:: GENERAL INFORMATION ::

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Distributed Mobility Management in Proxy Mobile IPv6 using Hash Function

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Abstract—This paper proposes a distributed mobility scheme using the hash function in the Proxy Mobile IPv6 (PMIP) networks. In the existing PMIP Localized Routing (PMIP-LR), all the control and data traffics are concentrated at the Local Mobility Anchor (LMA). This centralized scheme tends to increase the network operation costs due to overwhelming traffic overhead at LMA. In this paper, we propose a Hash-based Distributed PMIP (PMIP-HD) scheme, in which the control functions for binding update and query operations are performed based on a hash function and thus the traffic overhead is distributed onto Mobile Access Gateway (MAG). From the numerical analysis, it is shown that the proposed scheme can reduce the costs associated with signaling control and data delivery, compared to the existing PMIP, PMIP-LR and other distributed PMIP schemes.

Keywords—Proxy MIPv6, Distributed Mobility Management, Binding Update, Binding Query

I. INTRODUCTION

With the advent of smart phones and various mobile/wireless access networks, the number of mobile Internet users has been rapidly increasing. Accordingly, the mobility support becomes a critical issue in mobile Internet environment. However, most of the existing protocols (MIP) [1] and Proxy Mobile IPv6 (PMIP) [2], in which all control and data traffics will be proposed by a centralized anchor, such as Home Agent (HA) of MIP or Local Mobility Anchor (LMA) of PMIP.

In PMIP, when both a mobile node (MN) and a correspondent node (CN) are located in the same domain, the data packets of CN will be delivered to MN by way of the LMA, which may be distant from the Mobile Access Gateway of MN (MN-MAG) and Mobile Access Gateway of CN (CN-MAG). In this case, all of the control and data packets are processed by a centralized LMA. However, such a centralized mobility scheme is vulnerable to some problems. First, the centralized anchor may induce unwanted traffic into the core network, which tends to give a big burden to mobile network operators in terms of operational costs. Next, the route is non-optimal because the traffic is routed by way of LMA. In addition, a single point of failure of the central LMA anchor may affect overall performance of data transmission, which will increase the cost of network dimensioning and engineering.

To overcome these limitations of non-optimal PMIP, the IETF has recently proposed the Localized Routing for PMIP (PMIP-LR) [3, 4]. In the PMIP-LR scheme, a route is optimized between CN and MN, just after initial data packets are delivered via LMA during a certain time interval. However, this may still induce a bottleneck of traffic at LMA and the use of non-optimal routes until the LR operation has been completed.

In recently, some distributed mobility management (DMM) schemes have been proposed, which is classified into the Partially Distributed PMIP (PMIP-PD), where only data plane is distributed, and Fully Distributed PMIP (PMIP-FD), where both data and control planes are distributed [5, 6]. In the DMM, the route optimization will be intrinsically supported, and unnecessary traffic can be reduced if the two hosts communicate directly with each other, no relying on a centralized LMA. However, the PMIP-PD is vulnerable to a single point of failure, whereas the PMIP-FD will mitigate such problem to a local network. However, it may still suffer from large signaling costs for control operations.

In this paper, we propose a Hash-based Distributed PMIPv6 (PMIP-HD) for fast route optimization and traffic load balancing. In the proposed scheme, both control and data planes are distributed onto each MAG, as done in PMIP-FD. However, the binding update and query operations will be performed based on a hash function. When CN sends a data packet to MN, CN-MAG performs the binding query operation with the MAG that maintains the HoA and Proxy-CoA binding information of a mobile node will be determined by using a hash function for a given HoA of mobile node, so as to find the MN-MAG. After that, CN will deliver all the data packets over the optimal routing path from the beginning. The proposed scheme can improve data transmission throughput as well as packet processing overhead at LMA, compared to the existing PMIP, PMIP-LR, PMIP-PD and PMIP-FD schemes.

