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Evaluating the Benefits of Introducing PMIPv6 for Localized Mobility Management

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Abstract

Since recent years, it has been recognized that using global mobility protocol for managing localized mobility causes a number of problems, such as long registration delay. To overcome these problems, host-based and network-based localized mobility approaches have been proposed. Moreover, network-based mobility management is more desirable since it requires no host software stack changes. Proxy Mobile IPv6 (PMIPv6) provides a solution for network-based mobility management that can avoid tunneling overhead over the air and support for hosts without an involvement in the mobility management.

We first review the localized mobility proposals and explore three major benefits that PMIPv6 can bring. In particular, we evaluate two aspects of the handover performance through a mathematical model for Fast Handovers for MIPv6 (FMIPv6), Hierarchical MIPv6 (HMIPv6), Fast handovers for HMIPv6 (F-HMIPv6) and PMIPv6. These analytical studies show that PMIPv6 may cause high handover latency if the local mobility anchor (LMA) is located far from the current mobility access gateway (MAG).

In this paper, we therefore propose an enhancement for PMIPv6, so-called fast handovers for PMIPv6 (F-PMIPv6) to further reduce the handover latency. The analysis result ascertains that F-PMIPv6 is a promising mobility scheme to efficiently manage the localized mobility.

***Index Terms*— Internet Mobility, MIPv6, Hierarchical MIPv6 (HMIPv6), Fast Handovers for MIPv6 (FMIPv6), Proxy MIPv6 (PMIPv6)**

I. Introduction

Mobile IPv6 (MIPv6) [5] is a host based global mobility management scheme for IPv6 networks. However, there are three well-known problems involved in using global mobility protocol for every movement between access routers: 1) remote update latency; 2) signaling overhead; 3) location privacy [8]. These problems call for a protocol that is able to effectively manage regional movements. Furthermore, recent new IETF work on global mobility management protocols, such as Host Identity Protocol (HIP) [10] and IKEv2 Mobility and Multihoming (MOBIKE) [2], suggest that the future wireless IP nodes may be able to support diverse kinds of global mobility protocols. In addition, the success of Wireless LAN (WLAN) switch approach [11] that performs localized management without any host stack involvement, provides a possible paradigm to reduce host stack software complexity on the mobile node.

Motivated by above observations, localized mobility management has come recently a hot topic in the IETF. Some previous works on the localized mobility management, such as Fast-Handovers for Mobile IPv6 (FMIPv6) and Hierarchical Mobile IPv6 (HMIPv6) rely on host-based solutions that require host involvement at the IP layer, which however may not be compatible some other global mobility protocols other than MIPv6. Therefore, a network-based localized mobility protocol without requiring software support on the host is preferable for localized mobility management.

PMIPv6 [3] provides a solution for network-based mobility management that can avoid both tunneling overhead over the air and changes in hosts. Furthermore, the IETF expects that scaling benefits can be realized by introducing PMIPv6 for localized mobility management. Among these benefits, we can mention the following three since they are also the most important goals for the Network-based Localized Mobility Management (NETLMM) [7].

- *Handover performance optimization.* PMIPv6 can reduce the amount of latency in IP handovers by limiting the mobility management within the PMIPv6 domain. Therefore, it can largely avoid remote service which not only cause long service delay but consume more network resource.
- *Reduction in handover-related signaling overhead.* The handover-related signaling overhead can be alleviated in PMIPv6 since it can avoid tunneling overhead over the air and as well as the remote Binding Updates either to the Home Agent (HA) or to the Correspondent Node (CN).
- *Location privacy.* Keeping the mobile node's Home Address (MN-HoA) [3] fixed over a PMIPv6 domain dramatically reduces the chance that the attacker can deduce the precise location of the mobile node.

In this paper we explore the above mentioned benefits of PMIPv6 for localized mobility. Following the introduction, we give a brief overview of PMIPv6. Section 3 presents related works including FMIPv6 and HMIPv6. Based on theoretical analysis and comparison with existing localized mobility proposals, we identify some benefits of introducing PMIPv6 for the localized mobility. However, PMIPv6 may cause high handover latency if the local mobility anchor (LMA) is located far from the current mobility access gateway (MAG). In order to further enhance the handover performance for PMIPv6, in Section 5 we propose the fast handovers for PMIPv6 (F-

PMIPv6). Finally, we concludes this paper and outlines future work in Section 6.

