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碩士論文

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S-PMIPv6: 在 LMA 內部的移動模型

S-PMIPv6: an Intra-LMA model for IPv6 Mobility

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中文摘要

IPv6 是在 90 年代中期定義的 RFC 2460，IPv6 是 IP 第 4 版本（IPv4）的改進和簡化的繼任版本。它的目的是保存 IPv4 的優點同時提供更好的網絡互聯能力。移動 IP 使移動節點可以經由一個網絡移動到其它網路還可以識別的 IP 地址，儘管在不同網絡間，連接到不同的位置都無需用戶的參與。代理移動 IPv6（PMIPv6 的簡稱），作為基於網絡的移動性管理協議，由 IETF 於 2008 年發布支持 IP 移動的 RFC5213。但是 MN 的換手期間，也不能完全避免網絡鏈路的斷線。後來 IETF 在 2010 年發布 RFC5949 的快速代理移動 IPv6（F-PMIPv6 的簡稱）協議，該協議被設計為主要提高其換手的可靠性,特別是用於降低其切換延遲和封包遺失率，以及降低網絡鏈路斷線的機率。另一方面，無論多麼快的切換，它的延遲難免存在，且會提高封包遺失率。因此，在此研究中，我們提出了一種新的 PMIPv6 協議,稱為以 SCTP 作為代理移動 IPv6 的基礎(S- PMIPv6 的簡稱),其中集成 F-PMIPv6、流控制傳輸保護（SCTP 的簡稱）和路由優化，以提高其 IP 移動的可靠性，實現無縫切換。我們的模擬表明,S- PMIPv6 實際上可以先“連線”之後在“斷線”，有效地縮短了終端到終端的延遲封包傳輸和較低的封包遺失率。

關鍵詞 PMIPv6，F-PMIPv6，O-PMIPv6，路由優化，SCTP，換手

ABSTRACT

IPv6 defined in RFC 2460 in the mid-1990s is an improved and streamlined successor version of IP version 4 (IPv4). It is designed to coexist with IPv4, while providing better internetworking capabilities than this successor version. Mobile IP enables a mobile node to be recognized via a single IP address even though the node is traveling from one network to another. Despite reposition among different networks, connectivity at different positions is attained continuously with no user intervention. Proxy Mobile IPv6 (PMIPv6), as a network-based mobility management protocol, was released in 2008 by the IETF in RFC 5213 to support IP mobility. But during MN's handover, disconnection of a network link cannot absolutely be avoided. The IETF later in 2010 in RFC 5949 proposed Fast Proxy Mobile IPv6 (F-PMIPv6 for short) protocol, which was designed to mainly improve the reliability of its switching process, particularly for reducing its handover latency and packet loss rate, as well as lowering the probability of network-link disconnection. On the other hand, no matter how fast a handover is, its delay does unavoidably exist. It in turn rises the packet loss rate. Therefore, in this study, we propose a novel MIPv6 family protocol, called SCTP-based Proxy Mobile IPv6 (S-PMIPv6 for short), which integrates F-PMIPv6 with Stream Control Transmission Protocol (SCTP for short) and route optimization to enhance its IP mobility reliability and achieve the stage of seamless handover. Our simulation demonstrates that S-PMIPv6 can actually "make" before "break", effectively shorten end-to-end delay of packet delivery and lower packet loss rate.

Keywords − PMIPv6, F-PMIPv6, O-PMIPv6, Route Optimization, SCTP, Handover

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I. INTRODUCTION

In recent years, wireless network systems have been a part of our everyday lives. People rely on them to communicate with outside world when staying at home or somewhere in the world. Generally, while connecting to a wireless network, a mobile device during its movement continuously changes its locations. Mobile IPv6[1~4] is a standard that provides a method for a mobile device, known as mobile node (MN), to preserve connectivity, while it travels across different geographical areas. In fact, a MN belongs to only one home network which gives it a permanent home IP address. In addition, each home network has a home agent (HA) in charge of tracking MNs' movement as they roam in different networks. Once a MN leaves its home network e.g., H, and migrates to a neighbor network, e.g., N, its will obtain a new IP address [5~6], called care-of address (CoA), from N. However, the MIPv6 protocol are not widely employed by all wireless operators. One of the reasons is that it creates much burden for local mobility anchor (LMA for short) and mobile access gateway (MAG for short) proxy [7], particularly when a lot of MNs are now being served by the wireless system. This often results in high handover delays [8~10] and signaling costs [9~10]. A MIPv6 family protocol, like Proxy Mobile IPv6 (PMIPv6) [11~17], was then proposed to solve some of these problems. When MN has to hand over, its MAG will find a suitable neighbor MAG (NMAG) for it. However, due to PMIPv6's high handover delay and signaling cost, Fast Handover for PMIPv6 (F-PMIPv6) [18~20] was released. This protocol operates in two modes, predictive and reactive [21], depending on whether the MN has successfully attached to NMAG or not after it enters the serving area of the NMAG. In the reactive mode, MN is connected to NMAG, after the connection between PMAG and MN is disconnected so the MN disconnection time from network is longer. Further, in F-PMIPv6 (also in PMIPv6), MN and correspondent node (CN) send messages to each other through a non-optimal route, meaning that the functions of F-PMIPv6 can be further enhanced.

Although F-PMIPv6 improves PMIPv6's handover delay, its signaling cost is still high [22~24]. Hence, a new protocol named Optimized PMIPv6 (O-PMIPv6) [25~27] which combines localized routing [28~29] with the features of F-PMIPv6 was proposed. This protocol establishes a Route Optimization (RO) [28~31] path between the MN and CN to reduce the usage of LMA and unnecessary signaling cost. But it also increases the burden of MAG [32], including predicting the possible NMAG and establishing an optimized route between the MN's MAG and CN's MAG and so on. Therefore, in this study, we propose a novel MIPv6 family protocol, called SCTP-based PMIPv6 (S-PMIPv6 for short), which creates a seamless handover environment by adopting the Stream Control Transmission Protocol (SCTP) [27~28] to achieve make-before-break stage where SCTP is a multi-homing and multi-streaming transport protocol. S-PMIPv6 also improves O-PMIPv6 route optimization functions by employing LMA, rather than MAG, to choose NMAG for MN so as to reduce the burden of MAG, and balance the loads of MAG and LMA. In the S-PMIPv6, handover can be intra-LMA or inter-LMA where inter-LMA is the case in which MN hands over from PMAG which belongs to an LMA, e.g., LMA1, to NMAG which is under another LMA, e.g., LMA2, and LMA1 ≠ LMA2. When LMA1 = LMA2, we call it an intra-LMA handover. But inter-LMA will be studied in our other research. The focus of this study is only on intra-LMA. Our simulation demonstrates that S-PMIPv6 can actually make a connection between MN and NMAG before the association between MN and PMAG is disconnected (i.e., make-before-break). It also effectively shortens end-to-end delay and lower packet loss rate.

The rest of this paper is organized as follows. Section 2 describes the related work of this study. Section 3 introduces S-PMIPv6. Simulation results are presented and discussed in Section 4. Section 5 concludes this paper and outlines our future studies.

II. LITERATURE REVIEW

2.1 PMIPv6

PMIPv6, introduced in RFC 5213, is developed in 2008 to enhance the mobility management for mobile IP. It is one of the focuses of recent researches due to its overall benefits over those previously developed protocols. The main difference between MIPv6 and PMIPv6 is that MIPv6 is a host-based approach [1~4], while PMIPv6 is a network-based scheme [11~20]. When MN enters a PMIPv6 domain and links to an access channel (tunnel), MAG on the access channel will receive the MN's ID and determines whether to authorize the MN or not. If yes, it then provides the MN with mobile management services. MN will receive a configured address on its connection interface and move freely in the PMIPv6 domain. The configured address contains Home Network Prefix (HNP) address, the IP address of the router on the channel and other related configuration parameters, like AP-ID and NMAG-IP. PMIPv6 has the following features and advantages compared with those of MIPv6. (1) Deployment of MNs: MN does not require any modification for being served by service providers so that service providers can serve as many customers as they can; (2) Controllability of QoS: a network-based approach is advantageous as it gives network service providers the opportunity to control their networks in terms of traffic and QoS, such as differential services; (3) Performance improvement: the core entities of PMIPv6 include LMA and MAG, in which LMA is responsible for maintaining MN's connection status, while MAG, located along the access channel to which MN connects, takes charge of monitoring MN's mobility behaviors, including MN's binding registration with LMA, MN connecting to MAG through the access channel and leaving the channel, and MN's movement and locus, without letting MN deal with the signaling flow. Hence, the tunneling overhead and the number of exchanged messages are significantly reduced.

2.2 F-PMIPv6

F-PMIPv6, introduced in RFC 5949, also has predictive and reactive modes. In the predictive mode, a two-way channel between NMAG and previous MAG (PMAG) is established before an MN hands over from the PMAG to the NMAG. The reactive mode is used when MN's handover fails [33] or there is a late handover [34]. When the signal strength between MN and PMAG is weak, MN will prepare to leave PMAG. PMAG temporarily stores those packets CN sent to MN and delivers these packets to NMAG after the two-way channel between it and NMAG is established.

Note that both PMIPv6 and F-PMIPv6 perform routing localization for the routes between MN and NMAG and between NMAG and CMAG. After MN successfully hands over to NMAG.

2.3 O-PMIPv6

O-PMIPv6 [25-27] retains the advantageous features of F-PMIPv6 over PMIPv6, such as reducing its packet delivery delay by optimizing the delivery path. Therefore, each time after handing over, MN will maintain the Localized Routing (LR) session between itself and its CN so as to re-use the advantages of LR for delivering HI/HACK messages carrying the LRI/LRA information to NMAG. When the LR session is re-established, all the data packets that MN sends to CN will flow through the new optimized path. Note that combining the handover of MN and LR session has truly lowered O-PMIPv6's signaling cost and shortened its total handover delay.