The rest of this paper is organized as follows. In Section 2, we review the existing PMIP-LR, PMIP-PD and PMIP-FD schemes. Section 3 describes the proposed PMIP-HD scheme. In Section 4, we described the numerical analysis of the existing and proposed schemes in terms of signal control and data delivery costs. Section 5 concludes this paper.
II. RELATED WORK

A. Localized Routing for PMIP (PMIP-LR)

In the PMIP-LR scheme, the four cases are considered: A11, A12, A21 and A22 (refer to [4] for more detail). Among these cases, we only focus on the A21 case, in which a LMA supports the local routing for MNs that are attached to the two different MAGs within a same PMIP domain. It is noted that the similar operations can be applied to the other three cases. For PMIP-LR, the two new messages are defined: Localized Routing Initiation (LRI) and Localized Routing Acknowledgement (LRA).

The data delivery operations of PMIP-LR are shown in Figure 1. In PMIP-LR, the binding update and delivery operations are the same with those of PMIP (Step 1-6). During data transmission, LMA decides to optimize the routing path between MN and CN, and it performs the localized routing operations by exchanging the LRI and LRA messages with both CN-MAG and MN-MAG (Step 7). After that, the data path will be optimized from CN-MAG to MN-MAG without traversing the LMA (Step 8).

![Figure 1. Operations of PMIP-LR](image)

However, we note that the route optimization of PMIP-LR is performed during data transmission. So, the PMIP-LR scheme may induce the data traffic overhead of LMA and non-optimized path before the PMIP-LR operations have been completed. This problem may get more severe if LMA is topologically far away from MAGs.

B. Partially Distributed Proxy Mobile IPv6 (PMIP-PD)

Figure 2 shows the operation of Partially Distributed Proxy Mobile IPv6 (PMIP-PD). In PMIP-PD, the connection establishment and binding update operation are the same that of PMIP (Step 1, 2). When CN-MAG receives a data packet from CN (Step 3), CN-MAG sends the PBQ message all the MAGs in the domain by multicast. And then, only the MN-MAG responds with a PQA message to CN-MAG (Step 4). For multicast transmission, it is assumed that all the MAGs in the domain have already been subscribed to a specific multicast address in the initialization process. Note that all the MAGs in the domain are under the control of the same network administrator, and that the multicast transmissions will be allowed only within the local PMIP domain. During this process, CN-MAG may buffer the data packets received from CN. It is same reason of PMIP-PD. After that, data packet forwarding operation is the same with that of PMIP-PD (Step 5, 6).

![Figure 2. Partially Distributed PMIPv6 (PMIP-PD)](image)

However, we note that the centralized LMA still exists in PMIP-PD to manage the binding information of mobile node. So, the PMIP-PD scheme is vulnerable to a single point of failure at LMA.

C. Fully Distributed Proxy Mobile IPv6 (PMIP-FD)

Figure 3 shows the operation of Fully Distributed Proxy Mobile IPv6 (PMIP-FD). In PMIP-FD, the binding update operation is the same that of PMIP (Step 1, 2). When CN-MAG receives a data packet from CN (Step 3), CN-MAG sends the PBQ message all the MAGs in the domain by multicast. And then, only the MN-MAG responds with a PQA message to CN-MAG (Step 4). For multicast transmission, it is assumed that all the MAGs in the domain have already been subscribed to a specific multicast address in the initialization process. Note that all the MAGs in the domain are under the control of the same network administrator, and that the multicast transmissions will be allowed only within the local PMIP domain. During this process, CN-MAG may buffer the data packets received from CN. After that, data packet forwarding operation is the same with that of PMIP-PD (Step 5, 6).

![Figure 3. Fully Distributed PMIPv6 (PMIP-FD)](image)
However, it is noted that PMIP-FD may suffer from large signaling costs for control messages for binding query are generated in the domain.

III. PROPOSED HASH-BASED DISTRIBUTED PROXY MOBILE IPV6 SCHEME

A. Overview

In the proposed scheme, we consider a simple network model, in which CN and MN are located in the same PMIP domain and all of MAGs in the domain are employed same hash function, as depicted in Figure 4.

