A Route Optimization Scheme based on Roaming in PMIPv6 (pROR)

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Abstract—In PMIPv6, we propose a new Route Optimization (RO) scheme with roaming among the inter-domains. Previous works are used direct packet forwarding methods among the Mobile Access Gateways (MAGs) because the MAG manages the signaling for the mobile nodes (MNs) to support the mobility. However, previous works cause a lot of problems in security, packet delivery latency, and increasing the control messages. For this reason, we propose bi-directional tunnel among the Local Mobility Anchors (LMAs) and MAGs to support the RO when the MN handovers to the other PMIPv6 domains. We prove the RO with LMAs is more efficient than the previous work. Moreover, we implement our RO scheme and compare it with the roaming scheme in PMIPv6.

Keywords-component: PMIPv6, Location Management, Route Optimization

I. INTRODUCTION

While Mobile IP is considered to be the solution for global mobility across administrative domains, local mobility management (LMM) protocols are proposed to reduce the signaling overhead of the macro mobility. As the network-based approaches are used in 3G networks, the IETF NETLMM working group [4] is developing such as a network-based localized mobility management protocol and this protocol is called as Proxy Mobile IPv6 (PMIPv6). It is possible to support mobility for IPv6 nodes without extending MIPv6 signaling messages. In the PMIPv6 network, a Mobile Access Gateway (MAG) performs the signaling with the HA and does the mobility management on behalf of the mobile node (MN) attached to the network.

In the PMIPv6, [4, 5, 6] are proposed to the Route Optimization (RO) between MN and correspondent node (CN) and [7] is proposed to RO between PMIPv6 domains and MIPv6 domains. Also, [9] shows that the packet delivery latency reduces about 20% when the RO is used in the network. However, these RO schemes are not consider the inter-domain handover. When the MN moves into a new PMIPv6 domain from home PMIPv6 domain, the LMA in the new domain obtains the Home Network Prefix (HNP) of the MN from the home domain and new tunnel among the LMAs is created. And then previous RO schemes are performed for RO between the MN and the CN. As the result, there are unnecessary tunnel among the LMAs remains. Moreover, in [4, 5], they are not considered the Security Association (SA) among the MAGs and a lot of control message is added in the [6].

To avoid unnecessary tunneling in roaming scheme and security problem in route optimization, we propose a new LMA that support the route optimized tunneling options with roaming in the PMIPv6 (pROR-LMA). Depend on the location of the LMAs, the pROR-LMA selects the optimized tunneling among LMAs and MAGs. We present the new RO solution is more efficient than the previous RO solution and roaming solution by using the performance evaluation and compare the signaling message numbers.

The rest of the paper is organized as follows. Section 2 specifies RO solutions and inter-domain handover solutions as related works. A route optimized scheme with Roaming for PMIPv6 (pROR-PMIPv6) is proposed in Section 3. Section 4 presents performance evaluations. In Section 5, we conclude this paper.

II. RELATED WORKS

A. Route Optimization (RO) with Non Security Association (Non-SA)

[4, 5] are proposed for supporting the RO by internet-draft in the NETLMM working group. These schemes assume that the MNs and the CNs are located in the PMIPv6 domains. In these schemes, overall sequence for the RO without the control message is similar. First, the LMA detects that the RO can be established between the MN and the CN. If the RO can be established, the LMA sends the RO information to the MAG and the MAG create the RO path for the MN and CN. In the MIPv6, the tunneling is created for the SA between MN and CN. However, the RO path is not established but the tunneling is not created in the [4, 5]. In consequence,
if the MN and CN are located in the other PMIPv6 domains or the MN or CN handover the other PMIPv6 domains, the security problem can arise.

B. Route Optimization (RO) with Security Association (SA)

[6] use the HoTI/CoTI message for supporting the RO. Figure 3 shows the signaling message sequences. The MAG which is connected to the MN sends the HoTI message to the LMA and the LMA sends the HoTI message to the MAG which is connected to the CN. HoT message is sent from the MAG which is connected to the CN to the LMA and the MAG which is connected to the MN. If the MAG which is connected to MN is received the HoT message, the MAG sends the CoTI message to the MAG which is connected to the MN directly and the CoT message is replied. And then the tunnel between MAG which is connected to the MN and MAG which is connected to the CN is created. This mechanism solves the SA among the MAGs which are located in the other PMIPv6 domains. Moreover, if the MN (or CN) is located in the MIPv6 domains, the RO can be established between the MN (or CN) and the MAG because this mechanism using the HoTI/CoTI message.

But this RO scheme does not use the SA among the LMAS. In the [2, 3], the SA among the LMA is supported because the CN and the MN is located in the other PMIPv6 domains. And the RO set up time is extended because of using the HoTI/CoTI message.

