Network Mobility Support in PMIPv6 Network

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ABSTRACT
In this paper, we propose a network mobility supporting scheme (N-NEMO) in Proxy Mobile IPv6 (PMIPv6) network, which is an issue still up in the air for the PMIPv6. In the N-NEMO, a tunnel splitting scheme is used to differentiate the inter-Mobility Access Gateway (MAG) and intra-MAG mobility. The performance analysis and comparison between other related schemes show that N-NEMO reduces the signaling cost significantly. Besides, it enhances the efficiency and scalability to provide the comprehensive network mobility in the PMIPv6 context.

Categories and Subject Descriptors
C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design - Wireless Communication

General Terms
Design, Verification.

Keywords
NEMO, PMIPv6, tunnel splitting

1. INTRODUCTION
The NEMO basic supporting protocol (NEMO-BSP) [1] is designed based on the basic Mobile IPv6 (MIPv6) [2], which is a host-based mobility supporting protocol. 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 scenario.

In order to improve the performance by network-based mobility management, the Network-based Localized Mobility Management (NETLMM) functional architecture is defined [3]. Of the several alternatives considered by the NETLMM working group, the approach that has emerged is Proxy Mobile IPv6 (PMIPv6) [4]. PMIPv6 does not require the Mobile Node (MN) to be involved in any signaling exchange for the mobility management. However, the network-based localized mobility support provided by basic PMIPv6 was only designed for single host. An interesting scenario still up in the air, is the network mobility support.

So in this paper, our aim is to propose a novel network mobility supporting scheme in the PMIPv6 network. The remainder of this paper is organized as follows. Firstly, we briefly present the consideration of network mobility support in PMIPv6. Secondly, we present our network-based NEMO supporting scheme (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 are given finally.

2. RELATED WORK
2.1 NEMO-BSP
Based on the MIPv6, the NEMO-BSP is proposed to provide the network mobility support in the MIPv6 environment. The Mobile Router (MR) manages the movement of the entire mobile network and provides continuous and uninterrupted internet access to the Mobile Network Node (MNN). The MR combines MIPv6 MN functionality with basic router functionality and manages the delivery of packets to and from the mobile network. Home Agent (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. Although this simple forwarding mechanism is beneficial for implementers and operators, the nested mobile network suffers from a pinball routing problem. If the Correspondent Nodes (CNs) want to send data to the leaf MNN which is located at the bottom of the nested mobile network, the packets have to travel to all HAs that are mapped to the MRs of the nested mobile networks.

2.2 Proxy Mobile IPv6
The core functional entities in the PMIPv6 infrastructure are the Local Mobility Anchor (LMA) and the Mobility Access Gateway (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. Based on the basic PMIPv6, many new extensions including localized routing, bulk registration and interaction with MIPv6, are developed in the NETLMM and the Network-Based Mobility Extensions (NETEXT) working groups.

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 Access Router (AR) may be a MAG or a MR. Then we propose the idea in draft [6] to carry the HNP information in the authentication signaling in a proxy manner for the NEMO support. Besides, J.-H. Lee analyzes the possible NEMO scenarios in PMIPv6 network and related supporting schemes in draft [7]. 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 a MR, this MR behaves as a fixed MAG of the N-PMIPv6 domain. To deliver IPv6 packets addressed to a MNN attached to a connected MR, 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:

- 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.
- 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.
- 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 packet overhead.

In order to support the NEMO in a more efficient and scalable way, we propose the N-NEMO in this paper.

3. N-NEMO

The following terms are newly explained in our scheme:

- Access Router (AR): when deploying NEMO in the PMIPv6 network, the AR may be a MR or a general MAG. For MAG, it has some additional functions compared to the MAG in the basic PMIPv6.
- 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.
- HNP and MNP: every MR is allocated an HNP for its connectivity supporting as the MN does in PMIPv6. Besides, every MR manages a MNP for the connectivity of its LFN.
- 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 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 1. In the N-NEMO as shown in the right part of figure 1, 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 movement.

