A History-based Predictive Handover Scheme for Wireless Networks

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Abstract

In this paper, a history-based predictive handover scheme in PMIPv6, called HP-PMIPv6, is proposed. The objective of HP-PMIPv6 is to reduce the handover latency by maintaining the movement history of a mobile node (MN) and predicting a next MAG (nMAG), which the MN connects to, using the MN's movement history. In this study, the performance of HP-PMIPv6 is compared with PMIPv6 through mathematical modeling and simulation. Also, the performance of HP-PMIPv6 is evaluated using the SUMATRA dataset from Stanford University, which collects real-world user mobility data. The simulation results show that HP-PMIPv6 reduces the handover latency by nearly 30% compared to that of PMIPv6, while the result using the Stanford dataset shows around 10% improvement.

Keywords: PMIPv6, Proxy Mobile IPv6, Fast handover, Mobility history, Predictive handover

1 Introduction

In the recent two decades, users' demand for data traffic especially the Mobile Internet [1, 2] usage has dramatically increased. This increase is expected to continue at a steady pace in this decade. With respect to portability, personal laptops have turned computing into a mobile commodity where with the advent of mobile IP, users can now enjoy uninterrupted Internet roaming and transparent applications. The mobile IP promises a world of networked and interconnected devices that provide relevant content and information whatever the location of the user. In addition to the well-known access networks (e.g. wifi hotspot, 3G/4G/LTE), the mobile IP includes a new kind of networks known as low power and loss networks [3-4]. Such networks are composed of devices with limited energy resources, memory and computational power. Due to the pervasive nature of IP networks, it is likely that a host will move across different networks, especially when the mobile IP will be a reality. Layer 3 mobility (i.e. moving from one IPv6 network to another) requires a specific support to enable session continuity.

Proxy Mobile IPv6 [5-6] is a network based solution for layer 3 mobility support standardized by the IETF. By contrast to Mobile IPv6, the mobility management is carried out by new network entities (the local mobility anchor and the mobility access gateway) on behalf of mobile nodes. As a result, the mobility is fully transparent to the mobile nodes. This feature reduces resource optimization in the wireless networks and energy consumption and the handover signaling costs of an MN that need to support a mobility protocol. However, PMIPv6 has handover latency and packet loss problems during a handover [7].

To solve those problems, many schemes have been proposed to prevent the packet loss and support the fast handover in PMIPv6. Fast handover for PMIPv6 (FPMIPv6) and New handover process in PMIPv6 networks (NPMIPv6) use a Received Signal Strength (RSS) value to predict the handover of MN and to perform buffering packets towards an MN. The MN scans neighboring Mobile Access Gateways (MAGs) to find an appropriate next MAG (nMAG) [8-9], which the MN will be connected to. It supports the fast handover using the MN participating in the handover signaling procedure.

In this paper, the mobility history based predictive handover scheme in PMIPv6 (HP-PMIPv6) is proposed. HP-PMIPv6 prevents extra energy consumption of an MN by participating the handover procedure and packet loss during the handover by buffering packets after predicting the nMAG. The scheme predicts an nMAG in the PMIPv6 domain without participation of an MN. To predict an nMAG, HP-PMIPv6 uses a lezi-update scheme [10] to effectively manage the location of the MN. The lezi-update scheme keeps the movement path of an MN, and checks the movement history by constructing a search tree to estimate the next location of an MN. In HP-PMIPv6, the Authentication, Authorization and Accounting (AAA) server sends a nMAG information

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DOI: 10.3966/160792642018091905020

to the Local Mobility Anchor (LMA) and then the LMA makes the tunneling with the nMAG. The nMAG performs a packet buffering technique during handover to minimize the packet loss. The HP-PMIPv6 incurs some extra costs for an nMAG prediction such as mobility history management and for the tunneling establishment between the Local Mobility Anchor (LMA) and the nMAG. Through the experiment, proposed scheme reduced handover latency around 30% compare to original PMIPv6.

In the following sections, a literature review on PMIPv6 handover signaling in cellular networks and related technologies are presented in Section 2. In Section 3 and 4, we detail our proposed scheme. Experiments and measurement results are provided in Sections 5. Finally, we conclude the paper in Section 6.

2 Related Work

Recently, various efforts from both industry and academia are dealing with the specification of distributed mobility management (DMM). Several schemes have been proposed especially at the IETF DMM working group [11]. These proposals [12-15] mostly consider network-based approaches relying on PMIPv6; they support network based mobility management. When the MAG detects the MN's movements, it initiates mobility control signaling to the MN's LMA on behalf of the MN. The LMA performs the allocation of Home Network Prefix (HNP) to the MN and maintains the MN's location information [7].