II. PMIPv6 Overview

In this section, we exploit the PMIPv6 scheme with respect to its protocol operations.

Figure 1 gives a brief overview of the PMIPv6 architecture. In the PMIPv6 domain, a new entity – Mobile Access Gateway (MAG) – is introduced. It mainly has the following three functional roles: (1) detecting the mobile node's movement and initiating the signaling with the mobile node's Local Mobility Anchor (LMA) for updating the route to the mobile node's home address; (2) setting up the data path for enabling the mobile node to use its home address for communication from the access link; (3) emulation of the mobile node's home link on the access link. As the handover procedure is our main focus for analysis, it will be presented in details.

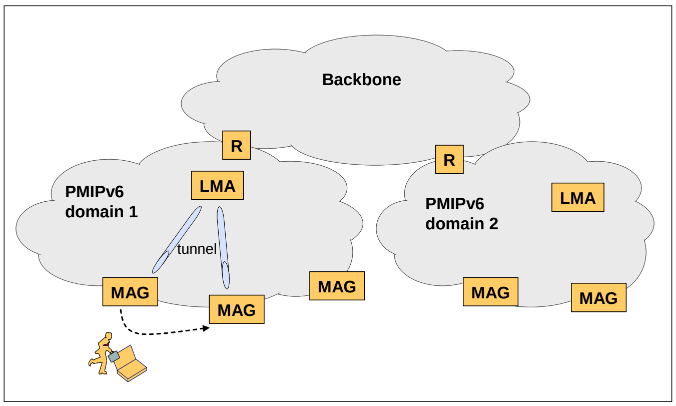

Fig. 1. PMIPv6 architecture

A. New Function

In the PMIPv6 domain, a new functional entity – Mobile Access Gateway (MAG) – is introduced, which conceals the roaming information to the mobile node by emulating mobile node's home link properties. It mainly has the following three functional roles: (1) detecting the mobile node's movement and initiating the signaling with the mobile node's Local Mobility Anchor (LMA) for updating the route to the mobile node's home address; (2) setting up the data path for enabling mobile node to use its home address for communication from the access link; (3) emulation of the mobile node's home link on the access link.

Besides, the LMA is the entity that has the functional capabilities of a home agent as defined in MIPv6 base specification [5] and with the additional required capabilities for supporting PMIPv6 as defined in the specification [3]. From the perspective of the LMA, the MAG is the special entity that sends MIPv6 signaling message on behalf of a mobile node, using its own identity.

B. Protocol Operation

The PMIPv6 protocol operation consists of five phases. The first phase is *Access Authentication* which ensures a valid mobile node connecting to the network. Through a successful authentication by the policy server (e.g., AAA-server), the MAG can retrieve the mobile node's profile using its current identifier. The *Binding Update (BU)* is the second phase, in which the MAG will send a Proxy BU request to the LMA in order to register the current point of attachment of the mobile node. Accordingly, a binding cache entry and a tunnel route for the mobile node's home prefix will be created. At the LMA's side, it will create a binding cache entry, a tunnel towards the active MAG, a route for the mobile node's home prefix as well. The third phase will be *the MAG emulating the mobile node's home interface on the access interface*. Therefore, the mobile node will always believe it is in the home network but attaches to a new default router. Fourthly, *the mobile node's interface will be configured* either by stateful or stateless address configuration methods. Lastly, for *packet routing*, the LMA will route all received packets over the established tunnel to the MAG. The MAG will in turn route these packets to the mobile node. Certainly, the MAG will relay all the received packets over the tunnel to the LMA and then they will be routed towards the destination.

C. Handover Procedure

Since above mentioned benefits are all highly related with handover procedure, we will present the PMIPv6 handover operations in details as follows.