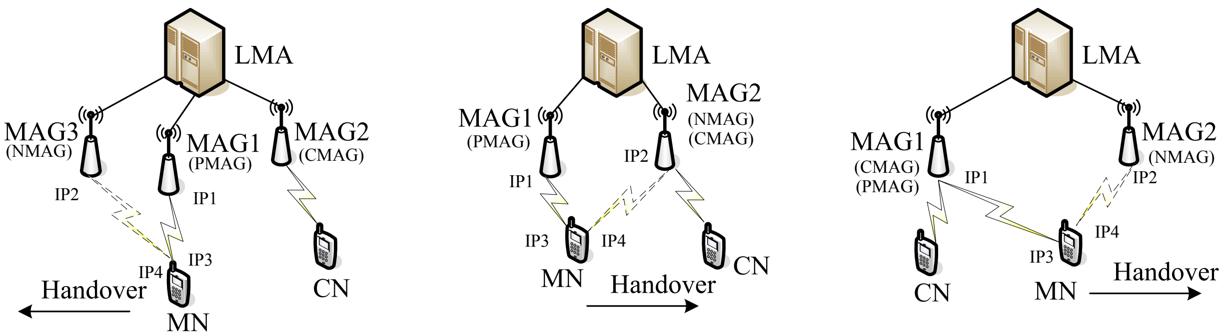
2.4 SCTP

The Stream Control Transmission Protocol (SCTP), defined [30] by the IETF Signaling Transport (SIGTRAN) working group in RFC 4960 in 2000, has been maintained by the IETF Transport Area (TSVWG) working group. RFC 3286 [31] provides an introduction. With SCTP, packets belonging to different processes created under the same operating system are transmitted independently, rather than sequentially (like that in TCP). In SCTP, a node needs *K* IP addresses to establish *K* links/paths between the node and its corresponding MAG or CN. This also enables transparent of fail-over among the *k* redundant links/paths. Each link/path is given a transport address defined as IP address + port number.

Generally, TCP and UDP, do not provide information of available remote transport addresses. But an SCTP path management function takes charge of choosing one of the *k* transport addresses as the primary one basically based on two aspects, SCTP user commands and qualified destination transport addresses currently available. This function periodically scans links, and reports the statuses of remote transport addresses so that the connectivity of the *K* links can be maintained. When the primary path fails, one of the *K*-1 alternate paths will be chosen to take over for it [35]. Namely, it can tolerate network-level errors.

III. THE S-PMIPv6 SCHEME

The intra-LMA handover (or just handover) can be divided into two categories, Category1 in which only MN hands over and Category 2 in which both MN and CN hand over. Category 1 has three cases, denoted by Topologies 1.1~1.3. In Topology 1.1, MN and CN, as shown in Figure 1a, are connected to different MAGs, e.g., MN is connected MAG1 (i.e., PMAG) and CN is to MAG2 (i.e., CMAG), but MN hands over to the third MAG, e.g., MAG3 (i.e., NMAG). We call the handover different-to-different scheme since PMAG ≠ CMAG and NMAG ≠ CMAG. In Topology 1.2, MN and CN as illustrated in Figure 1b are also connected to different MAGs, e.g., MN is connected to MAG1 (i.e., PMAG), and CN is linked to MAG2 (i.e., CMAG), and MN hands over to MAG2. We call the handover different-to-the same since PMAG ≠ CMAG, but NMAG = CMAG. Topology 1.3 is shown in Figure 1c, in which MN and CN are connected to the same MAG, e.g., MAG1, but MN hands over to another MAG, e.g., MAG2. Of course, this is a the-same-to-different scheme due to NMAG = CMAG.



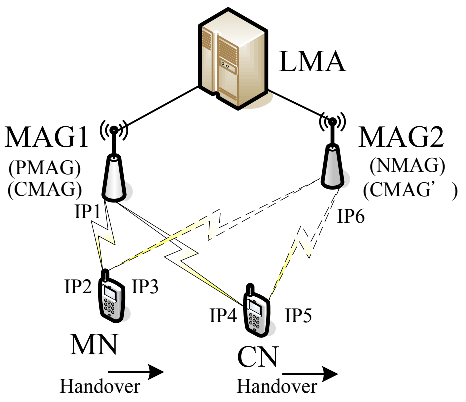
(a) Topology 1.1 (MN connects to MAG1, CN to MAG2 and MN hands over to MAG3) – the scheme of different-to-different

(b) Topology 1.2 (MN connects to MAG1, CN to MAG2, and MN hands over to MAG2) – the scheme of different-to-the-same

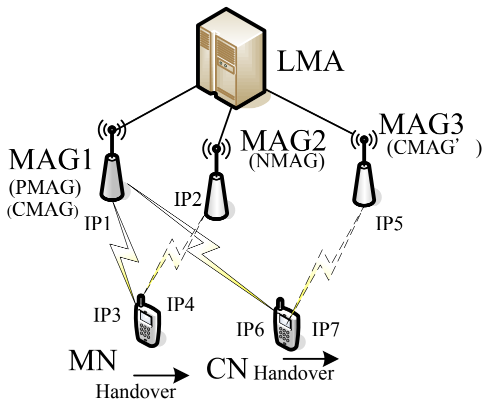
(c) Topology 1.3 (Both MN and CN connect to MAG1 and MN hands over to MAG2) – the scheme of the-same-to-different

Figure 1 S-PMIPv6 Topologies of Category 1 on Predictive mode

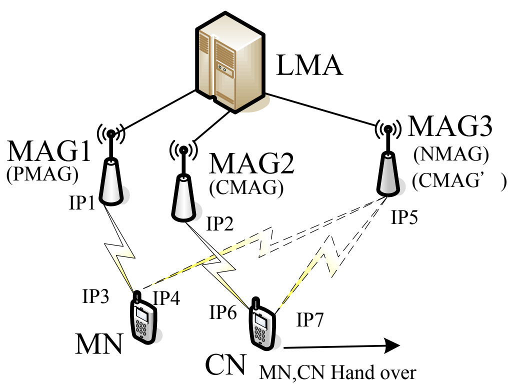
Category 2 has four cases, denoted by Topologies 2.1~2.4. In Topology 2.1, MN and CN, as plotted in Figure 2a, are connected to the same MAG, e.g., MAG1, and both of them hand over to the same MAG, e.g., MAG2. It is clear that this is a the-same-to-the-same scheme. In Topology 2.2, MN and CN, as shown in Figure 2b, are connected to the same MAG, e.g., MAG1, and MN hands over to MAG2 and CN hands over to MAG3. This is a the-same-to-different scheme. Topology 2.3 is the case in which MN (CN), as illustrated in Figure 2c, is connected to MAG1 (MAG2), and they hand over to the same MAG, e.g., MAG3. This is a different-to-the-same scheme: The last one, i.e., Topology 2.4, which as shown in Figure 2d, is the case of different-to-different in which MN (CN) is linked to MAG1 (MAG2), and MN (CN) hands over to MAG2 (MAG3).



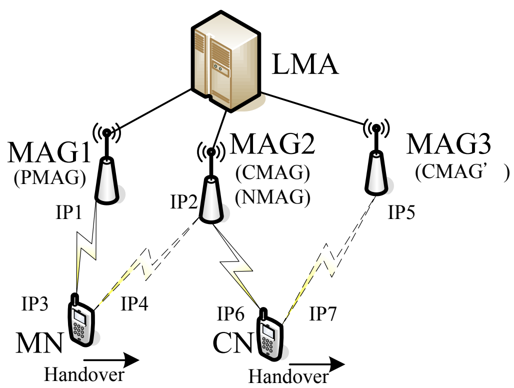
(a) Topology 2.1 (the-same-to-the-same)



(b) Topology 2.2 (the-same-to-different)



(c) Topology 2.3 (different-to-the-same)



(d) Topology 2.4 (different-to-different)

Figure 2 S-PMIPv6 Topologies of Category 2 on Predictive mode

3.1 Topologies

In Category 1, based on the features (also of S-PMIPv6 also of O-PMIPv6), the path between MN and CN, i.e., MN-PMAG-CMAG-CN, is optimized. Once MN is attached to the NMAG, due to the same reason, the new path MN-NMAG-CMAG-CN is also optimal, no matter whether it is Topology1.1, 1.2 or 1.3.

In Category 2, before MN and CN hand over, the path MN-PMAG-CMAG-CN is optimized. After MN and CN hand over, the path MN-PMAG-CMAG'-CN is also an optimal one where CMAG is CN's PMAG and CMAG' is CN's NMAG, regardless of which Category 2 topology is.

3.2 Handover procedures

Originally MN is connected to PMAG through its first IP under the assumption that an MN has at least two IPs.

(1) Predictive mode

The handover procedure of Category 1 on predictive mode is as follows.

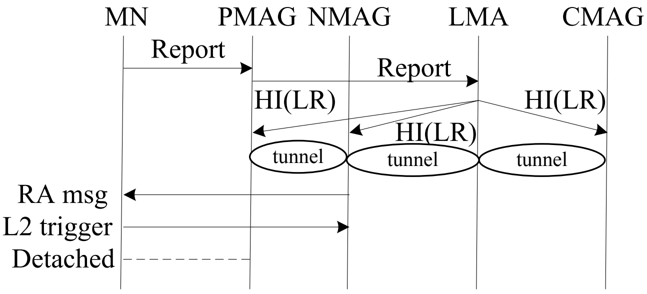
1) When MN detects that handover is requires, it sends a Report message, which contains MN-ID, N-AP-ID (new AP identifier) and LMA IP address, to PMAG. On receiving this message, unlike that of F-PMIPv6, S-PMIPv6 PMAG does not predict NMAG to avoid conducting a heavy burden to itself. Instead, it sends a handover initiated (HI) message to LMA.

2) After receiving this message, LMA predicts the most appropriate NMAG, and sends three HI (LR) messages to different nodes. The first, carrying NMAG's

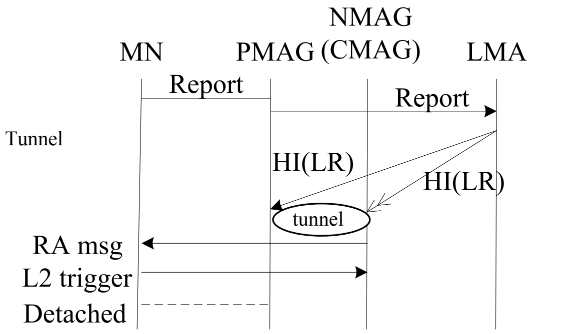
and CMAG's IP addresses and information for establishing an optimal path between PMAG and NMAG, is sent to PMAG. The second, containing PMAG's and CMAG's IP addresses and information for constructing an optimal path between NMAG and PMAG, is transmitted to NMAG. The third carrying PMAG's and NMAG's IP addresses is sent CMAG.