FPMIPv6 [8] was proposed to resolve handover latency and packet loss problems that occur in PMIPv6. FPMIPv6 operates in the predictive mode to support fast handover when the prediction succeeds and does in the reactive mode when the prediction is wrong. In order to support the fast handover, the MN operated in the predictive mode in FPMIPv6 performs scanning neighboring MAGs to find an appropriate nMAG. In reactive mode of FPMIPv6, when the nMAG receive the RS message from the MN, the nMAG and pMAG exchange the HI (Handover Initiation) and Hack (Handover Acknowledgement) messages to minimize the packet loss.

In the cellular network, the mobile node requests that its new foreign agent attempt to notify its previous Foreign Agent (FA) on its behalf by including a Previous Foreign Agent Notification (PFAN) extension in its Registration Request (RR) message sent to the new foreign agent. The new foreign agent then builds a Binding Update (BU) message and transmits it to the previous foreign agent of mobile node during registration, requesting an acknowledgement from the previous foreign agent. The notification will typically include the new care-of address of mobile node, allowing the previous foreign agent to create a binding cache entry for the mobile node to serve as a forwarding pointer [16] to its new location. To save these location registration signaling and paging costs, the lezi-update and User Mobility Pattern (UMP) schemes using previous movement path of MN have been proposed.

The UMP [17-18] scheme is introduced for location update and paging in mobile networks where mobile terminals (MTs) maintain their history data in a database called user mobility history (UMH). During a location update, a UMP is derived from UMH and registered to the network. Unless the MT detects that it has moved out of the registered UMP, it does not perform any other location update. However, cells are paged selectively according to the cell entry times in the registered UMP upon a call arrival for the MT.

In [19-20], they proposed a location management scheme based on Domain Name System (DNS) for PMIPv6. In their scheme, the DNS as a location manager provides PMIPv6 for global mobility. In [21] proposes a dynamic and integrated mechanism that assesses the interface used for each traffic flow and determines the need for flow transfer to offer the best Quality of Experience for the user while using cellular network resources in an optimal manner.

3 Proposed Scheme

In the history based predictive handover, the LMA sends the query of AAA message piggybacking the MAG-Identifier (MAG-ID) for authentiction of the MAG. The AAA server collects the path of an MN and predicts the nMAG by comparing the current location of the MN with the previous location based on the received query message of AAA. The AAA server sends the reply message to the destination including nMAG information. After that, LMA makes the tunnel through nMAG by using the nMAG-ID by exchanging the two additional messages (History Binding Update and History Binding Acknowledgement). In this section, we introduce the assumptions, detail scheme, flow of signaling, and the overhead of the proposed scheme. We developed initial version of Proxy Mobile IPv6 and its analytical model in 2013 [22]. This paper introduces the extended features of our previous work of PMIPv6 (see Figure 1).

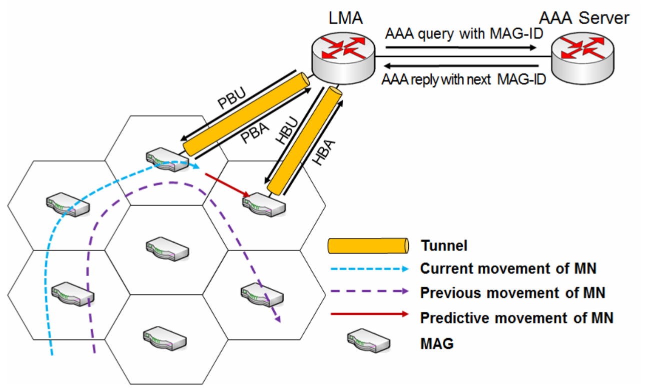


Figure 1. Overview of the proposed scheme

3.1 Motivation and Assumptions

As PMIPv6 does not resolve handover latency and packet loss problems, the schemes to solve these issues have been proposed as mentioned in Section 2. The FPMIPv6 and NPMIPv6 schemes support fast handover; the MN sends the nMAG information to the pMAG when the MN will roam. Therefore, the FPMIPv6 and NPMIPv6 schemes in which the MN participates in the handover signaling procedure are inconsistent with PMIPv6 and the role of the MN is aggravated by performing scanning of neighboring MAGs. In this paper, the mobility history based fast handover scheme in PMIPv6, called HP-PMIPv6 is proposed. HP-PMIPv6 prevents packet loss and supports fast handover by using the movement history in the AAA server. Furthermore, this process consistent with the PMIPv6 because the MN does not involve the procedure of handover signaling.