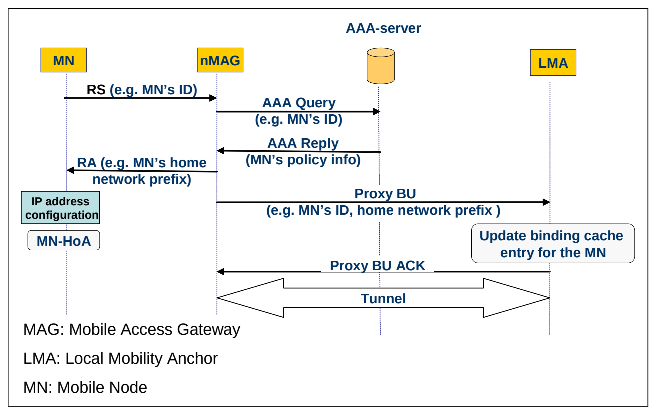

Fig. 2. PMIPv6 handover operations.

Figure 2 gives a brief overview of PMIPv6 handover operations. Once a IPv6-enabled mobile node attaches to a new MAG (nMAG) and after access authentication, it will typically send a Router Solicitation (RS) message. Based on the MN's identity, the nMAG can obtain the mobile node's configuration associated profile from the policy store, such as an AAA-server. Then, the nMAG will respond to the RS message with a Router Advertisement (RA) which includes the mobile node's home network prefix, nMAG address and other address configuration parameters.

Since the mobile node always detects the same home network prefix on the access link, it can continue to use its Home Address (MN-HoA). Such a operation exactly matches the purpose of location privacy since it is now quite difficult for attackers to obtain the current location of the mobile node.

However, the current link local address will be different from the one received in the previous Router Advertisement, which makes the mobile node believe that there is a new default router on the home link. For updating the current location to the LMA, the MAG sends a Proxy Binding Update (PBU) message to the LMA. Upon receiving the PBU request, the LMA sends a Proxy Binding Acknowledgment (PBA) message to the MAG. Once receiving the PBA message, the MAG will set up a tunnel to the LMA and add a default route over the tunnel to the LMA. Therefore, the LMA can forward any packet sent by any corresponding node to the mobile node through the current MAG.

III. Related Work

As mentioned above, FMIPv6 and HMIPv6 are host-based localized mobility management. In this section, we briefly overview these two protocols in order to facilitate the analytical evaluations in Section 4.

A. Fast Handover for MIPv6(FMIPv6)

FMIPv6 has been proposed to reduce the service degradation that a mobile node may suffer due to the change in its point of attachment. In its specification [9], two different mechanisms are described: predictive and reactive fast handover. The reactive mode relies on link layer triggers to perform fast handovers, which make the solution unfeasible for some link layer technologies. Nevertheless, the preactive mode is a link layer independent solution and in principal would be feasible solution. For brevity, we focus on the predictive mode which is the link layer independent solution.

When a mobile node discovers the information about the next point of attachment to which it will attach, the mobile node sends a Router Solicitation for Proxy (RtSolPr) to the Previous Access Router (PAR) with an identifier of the new point of attachment. Upon receiving the information, the PAR constructs an new CoA (NCoA) based on the mobile node's interface ID and the New Access Router's associated subnet prefix. Then, the PAR sends a Proxy Router Advertisement (PrRtAdv) to the mobile node with proposed NCoA and the NAR's IP address and link layer address.

To reduce the Binding Update latency, FMIPv6 specifies a tunnel between the PAR and the NAR. The mobile node will send a Fast Binding Update(FBU) to its PAR in order to establish such a tunnel. Simultaneously, the PAR sends a Handover Initiate (HI) message to the NAR, indicating the mobile node's Previous CoA (PCoA) and the proposed NCoA. On the receipt of HI message, the NAR first determines whether the proposed NCoA is a valid address for use. If the NCoA is acceptable, the NAR adds it into the proxy neighbor cache entry for a short time period and begins defending it. Consequently, the NAR responds with a Handover Acknowledgement (HAck).