3) After receiving the HI (LR) messages, PMAG and NMAG establish a tunnel between them, and CMAG and NMAG establish another. If MN is communicating with CN, PMAG will deliver the packets sent by CN to MN and currently stored in PMAG's buffer to NMAG. NMAG delivers a router advertisement (RA) message to MN for connecting itself and MN through MN's second IP address.

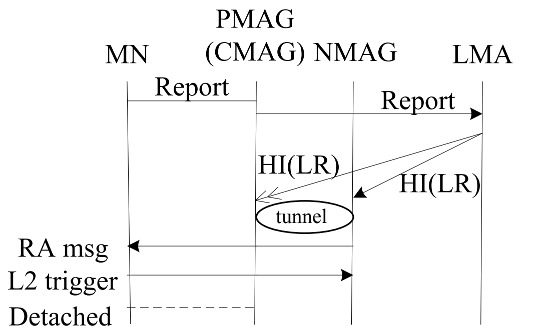
4) MN disconnects the connection between it and PMAG. Because of adopting SCTP, "make" occurs before "break", i.e., if only MN hands over, the path MN-NMAG-CMAG-CN is established before the path MN-PMAG-CMAG-CN is disconnected.



(a) Sequence chart of Topology 1.1 MN hands over from PMAG to NMAG where PMAG ≠ CMAG and NMAG ≠ CMAG (different-to-different).



(b) Sequence chart of Topology 1.2 MN hands over from PMAG to NMAG where NMAG = CMAG (different-to-the-same).



(c) The sequence chart of Topology 1.3 MN hands over from PMAG to NMAG where PMAG = CMAG, and NMAG ≠ CMAG (the-same-to-different).

Figure 3 Sequence charts of Category 1 on predictive mode (only MN hands over; ← : one HI (LR) message; ↞ : two HI (LR) messages).

Figures 3a-3c, respectively, illustrate the sequence charts of Topologies 1.1, 1.2 and 1.3. When both MN and CN hand over, there are two types of time sequence. Type1 as shown in Figure 4a is the case in which MN has successfully handed over to NMAG before CN starts handing over to CMAG', i.e., t1 < t2 < t3 < t4, where t1 (t3) is the time point when MN (CN) starts handing over to NMAG (CMAG') and t2 (t4) is the time point when MN (CN) successfully hands over to NMAG (CMAG'). Type2 is the case in which t1 < t3 ≦ t2 < t4, meaning CN starts handing over to CMAG' before MN successfully hands over to NMAG. Of course, CN may start handing over before MN does. But if we change the role of MN and CN, then the two cases will be the same as the two illustrated in Figures 4a and 4b. Basically, t2-t1 (t4-t3) is the handover and signaling cost of MN (CN).

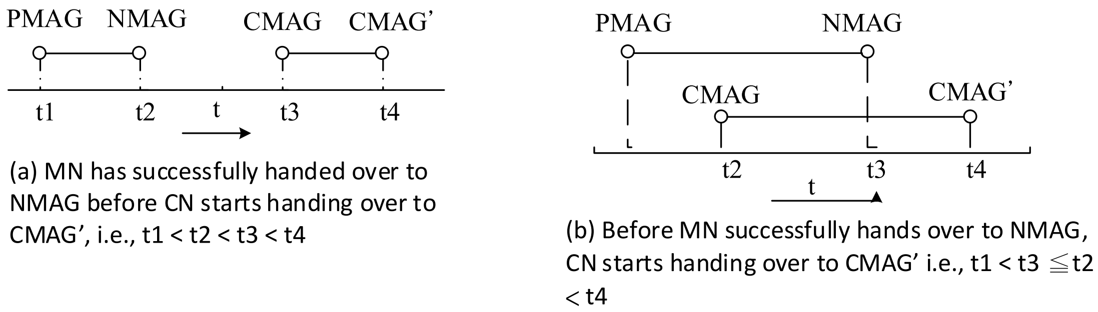
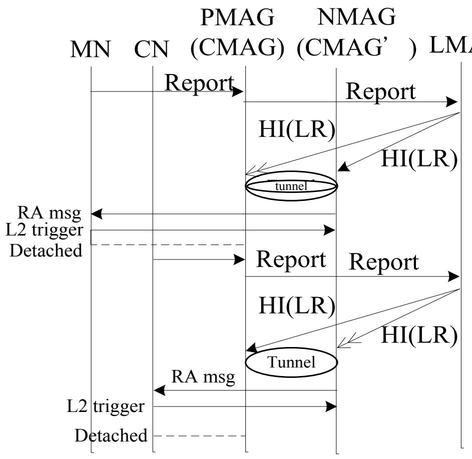
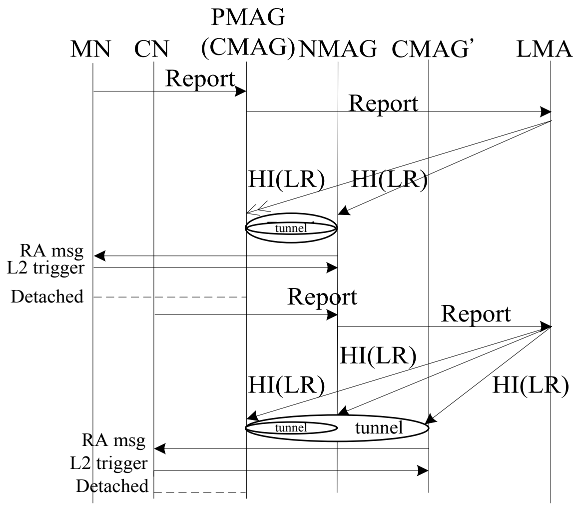


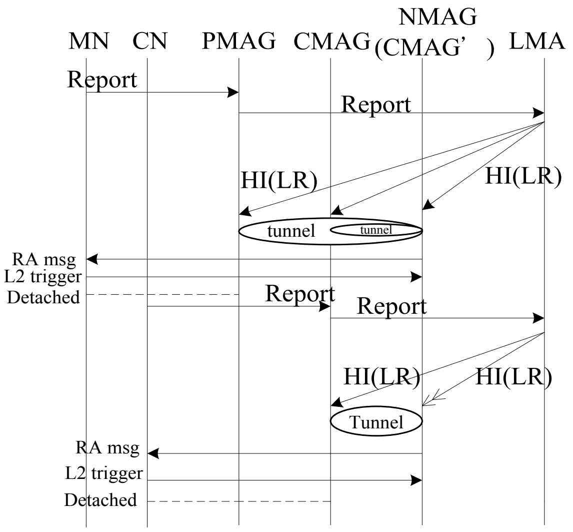
Figure 4 The relationship between MN's handover timings and CN's handover timings. T1 (t3) is the time point when MN (CN) starts handing over, and t2 (t4) is the time point when MN (CN) finishes its handover.



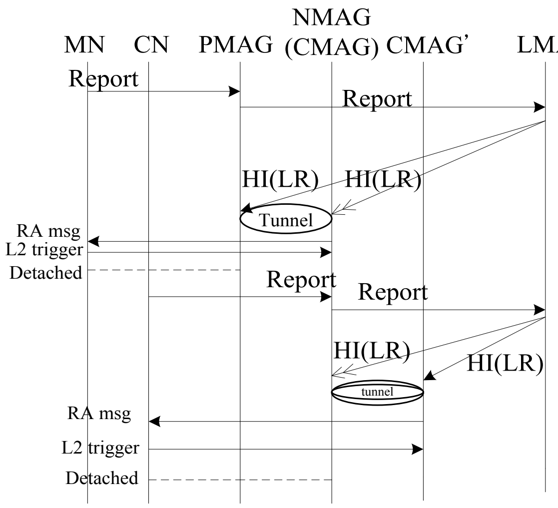
(a) Sequence chart of Topology 2.1 : PMAG = CMAG and NMAG= CMAG' (the-same-to-the-same).



(b) Sequence chart of Topology 2.2 : PMAG = CMAG and NMAG ≠ CMAG' (the-same-to-different).



(c) Sequence chart of Topology 2.3 : PMAG ≠ CMAG and NMAG = CMAG' (different-to-the-same).



(d) Sequence chart of Topology 2.4 : NMAG ≠ CMAG, and NMAG ≠ CMAG' (different-to-different).

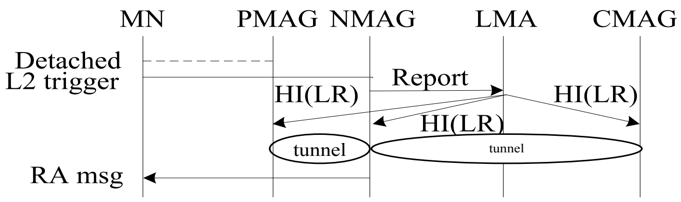
Figure 5 Sequence charts of Category 2 (both MN and CN hand over) on Predictive mode

The procedure of Category 2 on type 1 is similar to that of Categovy1. The only difference is in Step2. LMA sends a total of six, rather than three, HI (LR) messages. The roles of the first three HI(LR) messages individually sent to PMAG, NMAG and CMAG are the same as those of the three delivered when only MN hands over. In other words, it is a Category 1 handover. When CN as another MN hands over, it is a Category 1 again. Figures 5a-5d, respectively, illustrate the sequence charts of Topologies 2.1-2.4.

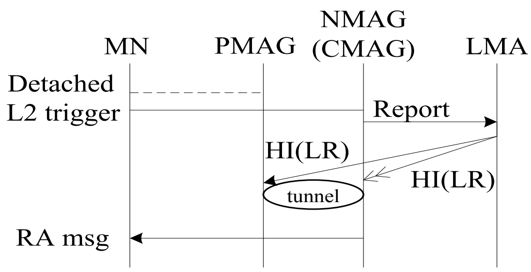
The handover procedure of Category 2 on type 2, i.e., $t1 < t3 \leqq t2 < t4$, is similar to that of Category 2 on type1, but different in that the upper half of Figure 5a, as an example, will be mixed with the lower half, but preserving the sequence of all elements themselves of the upper half and of the lower half. In other words, the three HI (LR) messages and their RA messages, L2 triggers and Detached of the lower half will be moved up to their corresponding positions, depending on when they occur under the assumption that MN starts handing over before CN does.

