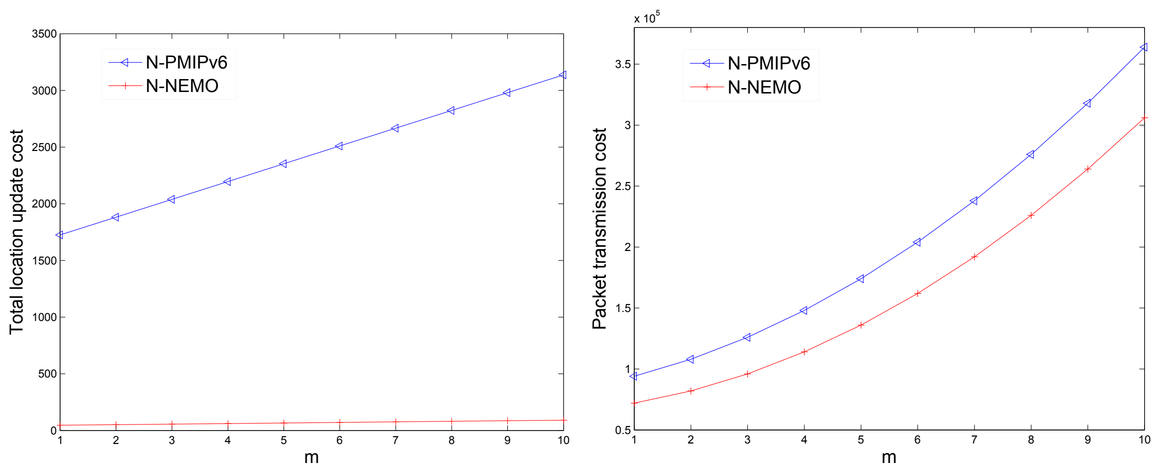

Figure 11: Effect of nested level on location update cost and packet transmission cost

6.1 Effect of nested level

Figure 11 represents the impact of nested level on the total location update cost and packet transmission cost.

In N-PMIPv6, the upper layer MR always sends the signaling message to LMA even the MR moves within the same MAG. However, the location update cost of N-NEMO decreases thanks to the localized mobility management. Besides, with the increased depth of the nested mobile network, the signaling cost of N-PMIPv6 and N-NEMO increases because of the longer path to exchange the singling messages.

For the packet transmission, the tunnel splitting scheme used by N-NEMO decreases the overlapped long tunnel and the cost is less than that in N-PMIPv6. Besides, when the intra-MAG communication increases, the advantage of the optimized packet transmission of N-NEMO is more obvious thanks to the optimized packet transmission route and encapsulation.

6.2 Effect of VMN number

Figure 12 shows the impact of VMN number and session length on the total signaling cost.

For NEMO service providers, it is important to support a large number of VMNs while keeping signaling traffic manageable. The left part of Figure 12 shows that the total signaling cost increases as the number of VMNs increases. However, the localized mobility management manner of N-NEMO

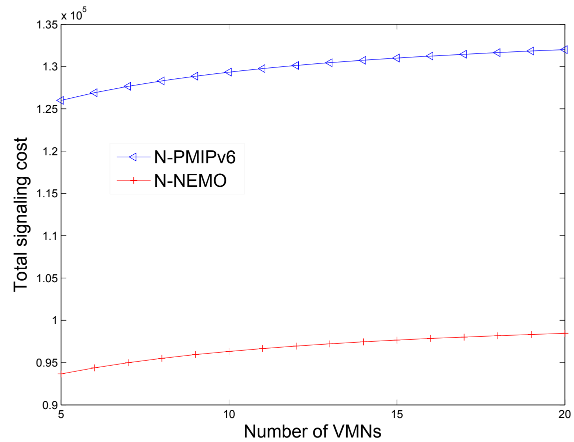

Figure 12: Effect of VMN number on total signaling cost

decreases the total signaling cost about 30%, regardless of the number of VMNs. This makes the N-NEMO the best choice for a large size NEMO.

6.3 Effect of session length

As the Figure 13 shows, the total cost of two schemes increase as the session prolongs due to heavier load.