Once receiving the HAck the PAR is ready to forward packets to the NAR. After validating the FBU, the PAR responds with a Fast Binding Acknowledgement(FAck) and send it to NAR as well. When the mobile node attaches to the NAR and its link layer connection is ready for network layer traffic, it sends a Fast Neighbor Advertisement (FNA) to allow the NAR to consider the mobile node to be reachable. Afterwards, all the waiting packets will be forwarded from the NAR to the mobile node.

Through tunnel establishment between the PAR and NAR and fast advertisement, FMIPv6 can expedite packet forwarding during the handover procedure.

B. Hierarchical Mobile IPv6 (HMIPv6)

The idea of mobility management in HMIPv6 is mainly relying on Mobility Anchor Point (MAP) to manage the movement. Actually, the MAP performs the identical operations as the Home Agent in MIPv6. For example, the MAP encapsulates packets addressed to registered mobile node and tunnels them to the associated on-link Care of Address(LCoA). Meanwhile, the functionality of LCoA is similar to the CoA's in the MIPv6 while Regional CoA (RCoA) represents the virtual home of address in the HMIPv6-aware domain. As long as the MN moves within the same administrative domain, the RCoA is kept unchanged. In order to achieve this objective, the MAP using Proxy Neighbor Advertisement to synchronize the mapping between RCoA and LCoA.

The operations in HMIPv6 can be largely divided into four different stages.

- MAP Discovery
- MAP selection
- Movement Detection
- Binding Updates

To discover and configure different MAPs, HMIPv6 relies on a MAP option in the Router Advertisements. This option includes the distance vector from the mobile node, the preference for this particular MAP, the MAP's global address and subnet prefix. When the MN receives more than one MAP option, it needs to select an appropriate MAP. For instance, a mobile node will register with the MAP with relatively higher *Preference* value and highest value in the Distance field.

When a mobile node performs a handover between two access routers within the same HMIPv6 domain, only the MAP has to be informed. However, it does not imply any change to the periodic Binding Updates which the mobile node has to send to the Home Agent, Correspondence Node and additionally to the MAP.

IV. Analytical Studies of Handover Performance

In this section, we analyze the handover performance when applying different local mobility solutions by a mathematical model. The analytical studies will be carried out in two separate aspects, namely, handover latency and handover signaling overhead. Nevertheless, the third benefit has been identified through the description of PMIPv6 operations.

The reason why we choose HMIPv6, FMIPv6, F-HMIPv6 and PMIPv6 is that all of them are complimentary to MIPv6 in terms of enhancing handover mechanism within a locality. It might be unfair to compare them with a global mobility solution like MIPv6 or HIP directly.

A. Considered Scenario

We firstly introduce a hierarchical topology used for analytical study. Figure 3 depicts the considered scenario. We assume that a mobile node is initially located at the AR and then moves from the AR to a new AR (nAR). The mobile node receives the data packets sent from the Corresponding Node (CN). The analysis will study the cases of FMIPv6, HMIPv6 and PMIPv6. When HMIPv6 is considered, the function of MAP will be performed at one of the routers within the HMIPv6 network. If we consider FMIPv6, the previous AR will be noted as PAR and the new AR will be NAR. Similarly, when considering PMIPv6 the function of the MAG will be performed at access routers. Besides, the function of the LMA will be at the same place as MAP for fairness and simplicity.

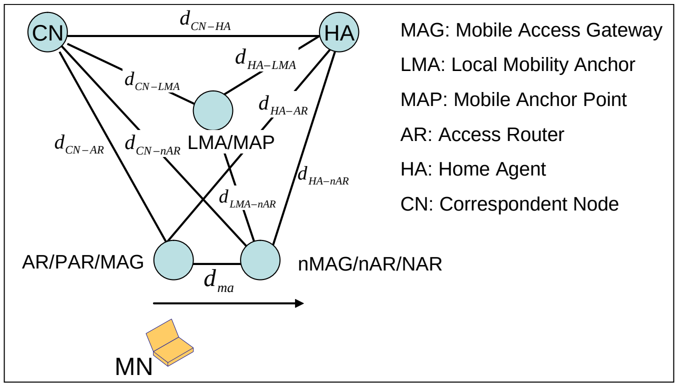

Fig. 3. Considered Scenario

B. Assumptions and Parameters

In order to compute the handover latency we have to consider the latency introduced by both the wireless and the wired part. The handover latency will be analyzed considering the mobile node initiated handover case. We assume that the processing delay are negligible compared to access to the channel and transmission delays. For the wireless part we suppose the same value for the uplink and downlink case. With respect to the parameters, we have the following assumptions.