(2) Reactive mode

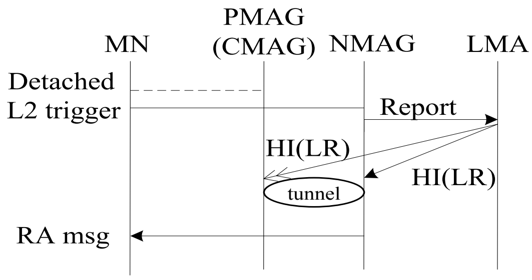
When MN tries to connect itself to NMAG, but if it moves very fast, the load of NMAG is heavy or something happens (e.g., loss of messages delivered for establishing a tunnel between PMAG and NMAG), the tunnel between PMAG and NMAG may not have been established. In this case, Predictive mode of S-PMIPv6 is inapplicable. In turn, Reactive mode will be triggered. This mode also has the two categories, only MN hands over (Category 1) and both MN and CN handover (Category 2). The procedure of Category 1 on Reactive mode is as follows.



(a) Sequence chart of Topology 1.1: (different-to-different).



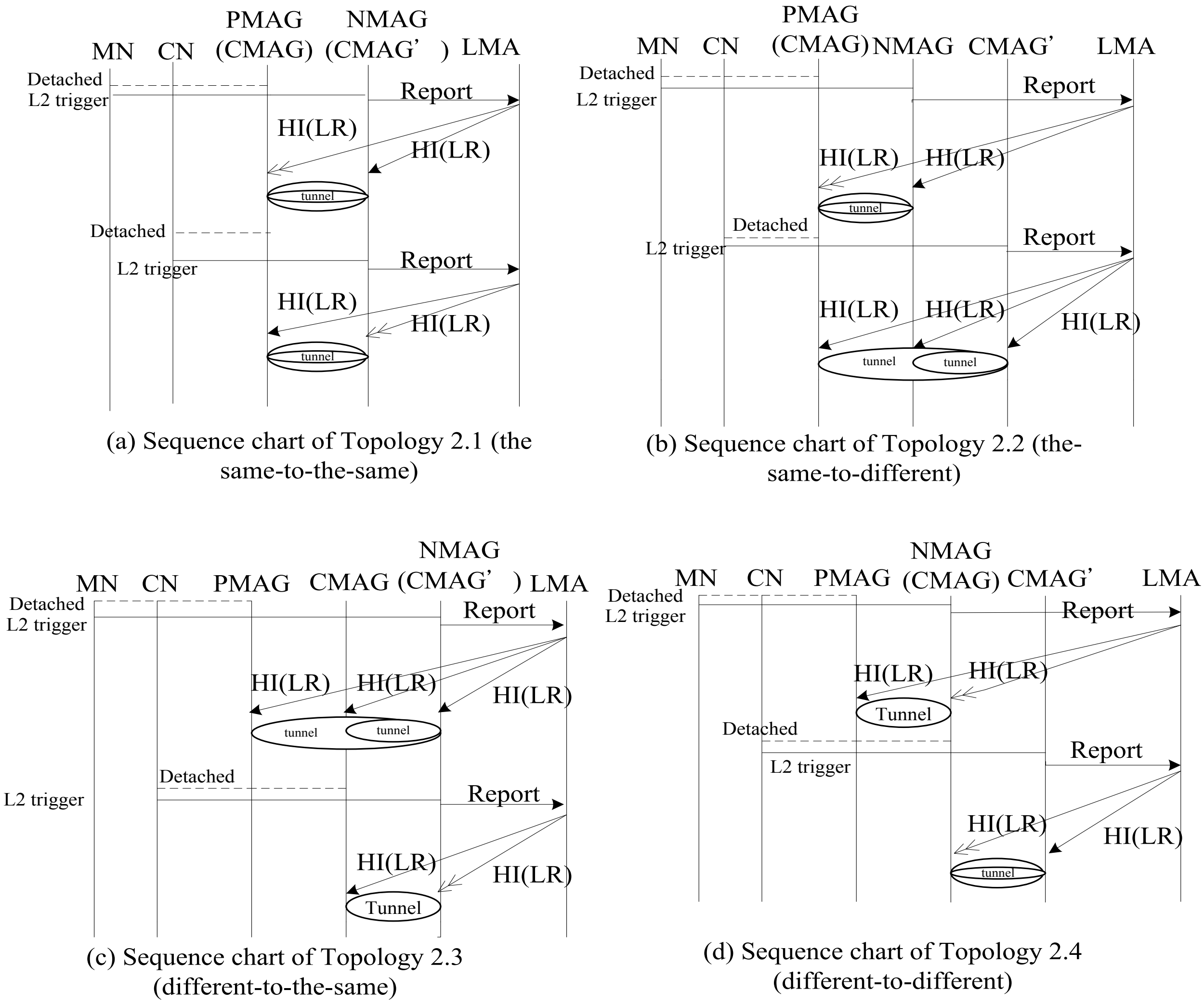
(b) Sequence chart of Topology 1.2: (different-to-the-same).



(c) Sequence chart of Topology 1.3: (the-same-to-different).

Figure 6 Sequence charts of Category 1 on Reactive mode (← : one message, ↞ : two messages.)

Due to the lack of PMAG-NMAG tunnel, NMAG sends a Report message to LMA, implying that MN has been detached from PMAG and it has created a L2 connection to NMAG. On receiving the Report message, like that in Predictive mode, LMA sends three HI (LR) messages individually to PMAG, NMAG and CMAG. The remaining steps as shown in Figure 6 are the same as those in Predictive mode with Detached and L2 trigger being moved to the positions upper than the positions of sending the three HI (LR) messages by LMA. Figure 7 illustrates the four sequence charts of Category 2 on type 1 (see Figure 4a). Sequence charts of Category 2 of Reactive mode on type 2 are similar to these of Category 2 of Predictive mode on type 2.



(a) Sequence chart of Topology 2.1 (the same-to-the-same)

(b) Sequence chart of Topology 2.2 (the-same-to-different)

(c) Sequence chart of Topology 2.3 (different-to-the-same)

(d) Sequence chart of Topology 2.4 (different-to-different)

Figure 7 Sequence charts of Category 2 on Reactive mode (← : one message, ↞ : two messages).

F-PMIPv6

Handover and signaling cost of F-PMIPv6 employing ANDSF, denoted by L(F-PMIPv6), is

L(F-PMIPv6) = T(L2) + T(PMAG-MN) + T(MN-ANDSF) + T(ANDSF-MN) + T(MN-PMAG) + T(PMAG-NMAG) + T(NMAG-PMAG) + T(NMAG-LMA) + T(LMA-NMAG) + T(NMAG-MN) + T(LMA-NMAG) + T(LMA-PMAG) + T(NMAG-LMA) + T(PMAG-LMA)

in which 2T(MN-MAG) is the cost for delivering an RA message and Report between MN and MAG, and 2T(MN-ANDSF) is the cost for sending an MN Inform ANDSF and an ANDSF Responses MN message between MN and ANDSF. 2T(PMAG-NMAG) is the cost for sending an HI message and an HACK message through the channel established between PMAG and NMAG. 6T(MAG-LMA) which is the cost for sending PBU, PBA, two LRIs and two LRAs between MAG and LMA.

S-PMIPv6

Handover and signaling cost of S-PMIPv6 utilizing ANDSF, denoted by L(S-PMIPv6), is

L(S-PMIPv6) = T(L2) + T(LMA-PMAG) + T(PNAG-MN) + T(MN-ANDSF) + T(ANDSF-MN) + T(MN-PMAG) + T(PMAG-LMA) + T(LMA-PMAG(NMAG)) + T(NMAG-MN)

in which 3T(MN-MAG) is the cost for delivering an RA message and Report between MN and MAG, and 2T(MN-ANDSF) is the cost for sending an MN Inform ANDSF and an ANDSF Responses MN message between MN and ANDSF. 5T(MAG-LMA) which is the cost for sending two NMAG-unpredictable message, predictable message, two HI (LR)s sent by LMA, one to PMAG, one to NMAG.

Enhancement S-PMIPv6

Handover and signaling cost of S-PMIPv6 employing ANDSF, denoted by L En (S-PMIPv6), is

L En(S-PMIPv6) = T(L2) + T(LMA-ANDSF) + T(ANDSF-LMA) + T(LMA-PMAG(NMAG)) + T(NMAG-MN)

in which 2T(MN-MAG) is the cost for delivering an RA message and Report between MN and MAG, and 2T(LMA-ANDSF) is the cost for sending an LMA Inform ANDSF and an ANDSF Responses LMA message between LMA and ANDSF. 2T(MAG-LMA) which is the cost for sending two HI (LR)s sent by LMA, one to PMAG, one to NMAG.

IV. SIMULATION ANALYSIS AND DISCUSSIONS

In this study, PMIPv6 [11-13], F-PMIPv6 [33-34], O-PMIPv6 [25-27], and S-PMIPv6 were tested. Their MN disconnection durations, defined as the time periods in which MN cannot send and receive data messages during its handover, were analyzed. Basically, there are two types of handover signaling, HI-signaling and LR-signaling. We list messages of the two types of the four schemes in Appendix A of this paper. Appendix B shows the sequence charts of the four schemes.

The signaling overheads of the four schemes are listed in Table 1 in which Authentication header as one of HI-signaling messages contains MN-ID and a profile. It is a message sent to AAA Sever for enquiring whether MN is a valid user or not. The sender of the message may be a MAG or LMA. AAA Sever then relies the sender with another Authentication header. That is why there is a ↔ between MAG and AAA Sever (also between LMA and AAA Sever), representing that an authentication header is delivered on both directions.

In Table 1, we can also see that F-PMIPv6 and O-PMIPv6 cancel the four Authentication headers originally transmitted in PMIPv6. O-PMIPv6 further omits two LRI messages sent to LMA by PMAG and NMAG and two LRA messages sent to PMAG and NMAG by LMA. S-PMIPv6 again cancels HACK, PBU, and PBA from O-PMIPv6 to shorten its handover delays.

Table 1 Signaling overheats of PMIPv6, F-PMIPv6, O-PMIPv6 and S-PMIPv6 (- : does not exist; → : message delivery direction; ↔ : a message delivered forth and back.)