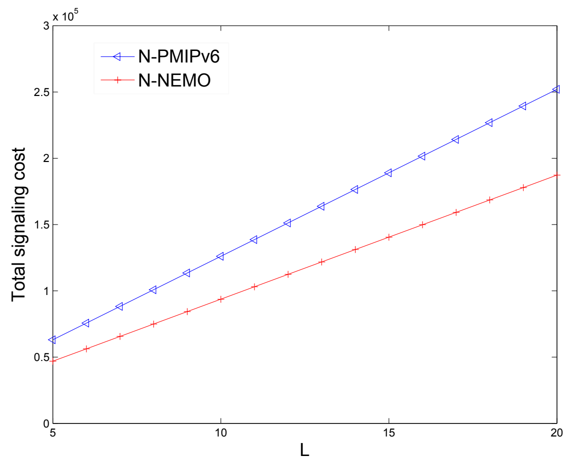

Figure 13: Effect of session length on total signaling cost

Besides, as the session length increases, the advantage of N-NEMO over N-PMIPv6 is more obvious. That is because the intra-MAG communication saves more signaling. In short, the N-NEMO can provide a consistent performance over a wide range of session lengths, and it is highly desirable in mobile networks with heterogeneous traffic patterns.

6.4 Effect of ρ_S

Higher value of ρ_S indicates low mobility, thus less number of updates and lower signaling cost.

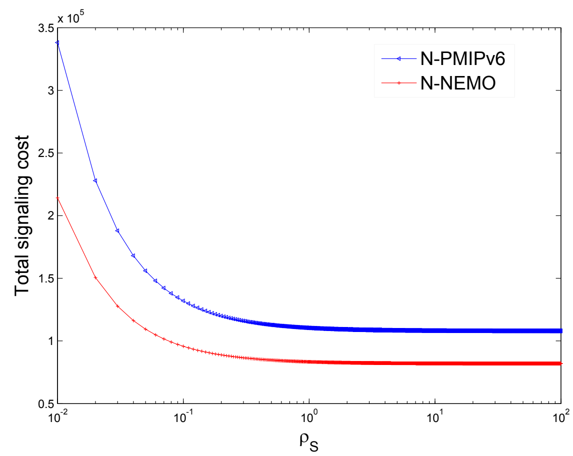

Figure 14: Effect of ρ_S on total signaling cost (m=5,L=10,N_V=5)

We can see from Figure 14 that the signaling cost decreases with the increase of ρ_S. Besides, we can see that the cost of N-NEMO decreases significantly compared with N-PMIPv6.

7 Conclusion

In this paper, after presentation of the PMIPv6 protocol and the consideration of its NEMO supporting scheme, we propose a novel NEMO supporting scheme which uses the extended RA message and splitting tunnel to differentiate the inter-MAG mobility and intra-MAG mobility. Besides, the recursive binding state lookup in MAG is used with the help of the extended "Dis" value in the LPBU registration message, which is a new extension of the PBU message. According to N-PMIPv6, the packets sent by MNNs must be sent to the LMA through the tunnel and then resent by LMA through another tunnel. In this way, the efficiency decreases and the cost and delay of packet transmission increase. However, in N-NEMO, the intra-MAG traffic can be confined within the MAG. In order to support the connectivity of the VMN, the HNP assigned to an VMN is always in consistent with the advised prefix by the AR. In this way, all kinds of mobility can be supported in the PMIPv6 domain. Then we set up a network model and analyze the cost performance of N-NEMO and N-PMIPv6. The numerical results show that the packet in N-NEMO can be transmitted through more optimized route in the intra-MAG communication and the cost of encapsulation can be decreased. And the total signaling cost can be reduced more than 30% compared with that of N-PMIPv6. Such a feature would especially favor to next generation network with the increasing deployment of mobile network and large scale traffic of mobile network.

8 Acknowledgement

This work was supported in part by the Ph.D Student Innovation Fund Program of Beijing Jiaotong University (No.141062522), National High Technology of China ("863 program") under contract No. 2008AA01A326 and in part by National Natural Science Foundation of China under Grant No. 60870015 and No. 60833002.

References

[1] V. Devarapalli, R. Wakikawa, A. Petrescu, P. Thubert, Network Mobility (NEMO) Basic Support Protocol, RFC 3963, January 2005.

[2] D. Johnson, C. Perkins, and J. Arkko, Mobility Support in IPv6, RFC 3775, 2004.

[3] J. Kempf, Goals for network-based localized mobility management (netlmm), RFC 4831, April 2007.

[4] S. Gundavelli, et al., Proxy Mobile IPv6 , IETF RFC5213, August 2008.

[5] CJ. Bernardos, PMIPv6 and Network Mobility Problem Statement, draft-bernardos-netext-pmipv6-nemo-ps-00, October 16, 2009.

[6] J. H. Lee, et al., Network Mobility Basic Support within Proxy Mobile IPv6: scenarios and analysis, draft-jhlee-netlmm-nemo-scenarios-01.txt, 2008.