- d_i only denotes the transmission delay between any two entities. For example, d_{CN-AR} is referred to as the time required by forwarding packets from the CN to the AR.
- It is assumed that the AR and nAR locate at the same access network. If d_{ma} is the latency of forwarding packets between two neighboring access routers, d_{ma} can be regarded as a quite small value when it is compared with d_{HA-nAR} or d_{CN-AR}.
- The following inequality is satisfied: $d_{ma} < d_{LMA-nAR} < d_{HA-nAR}$. Since the term LMA and HA are interchangeable and depend on the context in which the protocol is used. When the protocol specified in PMIPv6 is used for local mobility management of a host, i.e. within the scope of an access network or administrative domain, the term LMA is used or applicable. When the protocol is used for global mobility management of a host, the entity is essentially a HA.
- The processing latency of local trigger in a mobile node's protocol stack is ignored. Thus, the period used to receive a moment hint with link-layer support is zero.

C. Handover Latency Study

Considering FMIPv6, in our proposed scenario described in figure 3, we assume sending the FBack from the PAR as the start point for the analysis. The latency will be 1) the time required to send the FBack to the mobile node through the wireless medium and to the NAR, plus 2) the time required to send FNA, plus 3) the time required by the forwarded packet from the PNAR to the NAR, plus 4) the time required by the FNA to reach the NAR and plus 5) the delay caused by the wireless part to send the packet to the mobile node.

Thus, the handover latency performing a handover from the PAR to the NAR in FMIPv6 can be computed through the following formula:

$$max(d_w, d_{ma}) + d_{ma} + d_w + d_w. \tag{1}$$

where d_w denotes the delay introduced by the wireless part. Since the PAR responds with a Fast Binding Acknowledgement(FAck) to the mobile node and to NAR at the same time, we choose the maximum value of their delay, namely, $maxd_w, d_{ma}$.

Considering HMIPv6, the latency will be 1) the time required to send the LBU to and receive the LBAck from the MAP, plus 2) the time required by the forwarded packet from the MAP to arrive at the current nAR and plus 3) the delay caused by the wireless part to send the packet to the mobile node.

Thus, the handover latency performing a handover from the AR to the nAR in HMIPv6 can be computed through the following formula:

$$2d_w + 2d_{LMA-nAR} + d_{LMA-nAR} + d_w. \tag{2}$$

If we further consider the Fast handovers for HMIPv6 (F-HMIPv6) [6] which is actually a combination of HMIPv6 and FMIPv6. The latency will be 1) the time required by the FBack from the MAP to reach the NAR who will forward the packet to the MN, and to reach the PAR, plus 2) the time required by the forwarded packet from the MAP to the NAR, plus 3) the time required by the FNA to reach the NAR, and plus 4) the delay caused by the wireless part to send the packet to the mobile node.

Thus, the handover latency performing a handover from the AR to the nAR in F-HMIPv6 can be computed through the following formula:

$$max(d_{LMA-AR}, d_{LMA-nAR}) + d_{LMA-nAR} + d_w + d_w. \tag{3}$$

Considering the case of PMIPv6, the latency is 1) the time required to send the PBU from nMAG to LMA and receive PBA from LMA, plus 2) the time required by the forwarded packet from LMA to nMAG, plus 3) the delay caused by the wireless part to send the packet to the mobile node.

Thus, the handover latency performing a handover from the MAG to the nMAG in PMIPv6 can be computed through the following formula:

$$d_{LMA-nAR} + d_{LMA-nAR} + d_{LMA-nAR} + d_w. \qquad (4)$$

1) Handover Latency Results: To summarize the above analysis, the handover latencies introduced by FMIPv6, HMIPv6, F-HMIPv6 and PMIPv6 are represented in Table 1.