Packet	**Packet size (bytes)**				**Signaling type**
	PMIPv6	F-PMIPv6	O-PMIPv6	S-PMIPv6	
PBU (NMAG→LMA)	75	75	75	-	HI
PBA (LMA→NMAG)	75	75	75	-	HI
Authentication Header 1 (MAG↔AAA Sever)	50	-	-	-	HI
Authentication Header 2 (LMA↔AAA Sever)	50	-	-	-	HI
HI (PMAG→NMAG in Predictive mode) (NMAG→PMAG in Reactive mode)	-	57	71 (message sent is HI (LR), rather than HI)	71 (HI (LR)) (LMA→NMAG, PMAG, CMAG)	HI
HACK (NMAG→PMAG in Predictive mode) (PMAG→NMAG in Reactive mode)	-	57	71 (message sent is HACK (LR), rather than HACK)	-	HI
LRI (LMA→NMAG and LMA→PMAG)	71	71	-	-	LR
LRA (NMAG→LMA and PMAG→LMA)	71	71	-	-	LR
Router Advertisement (RA)	88 = |IPv6 header| of 80 bytes + |RA| of prefix option 8 bytes in length)				HI

4.1 Handover Signaling costs of PMIPv6, F-PMIPv6 and O-PMIPv6

In this section, handover and signaling costs of PMIPv6, F-PMIPv6 and O-PMIPv6 are evaluated. S-PMIPv6's will be described latter. In the following, *n*T (X - Y) generally means *n* messages are transmitted between entity X and entity Y.

(1) PMIPv6

Handover and signaling cost of PMIPv6, denoted by LP(PMIPv6), is

$$LP(PMIPv6)=T(L2)+2T(MAG\text{-}AAASever)+2T(AAASever\text{-}LMA)+6T(MAG\text{-}LMA)+T(MN\text{-}MAG) \quad (1)$$

where T(L2) is Layer 2 handover latency, and the remaining four items on the right hand size of Eq. (1) as listed in Table 1 are message-delivery delays between AAA Sever and MAG (i.e., 2T(MAG-AAASever) which is the cost for sending two Authentication-headers), AAA Sever and LMA (i.e., 2T(AAASever-LMA) which is the time required for delivering two Authentication-headers), MN and MAG (i.e., T(MN-MAG) which is the time consumed for transmitting an RA message) and between MAG and LMA (i.e., 6T (MAG-LMA) which is the cost for sending PBU, PBA, two LRIs and two LRAs between MAG and LMA). In PMIPv6, Report message sent by MN to PMAG may be or may not be considered as a signaling message. In this study, it is not included in Eq. (1). Also, PMIPv6 has no Predictive mode, only having Reactive mode.

(2) F-PMIPv6

Handover and signaling cost of F-PMIPv6 on Predictive mode, denoted by LP(F-PMIPv6), is

$$LP(F\text{-}PMIPv6) = T(L2) + 2T(PMAG\text{-}NMAG) + 6T(MAG\text{-}LMA) + T(MN\text{-}MAG) \quad (2)$$

in which T(MN-MAG) is the cost for delivering an RA message from MAG to MN, and 2T(PMAG-NMAG) is the cost for sending an HI message and an HACK message through the channel established between PMAG and NMAG. 6T(MAG-LMA) is described above. Since Report message is not considered as a signaling message, signaling cost of F-PMIPv6 on Reactive mode is the same as that of F-PMIPv6 on Predictive mode, i.e., Eq. (2).

(3) O-PMIPv6

Handover and signaling cost of O-PMIPv6 on Predictive mode, denoted by LP(O-PMIPv6), is

$$LP(O\text{-}PMIPv6) = T(L2) + 2T(PMAG\text{-}NMAG) + 2T(MAG\text{-}LMA) + T(MN\text{-}MAG) \quad (3)$$

Compared with F-PMIPv6 (Eq. (2)), O-PMIPv6 removes two LRI and two LRA messages. Only PBU and PBA are transported between MAG and LMA (see Table 1). That is why 6T(MAG-LMA) is reduced to 2T(MAG-LMA) in Eq. (3).

Since the difference between O-PMIPv6's Predictive mode and Reactive mode on handover and signaling cost is sending a Report message or without sending a Report message, and in this study, Report is considered as a data message, then handover and signaling costs of O-PMIPv6 on Reactive mode and Reactive mode are the same, i.e., Eq. (3).

4.2 Signaling costs of S-PMIPv6 on Predictive mode

As mentioned above, S-PMIPv6 handover has two categories, Category 1 and Category 2.

A. Category 1: only MN hands over

No matter which Category 1 topology is analyzed, the HI (LR) signaling includes

1) Three HI (LR)s sent by LMA, one to PMAG, one to NMAG, one to CMAG
2) RA message sent by NMAG to MN

The handover and signaling cost on Category 1, denoted by CC1P (S-PMIPv6), is

CC1P (S-PMIPv6) = T(L2) + T(MN-MAG) + T(MAG-LMA)

(4)

Since the three HI (LR) messages sent to PMAG, NMAG and CMAG are delivered almost at the same time (see Figure 3), in Eq. (4), there is only one T(MAG-LMA), rather than three. Some studies [11-13, 25-27, 33-34] did not deal with HI (LR) message sent to CN. In this case, due to delivering the HI (LR) messages in parallel, the handover and signaling cost is also Eq. (4).

B. Category 2: both MN and CN hand over

No matter which Category 2 topology is evaluated, the HI (LR) signaling is as follows under the assumption that MN starts handing over before CN does.

1) Six HI (LR)s sent by LMA,
   A. one to PMAG (for establishing a tunnel between NMAG and PMAG),
   B. one to NMAG (for establishing two tunnels, one between NMAG and PMAG and the other between NMAG and CMAG),
   C. one to CMAG (for establishing an optimized path between NMAG and CMAG),
   D. one to CMAG (for establishing a tunnel between CMAG and CMAG' when CN hands over),
   E. one to CMAG' (for establishing two tunnels, one between CMAG' and CMAG and the other between CMAG' and NMAG), and
   F. one to NMAG (for establishing the tunnel between NMAG and CMAG').
2) RA message sent by NMAG to MN

Its handover and signaling cost on Category 2 of Predictive mode, denoted by CC2P (S-PMIPv6), in its worst case is then

CC2P (S-PMIPv6) = T(L2) + T(MN-MAG) + 2T(MAG-LMA)

(5)

where the worst case is defined as t2=t3 in Figure 4, showing that CN starts handing over at the time point when MN just finishes its handover. In its best case defined as t1=t3, meaning MN and CN start handing over at the same time, the handover and signaling delay will be one T(MAG-LMA) reduced from Eq. (5). If we do not consider CN and the HI (LR) message sent to CMAG, the handover and signaling cost is still Eq. (5). In the following analyses on S-PMIPv6, it is always true. So we will not redundantly mention that again.

4.3 Signaling costs of S-PMIPv6 on Reactive mode

The analysis is also based on Category 1 and Category 2.

(1) Category 1

The signaling cost of S-PMIPv6 on Category 1 of Reactive mode is three HI (LR)s sent by LMA, one to PMAG, one to NMAG, and one to CMAG, in parallel. RA message is further cancelled. Therefore, its handover and signaling cost, denoted by CC1R (S-PMIPv6), is

CC1R (S-PMIPv6) = T(L2) + T(MAG-LMA)

(6)

(2) Category 2

The HI (LR) signaling of category 2 includes only six HI (LR)s sent by LMA. Their destinations and purposes are the same as those of S-PMIPv6 on Category 2 of Predictive mode. Thus, the handover and signaling cost, denoted by CC2R (S-PMIPv6), in its worst case is

CC2R (S-PMIPv6) = T(L2) + 2T(MAG-LMA)

(7)

Of course, in its best case, the cost will be one T(MAG-LMA) reduced from Eq. (7).

Table 2 Number of transmitted messages and signaling overheads on Predictive mode (x/y represents that there are x messages and their total length which is y bytes).

Signaling Message	PMIPv6	F-PMIPv6	O-PMIPv6	S-PMIPv6 (1)	S-PMIPv6 (2)	S-PMIPv6 (3)	S-PMIPv6 (4)
HI-signaling messages	6/350	4/264	4/292	2/142	3/213	4/284	6/426
LR-signaling messages	4/284	4/284	0/0	0/0	0/0	0/0	0/0
RA-signaling message	1/88	1/88	1/88	1/88	1/88	2/88	2/88
No. of signaling messages (msgs)/ Overhead (bytes)	11/722	9/636	5/380	3/230	4/301	6/460	8/602

Table 3 Number of transmitted messages and signaling overheads on Reactive mode (x/y represents that there are x messages and their total length which is y bytes).

Signaling Message	PMIPv6	F-PMIPv6	O-PMIPv6	S-PMIPv6 (1)	S-PMIPv6 (2)	S-PMIPv6 (3)	S-PMIPv6 (4)
HI-signaling messages	6/350	4/264	4/292	2/142	3/213	4/284	6/426
LR-signaling messages	4/284	4/284	0/0	0/0	0/0	0/0	0/0
No. of signaling messages (msgs)/ Overhead (bytes)	10/634	8/548	4/292	2/142	3/213	4/284	6/426

Table 2 summarizes the HI-signaling and LR-signaling messages and their lengths on Predictive mode for the four tested schemes. Table 3 lists those on Reactive mode. In the two tables, S-PMIP6 (1), S-PMIP6 (2), S-PMIP6 (3) and S-PMIPv6 (4) respectively represent S-PMIPv6 on Category 1 without dealing with CN, S-PMIPv6 on Category 1 also dealing with CN, S-PMIPv6 on Category 2 without dealing with CN and S-PMIPv6 on Category 2 also dealing with CN.

4.4 MN disconnection duration

MN disconnection durations of the tested schemes are as follows.

(1) PMIPv6

The MN disconnection duration of PMIPv6, denoted by D(PMIPv6), is calculated as

D(PMIPv6) = T(L2) + 2T(MAG-AAA Sever) + 2T(AAA Sever-LMA) + 6T(MAG-LMA) + T(MN-MAG) (8)

which as shown in Figure B1 in Appendix B is the same as the handover and signaling cost of PMIPv6 (i.e., Eq. (1)) since MN is detached from PMAG at the beginning of handover. The detachment lasts until it successfully connects to NMAG. During this time period MN is unable to send and receive messages.

