DESIGNS AND ANALYSIS OF LOCAL MOBILITY AGENTS DISCOVERY, SELECTION AND FAILURE DETECTION FOR MOBILE IPV6

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Abstract - This paper addresses the problem of Local Mobility Management (LMM) for Mobile IPv6. First, the analysis on the conformance of the Hierarchical Mobile IPv6 (HMIPv6) to the fundamental LMM Requirements set out in the Internet Engineering Task Force (IETF) Internet Drafts, is carried out. This paper then describes three of our proposed solutions for LMM namely, “Route Tracing”, “En-Route Local Mobility Agents (LMAs) Recording”, and “Hop-by-Hop LMA Probing”. These three proposals discover LMAs along the transmission route from the mobile node to its home agent and select the furthest LMA, within the visited domain, for local registration. The first two proposals are built on the HMIPv6’s LMAs discovery mechanisms, whereas the “Hop-by-Hop LMA Probing” is a standalone full-fledged novel design. The three proposals are analyzed for conformance to the fundamental LMM Requirements for Mobile IPv6 and shown to satisfy most of the requirements, with the “Hop-by-Hop LMA Probing” being the best compliance.

Keywords – Mobile IP, IPv6, Mobility Management, Local Mobility Agent, Hierarchical Mobile IP, Hop-by-Hop Probing.

I. INTRODUCTION

The imminent proliferation of mobile devices is pushing forth the need for mobility support to facilitate the roaming of mobile devices. Internet Engineering Task Force (IETF) has developed the Mobile IP protocol [1,2] to provide this mobility support, in a way that a mobile device can roam among different wired/wireless access networks while maintaining a permanent IP address.

However, as the mobile node (MN) roams from one network to another, even within the same domain, Mobile IP’s intrinsic design requires that the MN updates the home agent (HA) and all the correspondent nodes (CNs) of its new location. These re-registrations necessitate additional signaling and thus cause packet loss.

In IPv4, several solutions [3,4] had been proposed to perform registrations locally in the visited domain, where foreign agents are organized into a hierarchical structure.

In IPv6, a hierarchical mobility management model [5] is proposed as an extension to Mobile IPv6 for Localized Mobility Management (LMM) [6]. It utilizes a router, called the Mobility Anchor Point (MAP), Local Mobility Agent (LMA) equivalent in [6], located in the visited domain, to act as a local HA. When the MN changes its point of attachment within the MAP domain, only the MAP is informed, whereas its globally perceived IP address remains intact. This diminishes signaling for re-registration with HA and CNs.

Since the registration is localized in the visited domain, the handoff latency is also reduced.

In this paper, we propose solutions of LMM for Mobile IPv6, and analyze their conformance to the key fundamental requirements based on those set out in [6].

The rest of the paper is organised as follows. In Section II, we specify the key fundamental requirements to be considered in our LMM design. In Section III, related work is described and analyzed. Section IV presents the three proposals for the LMM design. In Section V, the analysis of the proposals is presented. Conclusions follow in Section VI and Future Work is described in Section VII.

II. LMM DESIGN REQUIREMENTS

The key fundamental requirements to be considered for LMM Designs are extracted from [6], as follows.

i) Minimize signaling traffic to HA and CNs
ii) Visited network must maintain topological confidentiality from MN
iii) Must not introduce any modifications or extensions over core Mobile IPv6 at HA and CNs
iv) Non LMM aware nodes must be able to inter-operate with LMAs
v) Regional signaling must not increase as local domain expands in size
vi) LMA must require minimal manual configuration
vii) Must not increase latency or packet loss that exists with core Mobile IPv6
viii) Minimum requirements on the carrier network and must not require that all routing elements be assumed to be LMM-aware in the signaling interactions

III. HIERARCHICAL MOBILE IPV6 (HMIPv6)

In the HMIPv6 Internet draft [5], the routers are arranged in a hierarchical structure. Two methods are proposed to discover the furthest MAP to register with.

In the Dynamic MAP Discovery method, a new MAP option is introduced in the IPv6 router advertisements (RAs) [7]. Upon reception of a RA with the MAP option and given that a router is configured to propagate this option, the router copies the option and re-send it after incrementing the distance field. If the router is also a MAP, it includes its own option in the same RA.

In the Route Renumbering (RR) [8] method, a new Prefix Code Operation (PCO), PROPAGATE, is defined. The MAP
option is included in the “Use Prefix” part of the RR message with the PROPAGATE command. On receiving this message, a router will propagate the MAP option.