TABLE I
HANDOVER LATENCY

Protocol	Handover Latency
FMIPv6	$2d_w + d_{ma} + max(d_w, d_{ma})$
HMIPv6	$3d_w + 3d_{LMA-nAR}$
F-HMIPv6	$2d_w + d_{LMA-nAR} + max(d_{LMA-AR}, d_{LMA-nAR})$
PMIPv6	$d_w + 3d_{LMA-nAR}$

2) Comparison: Based on the Table 1, we can explicitly compare the handover latency against each other. First, we compare the handover latency introduced by HMIPv6 with that of the PMIPv6. Then, the latency caused by FMIPv6 will be compared with the latency introduced by PMIPv6. Finally, the latency caused by PMIPv6-aware handover will be compared with that of F-HMIPv6.

Since $d_w > 0$, it is very easy to get the following result: $D_{HMIPv6} > D_{PMIPv6}$. It is reasonable because PMIPv6 can avoid the tunneling overhead over the air as well as hosts' involvement in mobility management.

When we compare the equation D_{FMIPv6} and D_{PMIPv6}, the difference between them is $d_w + d_{ma} + max(d_w, d_{ma}) - 3d_{LMA-nAR}$. Note that the LMA/MAP is usually an aggregated router located far from the current AR (i.e. the nAR) but the AR is very near from nAR. Without loss of generality, we can assume $d_{ma} < d_{LMA-nAR}$ and $d_{ma} < d_w$. Therefore, the difference between the handover latency caused by FMIPv6 and that of PMIPv6 is $2d_w + d_{ma} - 3d_{LMA-nAR}$.

If we compare the latency caused by F-HMIPv6 during the handover with that of PMIPv6, the difference between them is as follows: $d_w + max(d_{LMA-AR}, d_{LMA-nAR}) - 2d_{LMA-AR}$. Since the AR located quite near from the nAR, it can be assumed that $max(d_{LMA-AR}, d_{LMA-nAR}) = d_{LMA-nAR}$. Obviously, we can further conclude that the difference is $d_w - d_{LMA-AR}$.

3) Impacts of parameters: As the latency caused by wireless part and wired part are uncertain, we need to further consider them in details. Without loss of generality, we can further assume that the wireless latency is similar to wired part, regardless of unwanted noise and signals in wireless systems.

Based on above assumption, we can further compare D_{FMIPv6} with D_{PMIPv6}. Due to $d_{ma} < d_{LMA-nAR}$, the difference between them $2d_w + d_{ma} - 3d_{LMA-nAR} < 0$, thus indicating that the latency caused by FMIPv6 is less than that of PMIPv6.

Likewise, the latency caused by F-HMIPv6 is very similar to that of PMIPv6. We can conclude that PMIPv6 performs better than HMIPv6 but FMIPv6 causes the least latency among all of them. Besides, F-HMIPv6 seems to achieve quite better performance than HMIPv6 because it takes advantage of the "make-before-break" trait in FMIPv6. However, the latency caused by it is still higher than that of FMIPv6.

D. Handover Signaling Overhead

Following the above proposed scenario and assumptions, we will further compare the handover overhead caused by FMIPv6, HMIPv6, F-HMIPv6, and PMIPv6 respectively. For simplicity, we compute the minimal required overhead for each of the proposals.

1) Handover Overhead Analysis: In FMIPv6, the signaling overhead will be calculated as: 1) FBU message to the PAR, plus 2) FBack message sent to the mobile node and the NAR, plus 3) HI and HAck messages between PAR and NAR and plus 4) message FNA sent to NAR.

For HMIPv6, the signaling overhead will be: 1) the MAP option carried in the Router Advertisement message in order to indicate the mobile node that it roams within the same MAP domain, plus 2) LBU message sent to the MAP and plus 3) LBack message received by the MAP. Note that the MAP option is extra overhead required by HMIPv6. Therefore, the signaling overhead caused by HMIPv6-aware handover can be computed through the following formula:

For F-HMIPv6, the signaling overhead will be: 1) the Router Advertisement message with MAP option in order to indicate the mobile node that it roams within the same MAP domain, plus 2) LBU message sent to the MAP and plus 3) LBack message received by the MAP.