(2) F-PMIPv6

The MN disconnection duration of F-PMIPv6 on Predictive mode, denoted by DP(F-PMIPv6), is

DP(F-PMIPv6) = T(L2) +T(MN-MAG) (9)

As shown in Figure B2a in Appendix B, the duration begins when MN is detached from the underlying network after sending a Report message to PMAG. The duration lasts until MN successfully receives RA message from NMAG. So there is only one T(L2) and one T(MN-MAG). Its MN disconnection duration on Reactive mode, denoted by DR(F-PMIPv6), is

DR(F-PMIPv6) = T(L2) + 2T(PMAG-NMAG) + 6T(MAG-LMA) (10)

which is one T(MN-MAG) less than that in Eq. (2) since RA is omitted in Reactive mode (see Figure

B2b).

(3) O-PMIPv6

The MN disconnection duration of O-PMIPv6 on Predictive mode, denoted by DP(O-PMIPv6), is

$$DP(O\text{-}PMIPv6) = T(L2) + T(MN\text{-}MAG) \quad (11)$$

which is the same as that of F-PMIPv6 (i.e., Eq. (9)) since O-PMIPv6's handover procedure follows F-PMIPv6's. Its MN disconnection duration on Reactive mode, denoted by DR(O-PMIPv6), is

$$DR(O\text{-}PMIPv6) = T(L2) + 2T(PMAG\text{-}NMAG) + 2T(MAG\text{-}LMA) \quad (12)$$

in which 2T(PMAG-NMAG), as shown in Table 1 and Figure B3b, is the cost of delivering HI (LR) and HACK (LR) between PMAG and NMAG, and 2T(MAG-LMA) is the cost of sending PBU and PBA, respectively, by NMAG and PMAG to LMA.

(4) S-PMIPv6

The MN disconnection duration of S-PMIPv6 on Predictive mode, denoted by DP(S-PMIPv6), is 0 due to using SCTP. At any moment, MN is connected to PMAG and/or NMAG. The duration of its Reactive mode, denoted by DR(S-PMIPv6), is

$$DR(S\text{-}PMIPv6) = T(L2) + T(MAG\text{-}LMA) \quad (13)$$

in which T(MAG-LMA) is the cost for sending three HI(LR) messages to PMAG, NMAG and CMAG or two to PMAG and NMAG in parallel from LMA.

Table 4 lists the typical times consumed for sending a message in the case where wired (wireless) link delay is set 2 ms (10 ms), and wired (wireless) link Bandwidth is set to 100Mbps

(11Mbps). In the last column of this table, u and v may be MAG, LMA or AAA Sever. Since bandwidth of a wireless channel is often relatively narrow compared with that of a wired channel, T(MN-MAG), the cost for sending a message through a wireless link, is longer than T(u-v).

Table 4 The time consumed for sending a message.

T(L2)	T(MN-MAG)	T(u-v)
25 ms	8 ms	3 ms

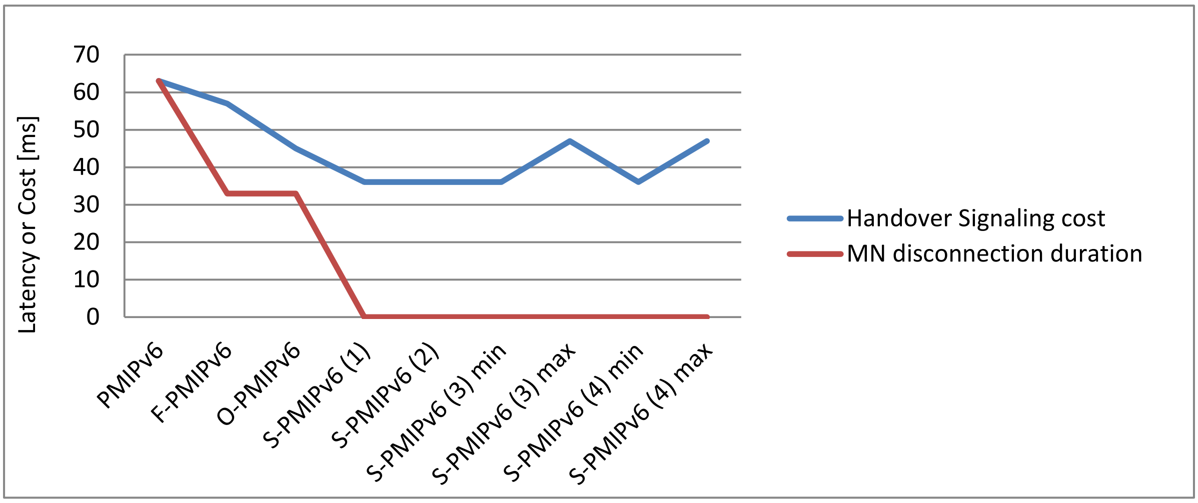


Figure 8 MN disconnection durations and costs for sending signaling messages. S-PMIP6 (1), S-PMIP6 (2), S-PMIP6 (3) and S-PMIPv6 (4) respectively represent S-PMIPv6 on Category 1 without dealing with CN, S-PMIPv6 on Category 1 also dealing with CN, S-PMIPv6 on Category 2 without dealing with CN and S-PMIPv6 on Category 2 also dealing with CN. Max and min represent that MN and CN hand over sequentially one by one and simultaneously, respectively.

MN's disconnection durations and the times consumed for sending signaling messages are illustrated in Figure 8, in which S-PMIP6 (1), S-PMIP6 (2), S-PMIP6 (3) and S-PMIPv6 (4) are respectively the same as those defined above. Max (including S-PMIP6 (3) max and S-PMIP6 (4) max) and min (including S-PMIP6 (3) min and S-PMIP6 (4) min) represent that MN and CN hand over sequentially one by one and simultaneously, respectively. We can see that PMIPv6's signaling cost is the highest, and S-PMIPv6's costs are lower than those of the other tested schemes. In S-PMIPv6 (1), the cost only includes L2 + T (MAG-LMA) since the HI (LR) messages as mentioned above are transmitted simultaneously. S-PMIPv6 (2), S-PMIPv6 (3) min, and S -PMIPv6 (4) min have the same phenomena. Because MN and CN in S-PMIPv6 (3) max and S-PMIPv6 (4) max hand over at different time points, their handover and signaling costs are both L2 + 2T (MAG-LMA). That is why in Figure 8, their costs are higher than those of the other S-PMIPv6 schemes.

Table 5 lists the lengths of control data of the seven topologies of S-PMIPv6. We can see that Topologies 1.1, 1.2 and 1.3 in Category 1, and Topologies 2.1, 2.2, 2.3, and 2.4 in Category 2 are themselves the same. In fact, the information carried in Table 5 is the same as those shown in the portion concerning S-PMIP6 (1), S-PMIP6 (2), S-PMIP6 (3) and S-PMIPv6 (4) in Tables 2 and 3, but showing them from topology viewpoints.

Table 5 Lengths of control data required by S-PMIPv6 (unit: bits).

Mode		Topology	
		1.1/1.2/1.3	2.1/2.2/2.3/2.4
Predictive mode	dealing with CMAG	301	514
	without dealing with CMAG	230	372
Reactive mode	dealing with CMAG	213	426
	without dealing with CMAG	142	284

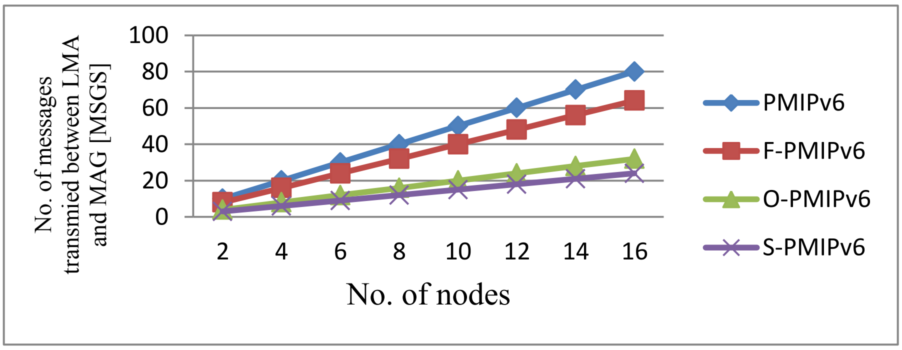


Figure 9 Number of messages delivered between LMA and MAG given different numbers of nodes that perform handover.

Figure 9 shows the numbers of signaling messages exchanged between LMA and MAG given different numbers of nodes, ranging between 2 and16 nodes. We can see that the cost is proportional to the number of nodes given. This is the case when path bandwidths are not saturated. Otherwise, the number of messages transmitted will be lowered. Also, PMIPv6 has the highest handover and signaling cost and F-PMIPv6's cost is lower than that of PMIPv6. O-PMIPv6 is in turn better than F-PMIPv6, and S-PMIPv6 outperforms the tested schemes. The reason has been described above.

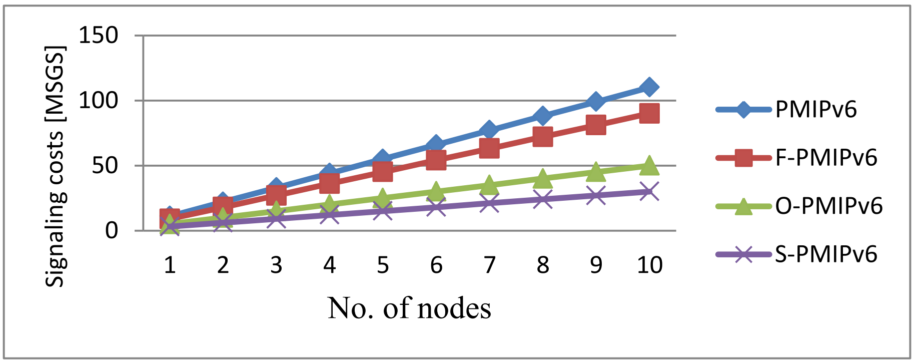


Figure 10 Signaling costs required given different numbers of nodes that perform handovers.

The signaling costs on different numbers of nodes, ranging between 1 to 10, are shown in Figure 10 in the case in which all MNs are communicating with their corresponding CNs. PMIPv6 has the highest handover and signaling cost since it employs extra signaling messages for sending Authentication headers between AAA Sever and LMA and between AAA Sever and MAG. F-PMIPv6 has lower handover and signaling cost than PMIPv6 has since it omits the Authentication headers. However, O-PMIPv6 is in turn better than F-PMIPv6 since it encapsulates the LRI/LRA information in the HI/HACK to reduce number of delivered messages. Basically, S-PMIPv6's handover and signaling cost is the lowest due to using HI (LR) and requesting LMA to choose the next MAG. In other words, it omits HACK (LR) messages.