![Figure 4. Hash-based Distributed PMIPv6 (PMIP-HD)](image)

In the figure, when MN is attached to an MN-MAG (Step 1), the MN-MAG determines the designated MN-MAG by using the hash function, and then performs the binding update operations with the determined MAG (Step 2). Now, when CN sends a data packet to MN (Step 3), the CN-MAG will first identify the MAG that is responsible for MN by using the same hash function, and perform the PBQ operations with the identified MAG to find the Proxy-CoA of MN (Step 4). After that, the data packet is forwarded to MN over the optimal path (Step 5 and 6).

B. Operations

Figure 5 shows the proposed Hash-based Distributed Proxy Mobile IPv6 (PMIP-HD) operations. When MN is connected to MN-MAG, the MN-MAG determines the designated MAG (H-MAG) for MN by using the employed hash function, and performs the PBU operations. By this, the H-MAG maintains HoA and Proxy-CoA binding of MN.

For data delivery, when CN sends a data packet to MN, CN-MAG first determines the MAG that is responsible for MN (H-MAG) by using the hash function and the HoA of MN, and then it sends a PBQ message to H-MAG. Then, H-MAG looks up its binding cache entry to find the Proxy-CoA of MN, and it respond to CN-MAG with the Proxy-CoA of MN. During this PBQ operation, CN-MAG may need to buffer the data packet of CN to prevent the packet loss.

After the PBQ operation, CN-MAG forwards the data packet to MN-MAG, in which the data packet is delivered with an appropriate tunneling scheme. Finally, the data packet is transferred from MN-MAG. The subsequent data packets can now be exchanged between CN and MN.

IV. NUMERICAL ANALYSIS

A. Analysis Model

To analyze the performances of the existing PMIP, PMIP-LR, PMIP-PD, PMIP-FD and the proposed PMIP-HD scheme, we consider the network model, as illustrated in figure 6, in which CN and MN are located within the PMIP domain.

![Figure 6. Network model for numerical analysis](image)

We define the parameters used for analysis in Table 1.

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<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
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<tr>
<td>$T_{a,b}$</td>
<td>Transmission cost of a packet between nodes $a$ and $b$</td>
</tr>
<tr>
<td>$P_c$</td>
<td>Processing cost of node $c$ for binding update or lookup</td>
</tr>
<tr>
<td>$N_{Host}$</td>
<td>Number of hosts per MAG</td>
</tr>
<tr>
<td>$N_{MAG}$</td>
<td>Number of MAGs in the PMIP domain</td>
</tr>
<tr>
<td>$H_{a,b}$</td>
<td>Hop count between nodes $a$ and $b$ in the network</td>
</tr>
<tr>
<td>$S_{Control}$</td>
<td>Size of a control packet (in byte)</td>
</tr>
<tr>
<td>$S_{Data}$</td>
<td>Size of a data packet (in byte)</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Unit cost of binding update at LMA</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Unit cost of lookup for MN at LMA/MAG</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Unit transmission cost of a packet per a wired link</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>Unit transmission cost of a packet per a wireless link</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Ratio of localized routing delivery in PMIP-LR</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Unit cost of hash operation at MAG</td>
</tr>
</tbody>
</table>
B. Cost Analysis

For cost analysis of candidate schemes, we define Total Cost (TC) as the sum of Signaling Control Cost (SCC) and Data Delivery Cost (DDC), that is, \( TC = SCC + DDC \).

1) PMIP

The signaling control cost of PMIP consists of the two parts: the initial connection establishment cost between MN and MN-MAG, and the binding update cost with LMA. We assume that initial connection establishment takes roughly \( T_{setup} \). After that, MN-MAG performs the PBU operations with LMA, and LMA will update its BCE. Then, the binding update cost of PMIP can be expressed as \( S_{control} \times 2T_{MAG-LMA} \) and \( P_{LMA} \), where \( T_{MAG-LMA} = \tau_{MAG-LMA} \) and \( P_{LMA} = \alpha \log(N_{MAG} \times N_{Host}) \) in the log scale by using a tree-based data structure to implement the database. Accordingly, the SCC of PMIP can be represented as follows.

\[
SCC_{PMIP} = T_{setup} + S_{control} \times 2T_{MAG-LMA} + P_{LMA}
\]