In contrast, the signaling overhead of PMIPv6 will be: 1) PBU message sent to the LMA and plus 2) PBack message received by the LMA.

2) Comparison: The signaling overhead caused by above protocols can be concluded in Table 2.

TABLE II
HANDOVER SIGNALING OVERHEAD

Protocol	Handover Overhead
FMIPv6	132
HMIPv6	72
F-HMIPv6	86
PMIPv6	72

After the handover overhead study, we can conclude that network-based localized mobility management protocol causes much less signaling overhead than FMIPv6 and F-HMIPv6. Moreover, HMIPv6 can achieve the least handover overhead as PMIPv6 because they all deploy a local home agent within the access network to provide mobility to the mobile nodes. However, HMIPv6 is a host-based mobility solution so that the mobile node inevitably involves in the mobility management. That causes extra handover latency and overhead over the air (e.g. wireless part). Besides, it requires the end host involvement at the IP layer similar to that required by MIPv6 for global mobility management.

V. Handover Performance Enhancement for PMIPv6

The above handover latency analysis indicates that combining with FMIPv6 may bring some benefits for alleviating PMIPv6 handover latency. In the this section, we will proposed a enhancement scheme for PMIPv6, so-called fast handovers for PMIPv6 (F-PMIPv6) which mainly focuses on improving the handover performance (e.g. handover latency) of basic PMIPv6.

After booting in the PMIPv6 domain and obtaining the address configuration, the mobile node moves between access links. If it attaches to a new access link (nMAG), it will present its identify, MN-ID, to the network for access authentication. Once it is authorized to access the network, the nMAG can obtain the mobile node's profile (e.g. home network prefix).

In the basic PMIPv6, the nMAG sends a PBU message to the LMA. Until receiving the PBack with indicating the acceptance of the Binding Update, the nMAG can setup a tunnel to the LMA and waits for the data forwarded from the LMA. We argue that the LMA may locate far from the current nMAG and such a mechanism wastes too much time.

A. F-PMIPv6 Handover Procedure

Motivated by FMIPv6, we propose the F-PMIPv6 protocol to reduce the handover latency and the packet loss ratio. The whole handover procedure is depicted in Figure 4.

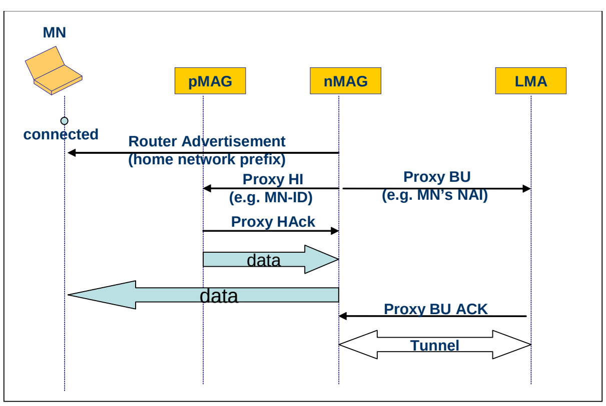

Fig. 4. Handover message flows of F-PMIPv6.

- After the nMAG sends AR message advertising the mobile node's home network prefix and other parameters, it will send a Proxy-HI (P-HI) message to the previous MAG (pMAG). At the same time, the nMAG sends PBU to the LMA in order to update the location of the mobile node.
- Upon receiving the P-HI message, the pMAG responses with the Proxy HAck (P-HAck) message.
- Data can be forwarded directly through the tunnel between the pMAG and nMAG. After receiving the data, the nMAG will immediately forward the data to the mobile node.
- Once the LMA updates the location information of the mobile node at its local binding cache entry, it sends a PBU Ack back to the nMAG. The following data packets will be forwarded directly through the tunnel from the LMA to the nMAG.
- Accordingly, the nMAG will tear down the established tunnel with pMAG.

Meanwhile, the Proxy-HI is an ICMPv6 message sent by an Access Router (e.g. nMAG) to another Access Router (e.g. pMAG) to indicate the mobile node's movement. Different from the HI message in FMIPv6, P-HI may only require the mobile node's home network prefix and MN-ID in the options field. Likewise, the Proxy HAck (P-HAck) may include the mobile node's home network prefix in the option field.