The main role of AAA server is allocating the storage space to keep the MAG-ID in HP-PMIPv6. The AAA server should predict the nMAG when the amount of history information is larger than a value of predefined threshold. The amount of history information consists of the amount of MAG-ID in the AAA server. All MAGs perform the buffering mechanism to prevent data packet loss. The LMA makes a decision of the packet path either to transmit to the pMAG or nMAG by extending the BCE message.

3.2 Basic Operation

HP-PMIPv6 operates in either a reactive or predictive mode. If the amount of history information of an MN is smaller than a predefined threshold, reactive mode operates. The predictive mode operates when the amount of history information is larger than a threshold value. In our experimental simulation, the threshold value is determined based on the basic settings of MAG hardware. More information is provided in Section 3.3.

If the MN is connecting to LMA, the MAG sends the Proxy Binding Update (PBU) message to the LMA. Upon receiving the PBU message, the LMA recognizes that the MN is connected to the MAG and sends the MAG-ID which is piggybacked on the AAA query message to the AAA server. The purpose of the AAA query message is tracking the MAG-ID. The LMA establishes the tunnel with the nMAG based on the nMAG-ID involved in the AAA reply message. The LMA sends the Home Binding Update (HBU) and Proxy Binding Acknowledge (PBA) messages to the nMAG and MAG, respectively. The HBU message consists of the MN-ID, link local address and HNP information. Upon receiving the HBU message, the nMAG makes the tunnel with the LMA by sending a Home Binding Acknowledgement (HBA) message.

When tunnel has been established, the LMA transmits packets to the MAG which the MN is connected until the RSS value of MN falls below the threshold. When the RSS value of the MN falls below the threshold, the MAG sends the DeReg-PBU message to the LMA. Then, the LMA transmits the packets to the nMAG by changing the flag value to 1 in the extended Binding Cache Entry (BCE) in Table 1. The nMAG keeps the packets in a buffer until the MN attaches to nMAG.

Table 1. Extended binding cache entry

ID	Prefix	Current MAG	Next MAG	Flag
MN1	2::/54	cMAG-ID	nMAG-ID	0
MN2	2::/54	cMAG-ID	nMAG-ID	1

The nMAG flushes the buffered packets to the MN when the MN is connected to it. It also performs the handover procedure with the LMA. As the result, HP-PMIPv6 reduces the handover latency because the MN receives all buffered packets before the handover signaling procedure.

3.3 The Signaling Procedure in HP-PMIPv6

HP-PMIPv6 operats in the predictive mode when the prediction succeeds while it does in the reactive mode when the prediction is wrong. The AAA server maintains the movement history of the MN in both predictive and reactive modes. Figure 2 shows the handover signaling procedure in the proposed reactive mode. The handover signaling messages exchanged is identical between the reactive mode in HP-PMIPv6 and PMIPv6. However, HP-PMIPv6 operating in the reactive mode sends the MAG-ID piggybacked on the AAA query message for collecting the movement history of the MN. Figure 3 shows the signling flow in predictive mode.

3.4 Costs and Expected Effects of HP-PMIPv6

Comparing to the standard PMIPv6, HP-PMIPv6 spends additional costs to support the fast handover and prevent packet loss first, the handover signaling cost is increased because the LMA exchanges the HBU and HBA messages to make the tunnel. Second, there is the cost of maintaining the movement history of MN and of predicting the nMAG. Third, the BCE is extended in the LMA. Fourth, all MAGs need space to keep the packets. Finally, the MAG-ID is included in the AAA query and AAA reply messages.

Even though HP-PMIPv6 requires additional costs, it has the advantages of reducing the handover latency and preventing packet loss by preparing the handover. Through those advantages, HP-PMIPv6 can support seamless service using a buffering mechanism and support the real time application programs by using fast handover.