C. Inter-domain handover

To provide inter-domain handover, SMA-PMIPv6[2] and H-PMIPv6[3] are proposed. In SMA-PMIPv6, the first attached Local Mobility Anchor (LMA) performs a role as the Session Management Anchor (SMA). When a MN is attached to the SMA, the SMA allocates a HNP to the MN and the HNP is stored into a policy store. When a MN actually attaches to an LMA, the LMA finds SMA. When a MN moves into a new LMA, new LMA sends a PBU (Proxy Biding Update [1]) to the SMA. Then the SMA tunnels packets bound for the MN to new LMA. This scheme represents that the MN initiates the connection with the CN. However, the scheme cannot be used by CN which wants to initiate communication with a MN. Figure 4 shows the scheme in SMA-PMIPv6.
regard to MN and Home LMA address sent from the home AAA, to the visit LMA. Home LMA address is delivered to the visit LMA and visit LMA sends PBU to Home LMA. Finally, the Home LMA sends PBA to visit LMA with HNP of the MN and visit LMA sends PBA to visit MAG. This scheme can be used by CN which wants to initiate communication with a MN. Figure 5 shows the scheme in H-PMIPv6.

![Figure 5. Roaming mechanism among PMIPv6 Domains](image)

However, SMA-PMIPv6 and H-PMIPv6 are not optimized because unnecessary tunneling between LMAs is used. To avoid unnecessary tunneling, we introduce route optimization with roaming LMA (pROR-LMA) and a bidirectional tunneling between pROR-LMA and visit MAG (v-MAG). Detail description is section 2.

III. A ROUTE OPTIMIZATION SCHEME BASED ON ROAMING IN PMIPv6 (pROR)

We assume that the address driven from the HNP is known to a CN like the home address of the MN in MIPv6. Also assume that the communication between LMAs is secure.

Figure 6 is basic architecture of pROR. The roaming scheme in pROR is similar with H-PMIPv6. MNs have pre-assigned HNP and the pre-assigned HNP is stored into the policy store. When a MN actually attaches to an LMA, the serving LMA (s-LMA) gets the pROR-LMA address from the serving policy store.

However, if the MN is not attached to the pROR-LMA firstly, tunneling between pROR-LMA and the s-LMA is needed. To avoid unnecessary tunneling, pROR includes a direct tunneling option when the s-LMA sends a PBU to pROR-LMA. When the s-LMA receives a PBU from a serving MAG (s-MAG; Mobile Access Gateway) after the MN is attached, the s-LMA makes a decision whether the MAG can attach to pROR-LMA directly. The decision is based on the administration profile and the information about link delay between pROR-LMA and the s-LMA. The s-LMA includes D-flag in the PBU when it decides the direct tunneling between pROR-LMA and the s-MAG. When pROR-LMA receives the PBU with D-flag, it includes a session key to a PBA (Proxy Binding Acknowledgement) and sends it to the s-LMA. If the serving LMA receives the PBA with the session key, it sends a PBA to the s-MAG. The PBA includes the MN’s HNP, the session key, and pROR-LMA address. The s-MAG sends a PBU to pROR-LMA if the PBA includes information for optimizing the forwarding route from pROR-LMA. With this Route Optimization (RO), the s-LMA is changed to pROR-LMA. Figure 6 shows the direct tunneling between pROR-LMA and s-MAG.

![Figure 6. The tunneling between pROR-LMA and s-MAG](image)

When MN moves to new LMA, pROR operation is identical repeated. Figure 7 shows the MN handover.

![Figure 7. MN handover](image)

pROR makes further RO if the CN is located in a PMIPv6 network. When pROR-LMA receives the first packet from a CN, if the prefix of the CN implies that the CN belongs to a PMIPv6 network, pROR-LMA can optimize the route from the CN to the MN. In this case, pROR-LMA checks the locations of three LMAs - the LMA of the CN (c-LMA), pROR-LMA, and the s-LMA of the MN, if any. If c-LMA is closely located from pROR-LMA, pROR-LMA sends a PBU with R-Flag (Redirect Flag), pROR-LMA address to c-LMA, c-LMA forwards a PBU to c-MAG (the MAG of the CN). c-MAG creates a direct tunnel between c-MAG and pROR-LMA. Figure 8 shows the tunneling between c-MAG and pROR-LMA.

However, if the c-LMA is remotely located from pROR-LMA, pROR-LMA checks the locations of s-LMA, if any. If s-LMA exists, pROR-LMA sends a PBU with s-LMA address. s-LMA creates a direct tunnel between s-LMA and itself, and notifies pROR-LMA with a PBA. If s-LMA is not
exists, pROR-LMA do not send PBU to c-LMA. Figure 9 shows the tunneling between c-LMA and s-LMA.