Both methods are based on the concept of a tree topology where the MAP advertisements are propagated from a central node all the way down to the lowest layer of routers/MAPs and finally to MN. The following provides an analysis of HMIPv6 based on the requirements set out in Section II.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Analysis</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>When handoff is performed within local domain, the HA and CNs need not be informed through the binding update, for the packets destined to MN will be sent to the registered MAP instead.</td>
<td>Met</td>
</tr>
<tr>
<td>ii</td>
<td>Topological confidentiality of visited network should be maintained, as the router advertisements sent by the lowest level of routers to MN, only contains the MAPs’ addresses. However, since network is arranged into a hierarchical structure and if all the routers propagating the MAP options, are acting as MAPs, then the topological structure might be disclosed to MN.</td>
<td>Partly Met</td>
</tr>
<tr>
<td>iii</td>
<td>Modification is not required on HA and CNs and the core Mobile IPv6 is preserved, with the exception that the CoA being registered is the MAP’s address.</td>
<td>Met</td>
</tr>
<tr>
<td>iv</td>
<td>Non LMM aware nodes would disregard any MAP advertisements and simply use the standard Mobile IPv6 implementation.</td>
<td>Met</td>
</tr>
<tr>
<td>v</td>
<td>As the local domain increases in size, the MAP options would be propagated across a wider scope. Therefore, regional signaling traffic load would increase.</td>
<td>Not Met</td>
</tr>
<tr>
<td>vi</td>
<td>Configuration on MAP involves choosing the central node, and setting the preference (optional) and interfaces for MAP option propagation.</td>
<td>Met</td>
</tr>
<tr>
<td>vii</td>
<td>Initial movement into the visiting domain involves certain delay as compared to standard Mobile IPv6, due to the discovery and selection process of MAP. After which, movements in the local domain would reduce latency if re-registrations with HA and CNs are not required. However, in the case of MAP or link failure, the MAP selection and registration process would be triggered resulting in higher latency.</td>
<td>Partly Met</td>
</tr>
<tr>
<td>viii</td>
<td>All routers involved in the MAP discovery must be modified to propagate the MAP options. Overhead is also introduced whereby the MAP options are propagated throughout the local domain.</td>
<td>Not Met</td>
</tr>
</tbody>
</table>

Table 1: Analysis of Hierarchical Mobile IPv6

When MN moves into the visiting domain, it will acquire its CoA and a list of available LMAs in the domain. At the same time, MN will attempt to find the LMAs along the path to its HA. The routing tables on each node will be examined to determine the exact transmission route to be taken based on the destination address.

In Figure 1, let’s assume that the "MN -> LMA3 -> LMA1 -> R1 -> HA" route will be taken. To find the furthest LMA on the transmission route from MN to HA, the Hop Limit field in the IPv6 [9] header, which specifies the maximum number of hops a packet may travel, is manipulated.

The probing starts with sending Internet Control Message Protocol (ICMP) [10] Echo Request packets to HA with incrementing values of Hop Limit, starting with one. Corresponding to each ICMP Echo Request packet, intermediate nodes will send ICMP Time Exceeded packets to MN. Finally, an ICMP Echo Reply packet from HA will mark the end of the route tracing process.

MN will then scan through the addresses of the intermediate nodes, from the furthest (R1) to the nearest (LMA3) hop to check if it is a LMA’s address. When a LMA
is found (in this case, LMA1), the scanning stops and this LMA is selected for registration. After the registration, all LMAs in the local domain will continue sending out LMA Discovery Messages periodically. Therefore, if MN could not receive these messages from the registered LMA, a node or link failure has occurred and the route tracing process will be repeated to locate another furthest LMA.

**B. En-Route LMAs Recording**

This method works by collecting the IP address of the intermediate LMAs along the transmission path from MN to HA, using a new IPv6 Hop-by-Hop option called the “Record LMAs”, similar to IPv4 Record Route [11], in the ICMP Echo Request packet destined for HA from MN.

The Hop-by-Hop option is used because unlike other extension headers, which are only processed by the destination node, this option will also be processed by the intermediate nodes. In addition, sufficient storage space must be pre-allocated in this option for the intermediate LMAs to append in their IP address as the ICMP Echo Request packet travels along the transmission route. When HA receives this ICMP Echo Request packet with the “Record LMAs” option, it will copy the data in the option fields into the ICMP Echo Reply packet’s data field and send it back to MN.

Referring to Figure 1, the addresses of LMA3 and LMA1 will be stored. When MN receives the ICMP Echo Reply packet from HA containing the LMAs addresses, it will acquire the address of the furthest LMA in the transmission route by referring to the last recorded address in the data field. Other parameters relating to this selected LMA are obtained from the MAP/LMA option propagated to MN by the HMIPv6’s discovery mechanisms. Registration with HA is then processed by MN.