V. Conclusions and Future Work

Generally, S-PMIPv6 is a make-before-break protocol which effectively shortens end-to-end delivery delays and mitigates packet/message loss rates. When an MN hands over from one MAG to another, it will face some disconnected duration, in which no messages can be sent or received. Moreover, the LR session between MN and its CN is torn down within this handover and needs to be re-established from the very beginning after the handover. It means during the time period between the completion of handover and the end of LR session re-establishment, a lot of data messages flow through a non-optimal path, causing higher utilization of LMA and MAG since messages may flow via them to MN.

In this research, S-PMIPv6 proposed in a single-LMA domain demonstrates more superior than PMIPv6, F-PMIPv6 and O-PMIPv6 do in total handover and signaling costs.

Generally, multiple-LMA domain handover may pose some problems, e.g., security since the information sent between two MAGs, such as MN context, may need to be safely protected when the two MAGs belong to two LMAs. In addition, the LMAs may be owned and controlled by different operators. Then information sharing among these LMAs should be carefully secured.

To solve these problems, we need shared prefixes across domains and an improved mechanism for establishing secure associations to make the system more practical. Also, we would like to derive the reliability model and behavior model for S-PMIPv6 so that users can predict its reliability and usage behaviors before using it. These will constitute our future studies.

REFERENCES

[1] X. P´erez-Costa, M. Torrent-Moreno, and H. Hartenstein, “A performance comparison of mobile IPv6, hierarchical mobile IPv6, fast handovers for mobile IPv6 and their combination,” *ACM Mobile Computing and Communication*. Review, vol. 7, no. 4, pp. 5-19, Oct. 2003.

[2] Y. Gwon, J. Kempf, and A. Yegin, “Scalability and robustness analysis of mobile IPv6, fast mobile IPv6, hierarchical mobile IPv6, and hybrid IPv6 mobility protocols using a large-scale simulation,” in *Proceedings of IEEE International Conference on Communications,* vol. 7, pp. 4087-4091, June 2004

[3] D. Johnson, C. Perkins, and J. Arkko, “Mobility support in IPv6,” *IETF RFC 3775*, June 2004.

[4] K.S. Kong, Y.H. Han, M.K. Shin, and H. You, “Mobility management for all-IP mobile networks: mobile IPv6 vs. Proxy Mobile IPv6,” *IEEE Wireless Communications*, vol. 15, no. 2, pp. 36-45, April 2008.

[5] S. Thomson, “IPv6 stateless address autoconfiguration,” *IETF RFC 4862*, Sept. 2007.

[6] R. Hinden, “IP version 6 addressing architecture,” *IETF RFC 4291*, Feb 2006.

[7] J. Korhonen, “Local Mobility Anchor (LMA) Discovery for Proxy Mobile IPv6,” IETF RFC 6097, Feb 2011.

[8] K. Lee, Y. Han, and M. Shin, “Handover latency analysis of a network-based localized mobility management protocol,” in *Proceedings of IEEE International Conference on Communications*, pp. 1-6, June 2009.

[9] L. Magagula, and H. Anthony, "Early discovery and pre-authentication in Proxy MIPv6 for reducing handover delay," in *proceedings of International Conference on Broadband Communications, Information Technology & Biomedical Applications*, pp. 23-26, Nov. 2008.

[10] H. song, J. Kim, J. Lee, and H.S. Lee, “Analysis of vertical handover latency for IEEE 802.21-enabled Proxy Mobie IPv6,” in *proceedings of IEEE International Conference on*

Advanced Communication Technology, Seoul, Korea, pp. 1059-1063, Feb. 2011.

[11] M. Liebsch, A. Muhanna, and O. Blume, "Transient binding for Proxy Mobile IPv6," *RFC 6058*, Mar 2011.

[12] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil, "Proxy Mobile IPv6," *RFC 5213*, Aug. 2008.

[13] Q. Zhang and Z. Shan, “Using fast handover to quicken the re-establishment procedure of localized routing for Proxy Mobile IPv6," in *proceedings of Wireless and Optical Communication Conference*, pp. 349 – 354, May 2013.

[14] D. Zhou, H. Zhang, Z. Xu, and Y. Zhang, “Evaluation of Fast PMIPv6 and Transient Binding PMIPv6 in vertical handover environment,” in *proceedings of IEEE international Conference on Communications*, pp. 1-5, July 2010.

[15] J. Lee, T. Chung, and S. Gundavelli, “A comparative signaling cost analysis of Hierarchical Mobile IPv6 and Proxy Mobile IPv6,” in *Proceedings of IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 1–6, Sept. 2008.

[16] H. Lee, M. Chung, S. Pack, and S. Gundavelli, “Shall we apply paging technologies to Proxy Mobile IPv6? ” in *Proceedings of of ACM International Workshop on Mobility in the Evolving Internet Architecture*, pp. 37–42, Aug. 2008.

[17] Y. Li, Y. Jiang, H. Su, D. Jin, L. Su, and L. Zeng, “A group-based handoff scheme for correlated mobile nodes in Proxy Mobile IPv6,” in *Proceedings of IEEE Global Telecommun. Conference*, pp. 1–6, Dec. 2009.

[18] H. Yokota, K. Chowdhur, R. Koodli, B. Patil, and F. Xia,“Fast handovers for Proxy Mobile IPv6,” *IETF RFC 5949*, Sept. 2010.

[19] R. Koodli, "Fast Handovers for Mobile IPv6,” The Internet Society, *RFC 5568*, July 2009.

[20] R. Koodli, “Fast Handovers for Mobile IPv6,” *IETF RFC 4068*, July. 2005.

[21] A. Rasem, C. Makaya, and M. St-Hilaire, “A Comparative analysis of predictive and reactive mode of optimized. PMIPv6,” *in proceedings of Wireless Communications and Mobile Computing Conference*, pp. 722 – 727, Aug. 2012.

[22] A. Rasem, C. Makaya, and M. St-Hilaire,” O-PMIPv6: Efficient handover with route optimization in Proxy Mobile IPv6 domain,” in proceedings of Wireless and Mobile Computing, Networking and Communications, pp. 47 – 54, Oct. 2012.

[23] K.S. Kong, W. Lee, Y.H. Han, and M.K. Shin, “Handover latency analysis of a network-based localized mobility management protocol,” in *proceeding of IEEE International Conference on Communications*, Beijing China, pp. 5838-5843, 2008.

[24] Y. Choi and T. Chung, “Enhanced light weight route optimization in Proxy Mobile IPv6,” in *Proceedings of the International Joint Conference on INC, IMS and IDC*, Fifth International Joint Conference on, pp. 501-504, Aug. 2009.

[25] B. Han, J. Lee, J. Lee, and T. Chung, “PMIPv6 route optimization mechanism using the routing table of MAG,” in *Proceedings of the International Conference on Systems and Networks Communications*, pp. 274–279, Oct. 2008.

[26] L. Magagula and H. Anthony, "IEEE802.21 optimized handover delay for Proxy Mobile IPv6", in *Proceedings of International Conference on Advanced Communication Technology*, pp. 1051-1054, Feb. 2008.

[27]L. J. Wand, G. Hua, D. Bin, and S. Yong-xin, "Research of enhanced route optimum algorithm for PMIPv6," in *Proceedings of International Conference on Wireless Communications, Networking and Mobile Computing*, pp. 12-14, Oct. 2008.

[28] L.A. Magagula, O.E. Falowo, and H.A. Chan, “Handover optimization in heterogeneous wireless networks: PMIPv6 vs. PMIPv6 with MIH,” *IETF RFC 4830*, April. 2007.

[29] R. Stewart, “Stream Control Transmission Protocol,” *IETF RFC 4960*, Sept. 2007

[30] L. Ong and J. Yoakum, "An introduction to the Stream Control Transmission Protocol," *IETF RFC 3286*, May 2002

[31] H. Kong, Y. Jang and H. Choo, "An efficient load balancing of mobile access gateways in Proxy Mobile IPv6 domains," in Proceedings of *International Conference on Computational Science and Its Applications,* pp.289-292, March 2010.

[32] R. Koodli and C.E. Perkins, "Fast handovers and context transfers in mobile networks," *ACM Mobile Computing and Conmrrrricnriorr Review*, vol. 31, no. 5, Oct. 2001.

[33] S. Tsourdos, A. Michalas, A. Sgora, "Enhanced fast handovers for PMIPv6 in vehicular environments," *Information, Intelligence, Systems and Applications, IISA 2014, The 5th International Conference on,* pp. 420~425 July. 2014.

[34] Y.H. Cho, K.Y. Oh, J.T. Park, "Intelligent mobile IPv6 handover with multiple pre-registrations and late tunneling," in *Proceedings of Conference on Communication Systems Software and Middleware and Workshops,* pp. 551~554, Jan. 2008.

[35] F.Y. Leu, F.L. Jeng and F.C. Jiang, "A path switching scheme for SCTP based on round trip delays," *Computers & Mathematics with Applications*, vol. 62, issue 9, pp. 3504-3523.

APPENDIX A: SIGNALING MESSAGES OF THE FOUR TESTED SCHEMES

Handover signaling messages consist of HI-signaling and LR-signaling messages.