In PMIP, the data delivery from CN to MN can be done as follows. First, a data packet of CN is delivered to LMA through CN-MAG, which is equal to \( S_{data}(TCN-MAG + T_{MAG-MAG}) \). LMA will look up the CoA of MN with its BCE, which takes \( P_{LMA} = \beta \log(N_{MAG} \times N_{Host}) \). Then, the data packet is forwarded to MN-MAG, and further to MN, which corresponds to \( S_{data}(T_{MAG-MAG} + T_{MAG-MN}) \). Accordingly, we get the DDC of PMIP as follows.

\[
DDC_{PMIP} = S_{data}(TCN-MAG + 2T_{MAG-LMA} + T_{MAG-MN}) + P_{LMA}
\]

2) PMIP-LR

The initial connection establishment cost and the binding update cost of PMIP-LR are the same with those of PMIP. In addition, if LMA decides to perform the localized routing operations between MN and CN, it will look up the CoA of MN from its BCE, which takes \( P_{LMA} = \beta \log(N_{MAG} \times N_{Host}) \). Then, the two separate LRI and LRA messages are exchanged between LMA and each of MN-MAG and CN-MAG. Thus, the local routing cost of PMIP-LR can be expressed as \( S_{control} \times 4T_{MAG-LMA} \) and \( P_{LMA} \). Accordingly, the SCC of PMIP-LR can be represented as follows.

\[
SCC_{PMIP-LR} = T_{setup} + S_{control} \times 2T_{MAG-LMA} + P_{LMA}
\]

3) PMIP-PD

The initial connection establishment cost and the binding update cost of PMIP-PD are the same with those of PMIP. In addition, if CN sends a data packet to MN, the CN-MAG exchanges the binding query messages with the LMA. Thus, the binding query cost of PMIP-PD can be expressed as \( S_{control} \times 2T_{MAG-LMA} \) and \( P_{LMA} \). Accordingly, SCC of PMIP-PD can be represented as follows.

\[
SCC_{PMIP-PD} = T_{setup} + S_{control} \times 2T_{MAG-LMA} + P_{LMA}
\]

In PMIP-PD, CN delivers data packets directly to MN, which takes \( S_{data}(TCN-MAG + T_{MAG-MAG} + T_{MAG-MN}) \). To forward the data packet to MN-MAG, CN-MAG needs to lookup the CoA of MN, which takes \( P_{MAG} \). Accordingly, we can express the DDC of PMIP-PD as follows.

\[
DDC_{PMIP-PD} = S_{data}(TCN-MAG + T_{MAG-MAG} + T_{MAG-MN}) + P_{MAG}
\]

4) PMIP-FD

The initial connection establishment is the same with that of PMIP. In PMIP-FD, it is need not to operate binding update. Instead, the binding query operation will be done by multicast. That is, the CN-MAG sends the PBQ message with all MAGs in the domain, only the MN-MAG will respond with a PQA message, which takes \( S_{control} \times T_{MAG-MAG} \) and \( (N_{MAG} - 1) \times P_{MAG} \). We get SCC of PMIP-FD as follows.

\[
SCC_{PMIP-FD} = T_{setup} + S_{control} \times T_{MAG-MAG} \times N_{MAG}
\]

After the binding query, the packet delivery operations are the same with those of PMIP-PD. Thus, we get

\[
DDC_{PMIP-FD} = DDC_{PMIP-PD}
\]
5) **PMIP-HD**

In PMIP-HD, the binding update cost of PMIP-HD can be expressed as \( S_{control} \times T_{MAG-MAG} + P_{hash} \) (for hash function using MN-HoA at MN-MAG) + \( P_{MAG} \) (for binding update to the designated MAG), where \( T_{MAG-MAG} = \tau H_{MAG-MAG}, P_{hash} = \delta \log(N_{Host}) \) and \( P_{MAG} = \alpha \log(N_{Host}) \). Likewise, the signaling operation for binding query takes \( S_{control} \times T_{MAG-MAG} + P_{hash} \) (for hash function using MN-HoA at CN-MAG) + \( P_{MAG} \) (for binding query to the designated MAG). Thus, we get SCC of PMIP-HD as

\[
SCC_{PMIP-HD} = T_{setup} + S_{control} \times 2T_{MAG-MAG} + P_{hash} + P_{MAG} + S_{control} \times 2T_{MAG-MAG} + P_{hash} + P_{MAG} = T_{setup} + S_{control} \times 4\tau H_{MAG-MAG} + 2\delta \log(N_{Host}) + (\alpha + \beta) \log(N_{Host})
\]