[7] Z. W. Yan, H. K. Zhang, H. C. Zhou J. F. Guan and S. D. Zhang, Consideration of Network Mobility in PMIPv6, draft-zhang-netlmm-nemo-01.txt, 2010.

[8] I. Soto, CJ. Bernardos, M. Calderon, A. Banchs and A. Azcorra. NEMO-Enabled Localized Mobility Support for Internet Access in Automotive Scenarios. IEEE Communications Magazine, vol. 47, no. 5, pp: 152-159, May 2009.

[9] Z. W. Yan, H. C. Zhou, H. K. Zhang, S. D. Zhang and I. You, Network Mobility Support in PMIPv6 Network, IWCMC 2010 (MoMoPE Workshop), Caen, France, pp: 890-894, June 28-July 2, 2010.

[10] T. Narten, E. Nordmark and W. Simpson, RFC 4861. Neighbor Discovery for IP version 6 (IPv6), September 2007.

[11] D. Premec, S. Gundavelli, K. Leung, S. Krishnan and B. Patil, Bulk Re-registration for Proxy Mobile IPv6, draft-premec-netlmm-bulk-re-registration-03, October 2009.

[12] A. S. Reaz, P. K. Chowdhury, M. Atiquzzaman, and W. Ivancic, Signalling Cost Analysis of SINEMO: Seamless End-to-End Network Mobility, IEEE/ACM MobiArch 2006, San Francisco, 2006.

[13] S. Pack and Y. Choi, A Study on Performance of Hierarchical Mobile IPv6 in IP-based Cellular Networks, IEICE Transactions on Communications, vol. E87-B, no. 3, pp. 462-469, March 2004.

[14] J. Xie and I. Akyildiz, A Distributed Dynamic Regional Location Management Scheme for Mobile IP, IEEE Transactions on Mobile Computing, vol. 1, no. 3, pp. 163-175, July 2002.

[15] Y. Fang, Movement-based Mobility Management and Trade Off Analysis for Wireless Mobile Networks, IEEE Transaction on Computer, vol. 52, no. 6, pp.791-803, June 2003.

[16] S. Lo, G. Lee, W. Chen, and J. Liu, Architecture for Mobility and QoS Support in All-IP Wireless Networks, IEEE Journal on Selected Area on Communications, vol. 22, no. 4, pp. 691-705, May 2004.

[17] X. Zhang, J. Castellanos, and A. Capbell, P-MIP: Paging Extensions for Mobile IP, ACM Mobile Networks and Applications, vol. 7, no. 2, pp. 127-141, April 2002.

[18] Y. Lin, A. Pang, and H. Rao, Impact of Mobility on Mobile Telecommunications Networks, Wiley Wireless Communications and Mobile Computing, vol. 5, no. 8, pp. 713-732, November 2005.

[19] S. Pack, T. Kwon, Y. Choi, and EK. Paik, An Adaptive Network Mobility Support Protocol in Hierarchical Mobile IPv6 Networks, IEEE transactions on vehicular technology, vol. 58, no. 7, pp: 3627-3639, 2009.

[20] R. Langar, N. Bouabdallah and S. Tohme, On the Analysis of Mobility Mechanisms in Micro Mobile MPLS Access Networks, Journal of communications, vol. 1, no. 6, pp: 18-27, September 2006.

Zhiwei Yan is a Ph.D. student in the National Engineering Laboratory for Next Generation Internet Interconnection Devices at Beijing Jiaotong University. His current research interests include mobility management, vertical handover and next generation Internet.

Huachun Zhou received his B.S. degree from People's Police Officer University of China in 1986. He also received his M.S. and Ph.D degree from Beijing Jiaotong University, Beijing, China in 1989 and 2008, respectively. He is now a professor in the National Engineering Laboratory for Next Generation Internet Interconnection Devices at Beijing Jiaotong University. His research interests include mobility management, mobile and secure computing, routing protocols, network management technologies and database applications.

Ilsun You received his M.S. and Ph.D. degrees in Computer Science from Dankook University, Seoul, Korea in 1997 and 2002, respectively. Since March 2005, he has been an Assistant Professor in the School of InformationScience at the Korean Bible University, South Korea. Prof. You served or is currently serving on the organizing or program committees of international conferences and workshops including CISIS'10-11, IMIS'07-11, MIST'09-11, MobiWorld'08-11, BWCCA'10-11 and so forth. Also, he has served as a guest editor for more than 10 international journals. He is on the editorial boards of International Journal of Ad Hoc and Ubiquitous Computing (IJAHUC), Computing and Informatics (CAI), and Journal of Korean Society for Internet Information (KSII). His main research interests include mobile Internet security and formal security verification.