By doing this, data packets can be immediately forwarded from the nMAG to the mobile node instead of long-time waiting for the PBAck from the LMA. Besides, it can also reduce the packet loss ratio in case the LMA still sends the packets to the pMAG.

B. F-PMIPv6 Handover Latency Analysis

According the proposed scenario in Figure 3, the latency caused by F-PMIPv6 is: 1) the time required to send the P-HI from the nMAG to the pMAG and receive P-HAck from the pMAG, plus 2) the time required by the forwarded packet from pMAG to nMAG, plus 3) the delay caused by the wireless part to send the packet to the mobile node.

The handover latency is calculated from the time of sending P-HI to the pMAG to the time that the mobile node receives the data. the handover latency performing a handover from the PAR to the NAR in FMIPv6 can be computed through the following formula: Therefore, the handover latency caused by F-PMIPv6 can be computed through the following formula:

$$D_{F-PMIPv6} = 3d_m + d_w. \tag{5}$$

Then, the Table 1 can be updated as follows.

TABLE III
Handover Latency

Protocol	Handover Latency
FMIPv6	$2d_w + d_{ma} + max(d_w, d_{ma})$
HMIPv6	$3d_w + 3d_{LMA-nAR}$
F-HMIPv6	$2d_w + d_{LMA-nAR} + max(d_{LMA-AR}, d_{LMA-nAR})$
PMIPv6	$d_w + 3d_{LMA-nAR}$
F-PMIPv6	$d_w + 3d_{ma}$

Based on the above assumption that $d_{ma} < d_{LMA-nAR}$, it is easy to get the following inequality: $D_{F-PMIPv6} < D_{PMIPv6}$.

Besides, we can further deduce that the following inequality is satisfied: $D_{F-PMIPv6} < D_{FMIPv6}$ since $d_{ma} < d_w$. So far, we can ascertain that F-PMIPv6 performs quite better than the PMIPv6, or even better than the FMIPv6. Nevertheless, F-PMIPv6 may require some extra signaling exchanges between the MAG and nMAG. As they are regional signaling, they will not cause any message overhead over the air, nor cause inter-domain overhead.

In summary, the proposed F-PMIPv6 is a network-based localized mobility management protocol, independent from any link layer protocol. Therefore, it can avoid tunneling overhead over the air and provides mobility to hosts that are not required to involve in any mobility management. Moreover, it can alleviate the handover latency and reduce the packet loss ratio by simply notifying the previous MAG about the mobile node's movements. Besides, F-PMIPv6 is able to support real-time applications which are sensitive to handover latency and packet loss.

VI. Conclusions and Future Work

Firstly, we give an overview of PMIPv6 in terms of its basic operations and review two recent localized mobility proposals. Then, we focus on evaluating three most important benefits of introducing PMIPv6 for the localized mobility management by the appropriate mathematical models. After the analytical studies and comparisons on the handover latency and overhead, we can conclude that network-based localized mobility management, PMIPv6 although can achieve fairly good performance but causes high handover latency. Therefore, we propose a enhancement to PMIPv6, so-called F-PMIPv6 to further improve the handover performance. After the analysis based on the same model, F-PMIPv6 has been identified to dramatically reduce the handover latency.

There are still some spaces for future work. For example, link layer intelligent detection techniques, such as 802.21 [4], and hierarchical architecture have been developed in the community and being considered useful, how to incorporate these techniques into PMIPv6 for further performance improvement is a meaningful work in the future. In addition, PMIPv6 has no specific concerns on global mobility management, but only relies on MIPv6, which lacks sufficient scalability and efficiency of delivery. Hence, inter-domain handover mechanisms will be further investigated for PMIPv6.

Besides, we are currently simulating the PMIPv6 using network simulator OMNeT++ [1] and evaluating its performance. We plan to compare PMIPv6 with other localized mobility proposals such as FMIPv6, HMIPv6, F-HMIPv6 in terms of handover performance. More PMIPv6-aware scenarios will be investigated where localized mobility management is desirable.

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