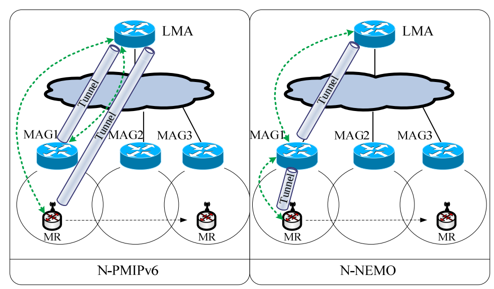

Figure 1. Tunnel splitting

When the MR attaches to an AR, the AR triggers the authentication process for the MR. When the authentication is successful, the AR gets the information of the MR. If the AR is a MAG, the Proxy Binding Update (PBU) message is 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 local fixed nodes (LFNs) can be transmitted by the LMA to the correct MAG. Besides, the MAG sends the Router Advertisement (RA) message to the MR and the MR can maintain its connectivity because the advised prefix is always its HNP. If the AR is a MR, the MR sends the LPBU (Localized PBU) message to the MAG. The format of LPBU message will be described in the next subsection in detail. If the MAG receives this LPBU message but finds there is no binding state of the MR, it sends the PBU message to the LMA. In the nested scenario, when the MR moves between other MRs but under the same MAG, only the LPBU message to MAG is needed to update the local tunnel between the attached MR and MAG. And the binding process between MAG and LMA is unnecessary.

3.2 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 a

MAG or a MR. Besides, the address of MAG has to be learned in order to establish the local tunnel.

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 2. Format of the MAG option

In order to recognize the identity of the AR, the extended RA [9] message is used. In the extended RA message, a "G" flag and a corresponding MAG option is added as shown in figure 2. The "G" flag is used to identify whether the AR is a MAG. If the flag is set to "1", the address of MAG is included in 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. 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. Each MR inserts the address of MAG received from upstream MR into the RA message and propagates the RA message downwards and the "Dist" should be added by 1. Then the MRs can learn the MAG address and the distance to the MAG. If the MR receives the RA message without this option, it gets the MAG address contained in the RA message. Then, it relays the RA message after appending the "G" flag and MAG option.

3.3 Handover process

Because the tunnel splitting scheme is used in N-NEMO, the new LPBU message is illustrated 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
	Sequence #
A H L K M R P N T Dist Reserved	Lifetime
Mobility options	

Figure 3. Format of LPBU message

The newly added "N" flag is used to differentiate the PBU and LPBU messages. When the AR is a 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 "Dist" value get from RA message 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.

The handover procedure is illustrated in figure 4. 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).

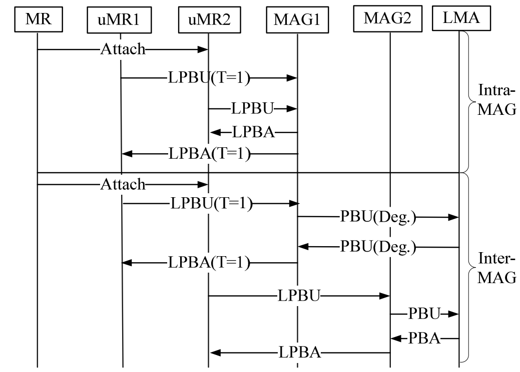

Figure 4. Handover procedure of N-NEMO

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.

3.4 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 HNP 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 HNP 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 a MNN, a change in the normal operation of a PMIPv6 MAG is introduced. We extend the MAG functionality to support recursive lookups in its binding state as shown in figure 5.

ID	Prefix	AR	Dist
MNN	MNN_HNP	MR(N)	N
MR(N)	MR(N)_HNP	MR(N-1)	N-1
⋮	⋮	⋮	⋮
MR(0)	MR(0)_HNP	MAG	1

Figure 5. Binding state of MAG

In a first lookup, the MAG obtains the MR to which the MNN is attached. After that, the MAG performs recursive lookups searching for this MR in its binding cache because the "Dist" is bigger than 1, then it finds the associated root MR. With this information, the MAG can encapsulate the received packets to the MNN attached MR through the root MR. Nested tunnels are only limited between MAG and MR in this case.