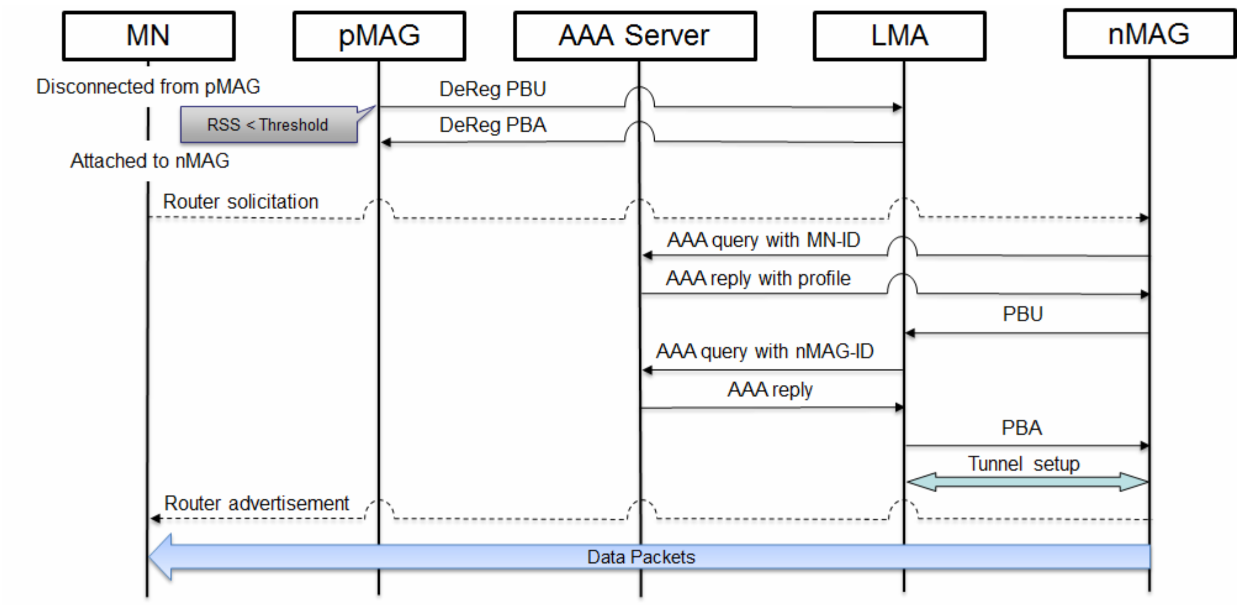


Figure 2. Signaling flow in reactive mode

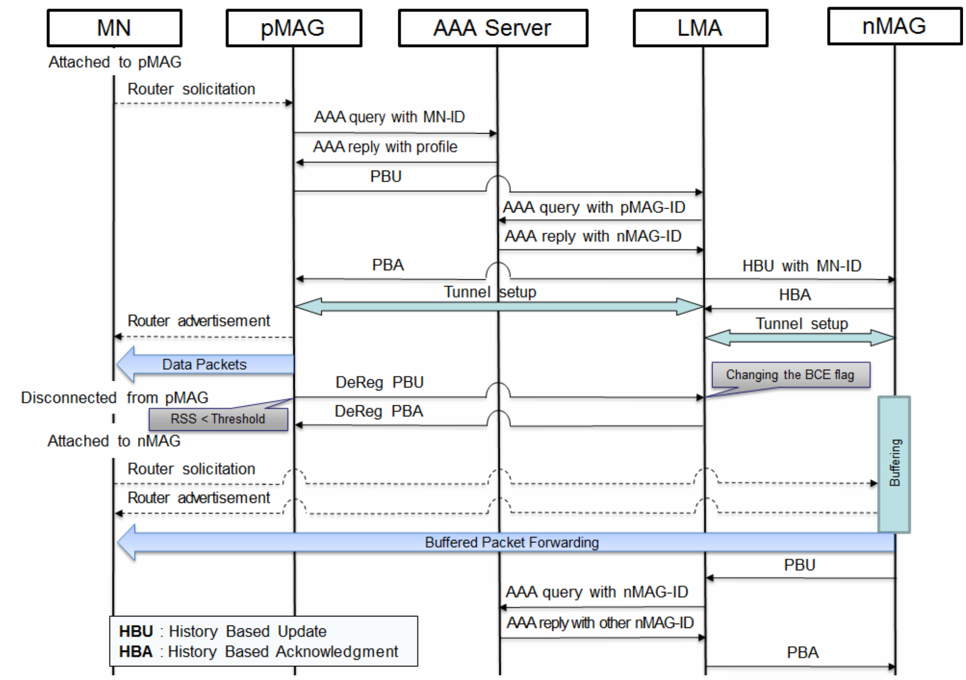


Figure 3. Signaling flow in predictive mode

4 Analytical Modeling

In this section, using mathematical analysis, the performance of HP-PMIPv6 is compared with PMIPv6. The comparison factors are handover latency, required buffer space, packet loss, and total signaling cost. Table 2 shows the parameters used for the analysis [23-27].