Referring to Figure 2, the addresses of LMA3 and LMA1 will be stored. When MN receives the ICMP Echo Reply packet from HA containing the LMAs addresses, it will acquire the address of the furthest LMA in the transmission route by referring to the last recorded address in the data field.

**C. Hop-by-Hop LMA Probing**

Contrary to the first two proposals, where a list of LMAs in the visiting domain is provided for the MN by the HMIPv6 LMAs discovery mechanisms, this proposal introduces a new LMA Discovery and Selection method. This is independent of HMIPv6. The following new option and messages are introduced.

**New Hop-by-Hop Option**
- LMA Probe Option

**New ICMPv6 Informational Messages**
- LMA Probe Reply
- LMA Configuration
- LMA Configuration Acknowledgement
- LMA Alive Notification

The format of the LMA Probe Hop-by-Hop Option is shown in Figure 3. The LMA Probe ID is used to match the LMA Probe Reply from the LMAs. The counter, used to locate the furthest LMA along the route, is initialized to 0 from the sending node, MN, and incremented by LMAs along the transmission route.

When MN moves into the visiting domain, it will send an ICMP Echo Request Message to its HA, with the LMA Probe Option. This new option will be skipped over by the intermediate processing IPv6 nodes if the option type is not recognized.

At the Domain Gateway External Interface (DGEI), which is any interface on the Gateway LMAs linked to external domains, the counter in the LMA probe option will be set to a “Boundary Encountered” value to indicate that a boundary is reached. After which, no LMAs should reply to this probing. This is to ensure that LMAs in other domains will not be discovered as the ones in the visiting domain.

In Figure 4, the DGEIs are indicated by O. Therefore, the en-route LMAs, LMA1 and LMA2, will check that the counter value is valid, and send back a LMA Probe Reply (Figure 5), to MN. Then, LMA1 will set the counter value to the “Boundary Encountered” value when the packet is
forwarded to its DGEI. After which, no LMAs will reply to this probe. If this LMM scheme is not implemented in the visited domain, but on the home domain alone, LMA(H) will receive the probe through its DGEI and set the counter value to the "Boundary Encountered" value, preventing further LMAs from replying to the probe.

In Figure 5, the LMA Probe ID is from the LMA Probe Hop-by-Hop Option. The Valid Lifetime is the minimum value of the preferred and valid lifetimes of the prefix assigned to the LMA’s subnet. The LMA IP Address is the LMA’s Global Routable IP Address.

![Figure 5: LMA Probe Reply Message Fields](image)

After receiving the ICMP Echo Reply from HA, MN will have acquired the information of all the LMAs residing in the visiting domain, along the transmission route. It will select the LMA with the highest counter value, based on the received LMA Probe Reply messages. At the same time, the LMA will send a LMA Configuration Message (Figure 6) to MN, whereby MN will acknowledge with a LMA Configuration Acknowledgement Message (Figure 7).

![Figure 6: LMA Configuration Message Fields](image)

In Figure 6, the LMA Probe ID is from the LMA Probe Reply Message and LMA Alive Notification Interval (in seconds) specifies the intervals that it will send LMA Alive Notification Message (in Figure 8) to MN.

In Figure 7, the LMA Probe ID is from the LMA Configuration Message and Status informs the LMA whether the configuration is successful.

![Figure 7: LMA Configuration Acknowledgement Message Fields](image)

MN will keep track of these messages. If one has not been received exceeding a Maximum Notification Delay, which is typically three times the Alive Notification Interval, it assumes that the registered LMA has failed. MN will then repeat the LMA Discovery and Selection process.