![Figure 8. The tunneling between c-MAG and pROR-LMA](image)

![Figure 9. The tunneling between c-LMA and s-LMA](image)

To summarize the RO options, the locations of three LMA have the five cases in Table 1.

<table>
<thead>
<tr>
<th>Case</th>
<th>Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>c-LMA, pROR-LMA and s-LMA are closely located</td>
</tr>
<tr>
<td>B</td>
<td>c-LMA and s-LMA are closely located but pROR-LMA is remotely located</td>
</tr>
<tr>
<td>C</td>
<td>c-LMA, pROR-LMA and s-LMA are all remotely located</td>
</tr>
<tr>
<td>D</td>
<td>c-LMA and pROR-LMA are closely located but s-LMA is remotely located</td>
</tr>
<tr>
<td>E</td>
<td>pROR-LMA and the s-LMA are closely located but c-LMA is remotely located</td>
</tr>
</tbody>
</table>

In case A, direct tunneling between c-MAG, pROR-LMA and s-MAG is preferred. In case B and C, direct tunneling between c-LMA and s-LMA is preferred. In case D, direct tunneling between c-MAG, pROR-LMA and s-LMA is preferred. In case E, direct tunneling between c-LMA, pROR-LMA and s-MAG is preferred.

![Figure 10. The location of three LMAs and the route path](image)

IV. PERFORMANCE EVALUATION

In this chapter, we compare the pROR with the previous RO with SA [6] and H-PMIPv6 for the performance evaluation.

A. Simulation Configuration

The PMIPv6 evaluation tool [8] is using the NS-2.29. We implement the previous RO with SA, H-PMIPv6, and the pROR by modifying the PMIPv6 evaluation tool. And the network topology is shown in the Figure 11 and 12.

In the Figure 11, the CN is not located in the PMIPv6 domain. In this network topology, we compare the pROR with the previous RO with H-PMIPv6. The Table 2 shows the network configuration. The link delay among all of the network entity in the PMIPv6 domains and between Router 0 and Router 1 is 1ms. The link delay between the CN and the Router0 is 10ms. The link delay between Router 0 and router 2 (LINK A) is increased 1ms to 20ms for the performance evaluation. We measure the packet delivery latency between the CN and the MAG.

| TABLE II. SIMULATION CONFIGURATION (CN IS NOT LOCATED IN THE PMIPV6 DOMAIN) |
|---------------------------------|----------------|
| The link delay of the network entity in the PMIPv6 domain | 1 ms |
| CN ↔ Router 0 | 10 ms |
| Router 1 ↔ Router 0 | 1 ms |
| Router 2 ↔ Router 0 (LINK A) | 1 ~ 20 ms |
| Traffic type | UDP |
Table 3 and Figure 12 show the network topology and configuration that the CN is located in the PMIPv6 domain. The link delay among all of the network entity in the PMIPv6 domains is 1ms. And the link delay among routers is increased 1ms to 20ms. We measure the packet delivery latency between MAG1 and MAG3 for comparing the pROR with the H-PMIPv6.

And also, we use this network topology for analyze the RO establishment time which of the previous RO with SA and the pROR.

### TABLE III. SIMULATION CONFIGURATION (CN IS LOCATED IN THE PMIPv6 DOMAIN)

| The link delay of the network entity in the PMIPv6 domain | 1 ms |
| Traffic type | UDP |
| LINK A, LINK B, LINK C | 1 ~ 20 ms |

B. Comparison with RO scheme

We compare the RO with non-SA, RO with SA, and pROR in the table 4. Security is very weak in the [4, 5] because these schemes do not mention the tunneling among the MAGs. Also, if the CN and MN are located in the other PMIPv6 domains, it is very difficult to create tunneling among the MAGs. In the RO with SA [6], the tunneling among the MAGs is used. For this reason, we measure the RO establishment time of the RO with SA and pROR.

And the control message of the pROR is not increased because pROR just uses the PBU and the PBA for the RO. Besides, the previous RO schemes [4, 5, 6] do not refer to the inter-domain handover. Consequently, the previous RO schemes cause the unnecessary tunneling overhead among the PMIPv6 domains.