The data packet delivery operations are the same with those of PMIP-PD. Accordingly, we get

\[
DDC_{PMIP-HD} = DDC_{PMIP-PD}
\]

C. **Numerical Analysis and Discussions**

Based on the cost analysis, we compare the numerical results. For numerical analysis, we set the default parameter values, as shown in Table 2, which is partly based on the work [6].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( \kappa )</th>
<th>( \tau )</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>( \gamma )</th>
<th>( \delta )</th>
<th>( T_{setup} )</th>
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<tr>
<td>Default Value</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0.95</td>
<td>1</td>
<td>10</td>
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</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( N_{Host} )</th>
<th>( N_{MAG} )</th>
<th>( H_{MAG-LMA} )</th>
<th>( H_{MAG-MAG} )</th>
<th>( H_{MAG-MN} )</th>
<th>( H_{MAG-CN} )</th>
<th>( S_{control} )</th>
<th>( S_{data} )</th>
</tr>
</thead>
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<tr>
<td>Default Value</td>
<td>200</td>
<td>20</td>
<td>20</td>
<td>5</td>
<td>1</td>
<td>50</td>
<td>1024</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7 shows the impact of the number of hosts per MAG (\( N_{Host} \)) on total costs. We see that the total costs are not nearly affected by \( N_{Host} \) for all schemes. This is because the binding update and lookup costs are proportional to \( N_{Host} \) in the log scale. It is noted that the propose PMIP-HD gives the lowest cost among the candidate schemes.

Figure 8 shows the impact of unit DHT operation costs (\( \delta \)) and unit binding update cost (\( \alpha \)) on total costs, in which \( \delta \) divided by \( \alpha (\delta/\alpha) \) is considered. We see that PMIP-HD gives better performance than PMIP-PD until \( \delta/\alpha \) reaches 256. However, \( \delta \) is typically similar to \( \alpha \), in which the proposed PMIP-HD can gives the best performance.

Figure 9 shows the impact of hop count between MAGs (\( H_{MAG-MAG} \)). In the figure, we can see that as \( H_{MAG-MAG} \) gets larger, the total cost linearly increases for candidate schemes except PMIP which is not affected by \( H_{MAG-MAG} \). This is because PMIP does not use the path between MAGs in the control and data planes. It is noted that the proposed PMIP-HD scheme gives the best performance among the candidate schemes.

Figure 10 compares the candidate schemes in terms of the hop count between MAG and LMA (\( H_{MAG-LMA} \)). From the figure, we can see that PMIP-FD and PMIP-HD are not affected by \( H_{MAG-LMA} \). This is because PMIP-FD and PMIP-HD are fully distributed mobility management approaches. So, there is no LMA at PMIP-FD and PMIP-HD. Although PMIP-PD is distributed mobility management approach, it uses the path between MAG and LMA in the control planes. It is noted that the proposed PMIP-HD scheme gives the best performance among the candidate schemes.
V. CONCLUSIONS

In this paper, we propose a distributed mobility management scheme using hash function in PMIPv6 networks. In the proposed scheme, the LMA functionality is completely distributed onto every MAG in the domain, and the binding update and binding query operations are performed, based on hash function.

From the numerical analysis, we can see that the proposed PMIP-HD scheme provides better performance than the existing PMIP, PMIP-LR, PMIP-PD and PMIP-FD schemes. Such the performance benefit comes from the hash-based distributed mobility management feature. That is, compared to existing centralized schemes, the proposed distributed scheme can reduce packet processing overhead at LMA and data transmission delays by using the optimized route from the beginning of data transmission. And the proposed scheme can reduce signaling control cost by using the hash function to dedicate MAG for query operations compared with PMIP-FD and it can reduce the cost to manage the binding cache entry between HoA and CoA at LMA compared with PMIP-PD.

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