V. LMM DESIGN ANALYSIS

Analysis on the conformance to the requirements set out in Section II is performed on the three proposed LMM Design. The details of the analysis and the result are shown in the following table. Requirements are labeled from ‘i’ to ‘x’. ‘A’ stands for Analysis, and ‘R’ stands for Result.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Analysis</th>
<th>Result</th>
</tr>
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<tbody>
<tr>
<td>i. Signaling traffic to HA is incurred when MN moves to the visiting domain initially. This is required to locate the furthest LMA along the transmission route. After which, only regional registration occurs for handoffs performed within local domain.</td>
<td>A MET MET MET</td>
<td>R MET MET MET</td>
</tr>
<tr>
<td>ii. Since the implementation is topology independent, the network topology could not be assumed by the MN. Even when all routers along the transmission route are serving as LMAs, the network could be in a mesh topology where the actual layout is unknown.</td>
<td>A MET MET MET</td>
<td>R MET MET MET</td>
</tr>
<tr>
<td>iii. Modification or extensions over core Mobile IPv6 at HA and CNs are not required. Modification to ICMP Echo Reply mechanism is required on HA to copy back records of LMAs' addresses.</td>
<td>A MET MET MET</td>
<td>R MET NOT MET MET</td>
</tr>
<tr>
<td>iv. Non LMM aware nodes would disregard any LMA advertisements. ICMP Echo Messages used in Route Tracing, are standard implementation on all IP nodes. Non LMM aware nodes would simply skip over the Record LMAs Hop-by-Hop option.</td>
<td>A NOT MET NOT MET MET</td>
<td>R MET MET MET</td>
</tr>
<tr>
<td>v. As the local domain increases in size, the LMA discovery options would be propagated across a wider scope. When the number of intermediate nodes on the transmission path increases, the signaling traffic would increase, as the number of pairs of ICMP Echo Request and Reply Messages required, is equal to the number of hops the HA is from MN. As the local domain increases in size, the LMA discovery options would be propagated across a wider scope. However, only a pair of ICMP Echo Request and Reply Messages would be incurred regardless of domain size. When the local domain increases in size, the regional signaling would not increase, unless the number of intermediate LMAs en-route increases. LMA Probe Reply messages would then increase.</td>
<td>A NOT MET NOT MET MET</td>
<td>R MET MET MET</td>
</tr>
<tr>
<td>vi. Similar to HMIPv6. Configuration involves setting the DGEI for confining the LMA Discovery to the visited domain.</td>
<td>A MET MET MET</td>
<td>R MET MET MET</td>
</tr>
</tbody>
</table>
Initial movement into the visiting domain involves delay due to the discovery and selection process of LMA. After which, movements in the local domain would reduce latency. However, in the case of LMA or link failure, the LMA selection and registration process would be triggered, resulting in higher latency.

All routers involved in the LMA discovery must be modified to propagate the LMA options. Overhead is also introduced whereby the LMA options are propagated throughout the local domain. Routers not serving as LMAs need not be specially configured. LMAs not on the transmission route from MN to HA could remain dormant in LMM capacity.

Table 2: Analysis of the three new proposals

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<td>vii</td>
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<tr>
<td>viii</td>
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The analysis of the three proposals and the HMIPv6 (Section III) on the conformance to the fundamental requirements of LMM Design shows that the order of conformance of each method starting with most requirements met, is as follows:

- Hop-by-Hop LMA Probing
- Route Tracing
- Hierarchical Mobile IPv6
- En-Route LMAs Recording

However, the level of conformance to each requirement, comparison of exact amount of overhead incurred, amount of additional signaling traffic introduced, latency and packet loss of each method are not yet analyzed. Simulations would have to be performed to come up with the above-mentioned detailed information.

VI. CONCLUSIONS

In this paper, the HMIPv6, a LMM Design proposed to IETF is analysed for conformance to the key requirements stated in the IETF LMM Requirements Internet Draft. Three new proposals namely, “Route Tracing”, “En-Route LMAs Recording” and “Hop-by-Hop LMA Probing”, are for the first time, introduced in this paper. They, too, are analyzed for their conformance to the LMM Requirements. It is shown that all four satisfy most of the requirements, with the Hop-by-Hop LMA Probing being the best compliance. With respect to the regional signalling requirement (Requirement v), for HMIPv6, as the local domain increases in size, the LMA information would be propagated across a wider scope, resulting in the increase of regional signalling traffic load. However, in “Hop-by-Hop LMA Probing”, when the local domain increases in size, the regional signaling would not increase, unless the number of intermediate LMAs along the transmission route increases. In this case, it would only result in linear increase of the number of LMA probing reply messages with the number of intermediate LMAs. For the requirement on modification to the carrier network (Requirement viii), in HMIPv6, all routers involved in the LMA discovery must be modified to propagate the LMA information. However, in “Hop-by-Hop LMA Probing”, routers not serving as LMAs need not be modified to recognize the new messages. In addition, LMAs not on the transmission route from MN to HA could remain dormant in LMM capacity.

VII. FUTURE WORK

The level of conformance to each requirement, comparison of exact amount of overhead incurred, amount of additional signaling traffic introduced, latency and packet loss of each method will need to be further analyzed. Their level of significant improvement over core Mobile IPv6 would have to be investigated too. Simulations would be performed at a later stage to obtain these informations.

REFERENCES