### TABLE IV. COMPARISON WITH RO SCHEME

<table>
<thead>
<tr>
<th></th>
<th>RO with non-SA</th>
<th>RO with SA [6]</th>
<th>pROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>RO setup message [4]</td>
<td>X</td>
<td>X</td>
<td>0</td>
</tr>
<tr>
<td>CB Update message [5]</td>
<td>6 (Init/Init Ack, Setup/Setup Ack, Report/Report Ack)</td>
<td>1 (CB Update)</td>
<td>4 (HoTI/HoT, CoTI/CoT)</td>
</tr>
<tr>
<td>RO end-point</td>
<td>MAG</td>
<td>MAG</td>
<td>MAG</td>
</tr>
<tr>
<td>RO among Inter Domains</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Inter Domain Handover</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure 13 shows the RO establishment time. pROR just use the session key which is made by the LMA for creating tunnel, but the RO with SA uses the additional control message. In the pROR, the LMA forward the session key to the MAG and then the tunneling is created directly. However, in the RO with SA, the MAG send the HoTI/HoT message through the LMA to the other MAG and then the CoTI/CoT message is sent from the MAG for the security association. Therefore, pROR is more rapidly than the RO with SA about 20%.
In the Figure 14, we compare the two tunneling types. One is the tunneling among the MAGs and the other type is the tunneling among the LMAs. We measure the packet delivery latency between the MAG1 and the MAG3 in the Figure 9. The link delay of the LINK A, LINK B, and the LINK C is increased from 1ms to 10ms. The difference between the RO with the MAG and the RO with the LMA is about between 1% and 3% and can be ignored in the VoIP service, etc.

![Figure 14. The RO with LMA and the RO with MAG](image)

C. Comparison with Roaming Solution

1) CN is located in the None-PMIPv6 domain

Figure 15 shows the packet delivery latency and the latency ratio of the H-PMIPv6 and the pROR. We measure the packet delivery latency between the CN and the MAG2 in the figure 8. If the link delay is over 14ms, the difference between the H-PMIPv and the pROR is just about 2% and this performance improvement does not have effect on the network latency. This result is caused by the MAG and the LMA are network entity in the PMIPv6 domain and the latency among the network entities is too little. On the other side, the latency between the CN and the boarder gateway of the PMIPv6 domain is too larger than the latency among the network entities. Consequently, whether the end-point of the RO is the MAG or the LMA, we do not expect that the performance improvement.

Furthermore we can analyze that the packet delivery latency is not improve when the link delay among the gateways is over 10ms, and we choose the threshold of the tunneling detection to the 10ms. In the inter-domain RO simulation, if the packet delivery latency among the LMA is over 10ms, the LMA selects the tunneling with LMAs not MAGs.

![Figure 15. Latency analysis](image)

2) CN is located in the PMIPv6 domain

Table 5 shows the simulation configuration when the CN is located in the PMIPv6 domains. We evaluate the five cases in the Table 1. If the packet delivery latency among the LMAs is lower than 10ms, the Case A is applied. But if the packet delivery latency is over 10ms, the CASE B, C, D, and E are executed that we mention above.

<table>
<thead>
<tr>
<th>LINK A</th>
<th>LINK B</th>
<th>LINK C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case B</td>
<td>1 ms</td>
<td>1 ~ 20 ms</td>
</tr>
<tr>
<td>Case C</td>
<td>1 ~ 20 ms</td>
<td>1 ~ 20 ms</td>
</tr>
<tr>
<td>Case D</td>
<td>1 ms</td>
<td>1 ms</td>
</tr>
<tr>
<td>Case E</td>
<td>1 ~ 20 ms</td>
<td>1 ms</td>
</tr>
</tbody>
</table>

First, we evaluate the Case D and E shown in the Figure 16 and 17. In the Case D, pROR use the tunneling between the MAG3 and the LMA1 when the LINK C delay is lower than 9ms and the packet delivery latency is decreased about 4ms. And then the LINK C delay is over 10ms, the tunneling between the LMA3 and the LMA1 is applied and the packet delivery latency is decreased about 2ms. In the Case E, the simulation result is identically with Case D.

In these cases, we cannot conclude that the pROR improve the packet delivery latency between the MN and CN.

However, in the Case B and C, the packet delivery latency is dramatically improved. Figure 18 and 19 show the packet delivery latency between the MN and the CN. In these cases, if the packet delivery latency among the LMAs is over 10ms, the tunneling between the LMA which is MN and the LMA which is CN is used for the RO. Moreover, we increase the link delay of the LINK A, B, and C and the Figure 20 shows this simulation results. In the H-PMIPv6, the packets from the CN are always forwarded to the home LMA of the MN and then the packets are forwarded to the serving LMA of the MN again. But the packets form the CN are forwarded to the serving LMA of the MN directly in the pROR. Accordingly, one hop delay is decreased in the pROR and this difference can be affected in the VoIP services and real-time streaming services.
V. CONCLUSION

We proposed pROR to provide route optimization with location management in PMIPv6. pROR follows closely the PMIPv6 standard and extends existing messages by defining two flags using unused flags and adding new options. By using direct tunneling with RO options, pROR can bypass pROR-LMA. This RO is similar to that of MIPv6 RO between CN and MN.

REFERENCES