4. PERFORMANCE ANALYZING

In this section, we analyze our proposal and compare the performance of our proposal with that of N-PMIPv6. The analytical model is shown in figure 6.

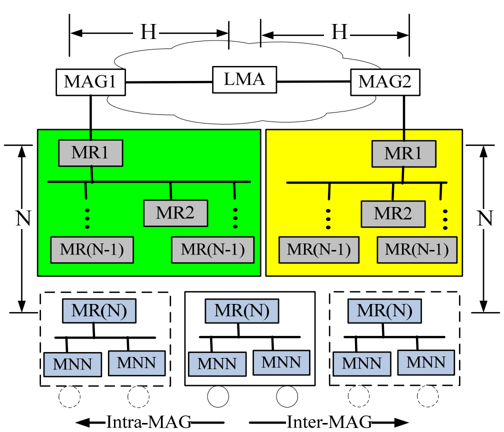

Figure 6. Analytical model

In this paper, we evaluate the location update latency and packet transmission cost of the protocols. The used parameters and their descriptions are listed in table 1.

Table 1. Parameter for Performance Analyzing

Parameter	Description
N	hop count between attached MR and MAG
H	hop count between LMA and MAG
d	one way transmission delay of one hop
q	inter-MAG mobility probability
α	intra-MAG communication probability
β	inter-MAG comm. probability ($\alpha+\beta=1$)

4.1 Location update latency

In our proposal, there is only one LMA-MAG bi-directional tunnel regardless of the number of MRs. Thus, we can decrease the tunneling cost of the N-PMIPv6 protocol. And local handovers are managed within the MAG. If we ignore processing delays, the binding update delay of moving MR in N-NEMO is defined as:

$$B_{N-NEMO} = (N + q \times H) \times d \quad (1)$$

While, the delay of N-PMIPv6 is

$$B_{N-PMIPv6} = (N + H) \times d \quad (2)$$

4.2 Packet transmission cost

When a mobile network is nested, the number of encapsulation simply increases as the nest becomes deeper. Such multiple encapsulations can become a severe overhead where additional bits consumed over the link effect the overall performance. The packet transmission performance is evaluated by the tunneling overhead, which is defined as *tunneling header size* × *hops* and we assume that the size of the IPv6 header is 40bytes.

4.2.1 Intra-MAG communication

For N-NEMO, the packets can be limited within the MAG if the two corresponding nodes are located under the same MAG. So the packet transmission cost is

$$\Psi_{N-NEMO} = 40 \times \{2 \times [N + (N-1) + ... + 1]\} \quad (3)$$

Where the $2 \times [N + (N-1) + ... + 1]$ denotes the sum of hops to encapsulate the packets within the same MAG.

For N-PMIPv6, the outgoing packets have to be transmitted to the LMA, so the packet transmission cost is

$$\Psi_{N-PMIPv6} = 40 \times \{2 \times [N + (N-1) + ... + 1 + (N+1)H]\} \quad (4)$$

Where the $(N+1)H$ is the hops to encapsulate the packets between the MAG and LMA.

4.2.2 Inter-MAG communication

For N-NEMO, the multiple tunnels are needed within the MAG. However, only one tunnel encapsulation is needed between MAG and LMA. So the packet transmission cost is

$$\Psi'_{N-NEMO} = 40 \times \{2 \times [N + (N-1) + ... + 1 + H]\} \quad (5)$$

For N-PMIPv6, the packet transmission cost equals to the cost of intra-MAG communication.

$$\Psi'_{N-PMIPv6} = 40 \times \{2 \times [N + (N-1) + ... + 1 + (N+1)H]\} \quad (6)$$

Than the total packet transmission cost is

$$\begin{cases} \Psi^{PT}_{N-NEMO} = \alpha \Psi_{N-NEMO} + \beta \Psi'_{N-NEMO} \\ \Psi^{PT}_{N-PMIPv6} = \alpha \Psi_{N-PMIPv6} + \beta \Psi'_{N-PMIPv6} \end{cases} \quad (7)$$

4.3 Results

In this section, we compare the performance of N-PMIPv6 and N-NEMO. The default value of H is 5, and the value of d is 0.01s. The default value of q is set to 0.5, which means that the MR moves intra-MAG and inter-MAG with the same probabilities [10-12].