1. PMIPv6:

(1) PMIPv6 has 7 HI-signaling messages, including

1) Authentication Header sent by NMAG to AAA Sever
2) Authentication Header sent by AAA Sever to NMAG
3) PBU sent by NMAG to LMA

4) Authentication Header sent by LMA to AAA Sever

5) Authentication Header sent by AAA Sever to LMA

6) PBA sent by LMA to NMAG

7) RA message sent by NMAG to MN

(2) PMIPv6 has 4 LR-signaling messages, including

1) LRI sent by LMA to NMAG

2) LRI sent by LMA to CMAG

3) LRA by NMAG to LMA

4) LRA sent by CMAG to LMA

2. F-PMIPv6

(1) F-PMIPv6 on Predictive mode has 5 HI-signaling messages, including

1) HI sent by PMAG to NMAG

2) HACK sent by NMAG to PMAG

3) PBU sent by NMAG to LMA

4) PBA sent by LMA to NMAG

5) RA message sent by NMAG to MN

(2) F-PMIPv6 on Predictive mode has 4 LR-signaling messages, containing

1) LRI sent by LMA to NMAG

2) LRI sent by LMA to CMAG

3) LRA sent by NMAG to LMA

4) LRA sent by CMAG to LMA

(3) F-PMIPv6 on Reactive mode has 4 HI-signaling messages, including

1) HI sent by NMAG to PMAG

2) HACK sent by PMAG to NMAG

3) PBU sent by NMAG to LMA

4) PBA sent by LMA to NMAG

(4) F-PMIPv6 on Reactive mode has 4 LR-signaling messages, containing

1) LRI sent by LMA to NMAG

2) LRI sent by LMA to CMAG

3) LRA sent by NMAG to LMA

4) LRA sent by CMAG to LMA

3. O-PMIPv6

(1) O-PMIPv6 on Predictive mode has 5 HI-signaling messages, including

1) HI (LRI) sent by PMAG to NMAG

2) HACK (LRA) sent by NMAG to PMAG

3) PBU sent by NMAG to LMA

4) PBA sent by LMA to NMAG

5) RA message sent by NMAG to MN

(2) O-PMIPv6 on Reactive mode has 4 HI-signaling messages, including

1) HI (LRI) sent by NMAG to PMAG

2) HACK (LRA) sent by PMAG to NMAG

3) PBU sent by NMAG to LMA

4) PBA sent by LMA to NMAG

4. S-PMIPv6

(1) S-PMIPv6 on Category 1 of Predictive mode without dealing with CN has 3 HI-signaling messages, including

1) HI (LR) sent by LMA to NMAG
2) HI (LR) sent by LMA to PMAG
3) RA message sent by NMAG to MN

(2) S-PMIPv6 on Category 1 of Predictive mode also dealing with CN has 4 HI-signaling messages, including

1) HI (LR) sent by LMA to NMAG
2) HI (LR) sent by LMA to PMAG
3) HI (LR) sent by LMA to CMAG
4) RA message sent by NMAG to MN

(3) S-PMIPv6 on Category 2 of Predictive mode without dealing with CN has 6 HI-signaling messages, including

1) HI (LR) sent by LMA to MN's NMAG
2) HI (LR) sent by LMA to MN's PMAG
3) HI (LR) sent by LMA to CN's NMAG
4) HI (LR) sent by LMA to CN's PMAG
5) RA message sent by NMAG to MN
6) RA message sent by NMAG to CN

(4) S-PMIPv6 on Category 2 of Predictive mode also dealing with CN has 8 HI-signaling messages, including

1) HI (LR) sent by LMA to MN's NMAG
2) HI (LR) sent by LMA to MN's PMAG

3) HI (LR) sent by LMA to MN’s CMAG

4) HI (LR) sent by LMA to CN’s NMAG

5) HI (LR) sent by LMA to CN’s PMAG

6) HI (LR) sent by LMA to CN’s CMAG

7) RA message sent by NMAG to MN

8) RA message sent by NMAG to CN

(5) S-PMIPv6 on Category 1 of Reactive mode without dealing with CN has 2 HI-signaling messages, including

1) HI (LR) sent by LMA to NMAG

2) HI (LR) sent by LMA to PMAG

(6) S-PMIPv6 on Category 1 of Reactive mode also dealing with CN has 3 HI-signaling messages, including

1) HI (LR) sent by LMA to NMAG

2) HI (LR) sent by LMA to PMAG

3) HI (LR) sent by LMA to CMAG

(7) S-PMIPv6 on Category 2 of Reactive mode without dealing with CN has 4 HI-signaling messages, including

1) HI (LR) sent by LMA to MN’s NMAG

2) HI (LR) sent by LMA to MN’s PMAG

3) HI (LR) sent by LMA to CN’s NMAG

4) HI (LR) sent by LMA to CN’s PMAG

(8) S-PMIPv6 on Category 2 of Reactive mode also dealing with CN has 6 HI-signaling messages, including

1) HI (LR) sent by LMA to MN's NMAG

2) HI (LR) sent by LMA to MN's PMAG

3) HI (LR) sent by LMA to MN's CMAG

4) HI (LR) sent by LMA to CN's NMAG

5) HI (LR) sent by LMA to CN's PMAG

6) HI (LR) sent by LMA to CN's CMAG

APPENDIX B: SEQUENCE CHARTS OF PMIPV6, F-PMIPV6, O-PMIPV6 AND S-PMOPV6

In the following figures, red lines indicate that the messages are delivered in MN disconnection duration.

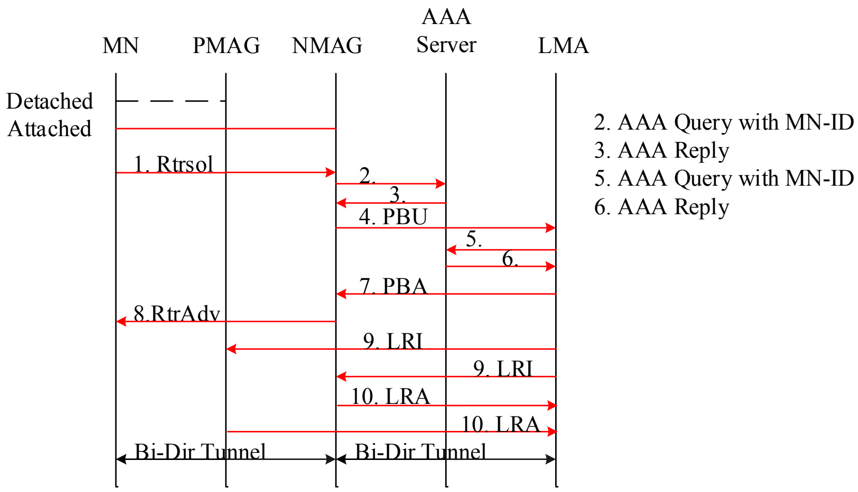
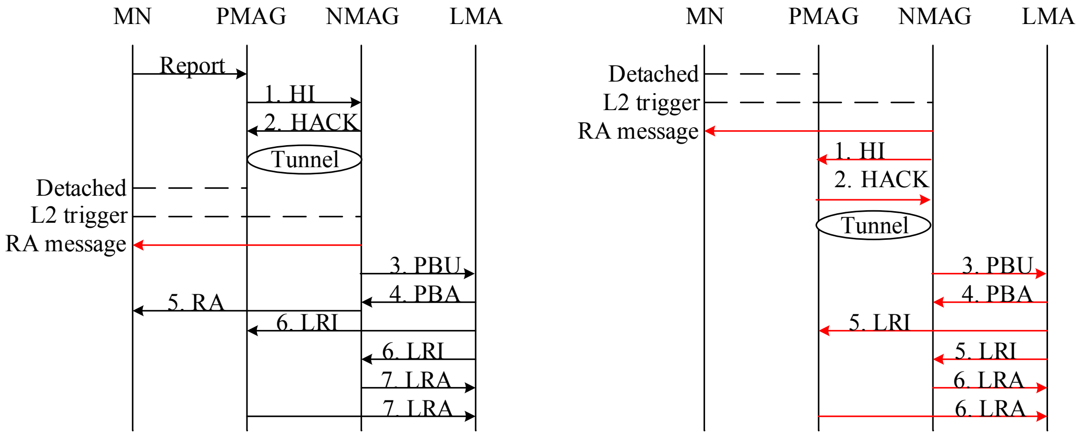
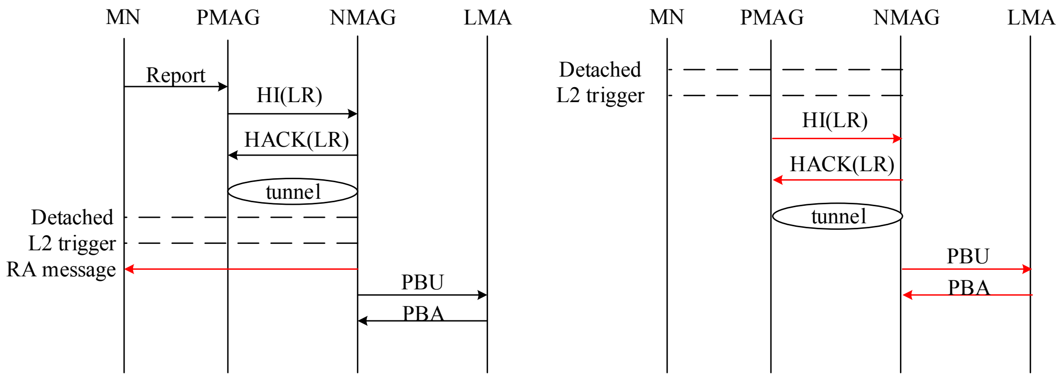


Figure B1 Sequence chart of PMIPv6



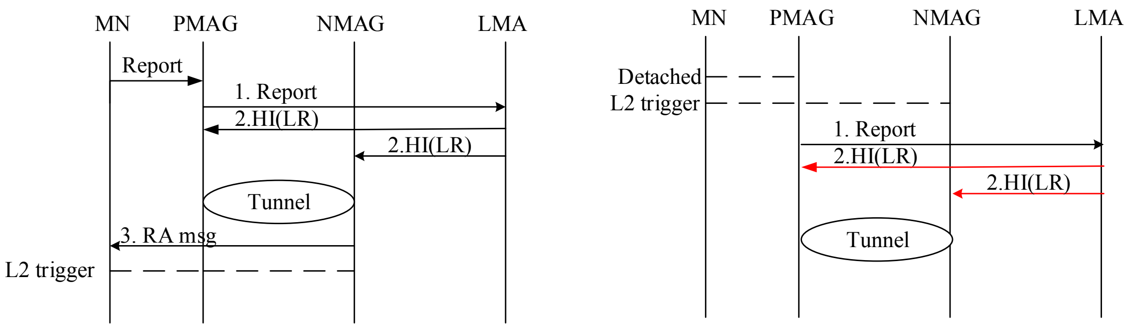
(a) Predictive mode (b) Reactive mode

Figure B2 Sequence charts of F-PMIPv6



(a) Predictive mode (b) Reactive mode

Figure B3 Sequence charts of O-PMIPv6



(a) Predictive mode (b) Reactive mode

Figure B4 Sequence charts of S-PMIPv6