4.3.1 Location update latency

Figure 7 represents the location update latency.

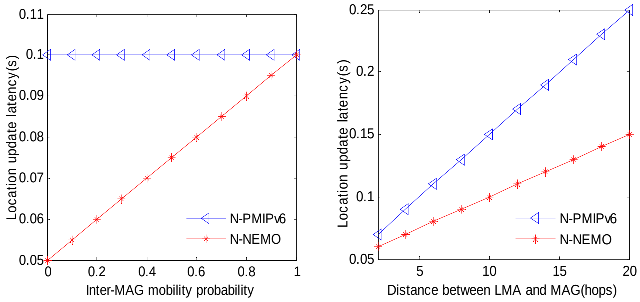

Figure 7. Location update latency

As shown in the left part of figure 7, as the probability of the inter-MAG mobility becomes lower, the gain of our proposal is larger and larger. In N-PMIPv6 approach, PBUs are used when the AR finds the attachment of MR. Thus, in the aspect of intra-MAG mobility, our proposal is more efficient than N-PMIPv6 approach. When the inter-MAG mobility probability equals to 1, the latency of N-NEMO equals to that of N-PMIPv6. That is because all the mobility triggers the binding update to the LMA in this case.

Besides, as shown in the right part of figure 7, with the increased depth of the nested mobile network, the location update latency of N-PMIPv6 and N-NEMO increase due to the longer path to exchange the singling messages. However, both the slope and value of N-NEMO are lower than those of N-PMIPv6. That is because the N-NEMO can differentiate the inter-MAG and intra-MAG handovers and the signaling messages can be limited in the local area for the intra-MAG handover.

4.3.2 Packet transmission cost

Figure 8 represents the tunneling cost for the packet transmission.

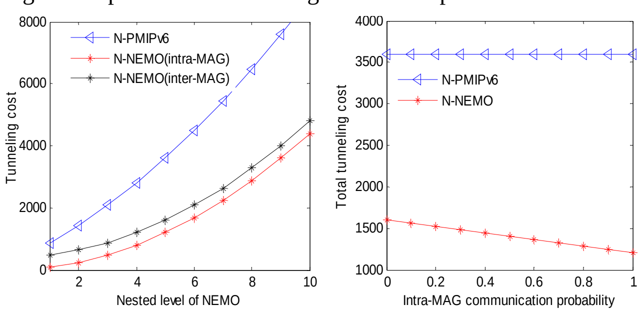

Figure 8. Packet transmission cost

As shown in the left part of figure 8, the tunnel splitting scheme used by N-NEMO decreases the overlapped long tunnel and the cost is less than that of N-PMIPv6. However, with the increase of the nested level of the NEMO, the cost of both N-NEMO and N-PMIPv6 increase due to the increased encapsulations.

However, as shown in the right part of figure 7, 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 decreased encapsulation.

5. CONCLUSION

In this paper, after presentation the related work of NEMO supporting schemes in the PMIPv6 environment, we propose a novel NEMO supporting scheme which uses the extended RA message and tunnel splitting scheme to differentiate the inter-MAG mobility and intra-MAG mobility. Besides, the recursive binding state lookups in MAG is used with the help of the extended "Dist" option in the LPBU registration message, which is a new extension of the PBU message.

Then, we set up a network model and analyze the performance of N-NEMO. The numerical results show that the tunnel splitting scheme used in N-NEMO can support the fast handover of intra-MAG mobility. Besides, packet can be transmitted through the more optimized route in the intra-MAG communication and the cost of encapsulation can be decreased significantly. Such a feature would especially favor to next generation network with the increasing deployment of mobile network.

6. ACKNOWLEDGEMENT

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