4.1 Handover Latency

In this paper, we define the handover latency as the time period during the MN is not able to receive a service. In other words, it is duration between the time point that the MN is no more receiving packets from the pMAG and the time point when the MN receives the first packet from the nMAG.

$$T_{Reactive} = T_{PMIPv6} = t_{L_2} + t_{WRS} + t_{RS} + t_{PBU} + 2t_{AAA\ query} + 2t_{AAA\ reply} + t_{PBA} + t_{RA} \quad \textbf{(1)}$$

Table 2. Parameters

Parameters	Symbols	Values	Parameters	Symbols	Values
The transmission time of HBU message	tHBU	0.06 sec	The number of hops between LMA and CN	dLMA,CN	10 hops
The transmission time of HBA message	tHBA	0.06 sec	The number of hops between LMA and MAG	dLMA,MAG	4 hops
The delay required for L2 up from L2 down	tL2	0.2 sec	The number of hops between MAG and MN	dMAG,MN	1 hop
The delay before sending RS message	tWRS	0.2 sec	The number of hops between LMA and AAA	dLMA-AAA	1 hop
The transmission time of RS message	tRS	0.015 sec	Regularity	ψ	72%
The transmission time of RS message	tPBU	0.06 sec	The average session arrival rate per sec at MN	λ_S	0.7
The transmission time of PBU message	tPBU	0.06 sec	The average length of packets	E(S)	20 bytes
The transmission time of RA message	tRA	0.015 sec	The weighting factors of tunneling effect	α	0.2
The transmission time of AAA query message	tAAA query	0.01 sec	The weighting factor of dropping effect	β	0.8
The transmission time of AAA reply message	tAAA reply	0.01 sec	The unit transmission cost of wired link	κ	10
The number of hops between MAG and AAA	dMAG-AAA	1 hop	The weighting factor for wireless link	T	1

Figure 4 is a timing diagram to show the handover start time and end time in the PMIPv6 and in the HP-PMIPv6 reactive mode. It shows that the handover signaling procedure is divided into time and each message intervals. In PMIPv6 and the HP-PMIPv6 reactive mode, the triggering point of handover latency is that receiving the DeReg-PBU message from the pMAG. The finishing point of handover latency is the time that the MN receives the RA message after connecting to the nMAG. In PMIPv6 and the proposed reactive mode, the handover signaling is identical except the AAA query message added to the MAG-ID. That is the reason of the handover latency is identical. The handover latency is calculated by sum of the transmission delay of each message. The handover latency of the PMIPv6 and the proposed reactive mode is expressed in equation (1).

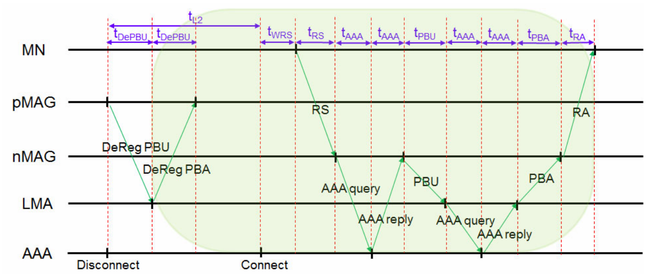


Figure 4. Timing diagram of PMIPv6 and reactive mode

Figure 5 is a timing diagram of the HP-PMIPv6 predictive mode showing the handover start time and end time. The predictive mode exchanges the HBU and the HBA messages between the LMA and nMAG. Also, the authentication is not necessary by sending the HBU message with MN-ID. Before exchanging the PBU and PBA messages between the LMA and the MAG, the nMAG perform the buffering. If the MN sends the RS message to the nMAG, the nMAG flushs all the buffered packets with the RA message. We do not counted the time required for authentication of the MN and transmission time of the PBU and PBA messages. The handover latency of the HP-PMIPv6 predictive mode is expressed by:

$$T_{Predictive} = t_{L_2} + t_{WRS} + t_{RS} + t_{RA} \quad \textbf{(2)}$$

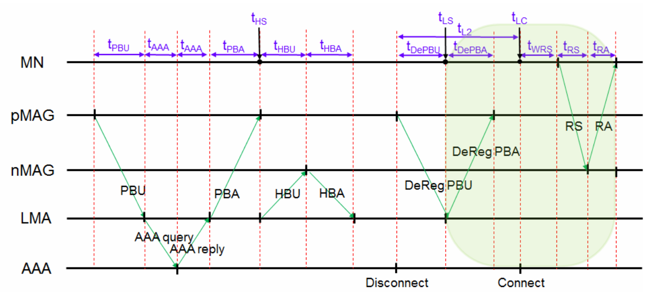


Figure 5. Timing diagram of predictive mode

HP-PMIPv6 predicts the nMAG using the mobility history of the MN. However, HP-PMIPv6 also operates in a reactive mode when the MN moves to aother MAG. Thus, we are considering the success and failure probability in HP-PMIPv6. HP-PMIPv6 also definesthe regularity used in the UMP scheme in Section 2 to calculate the handover latency. The handover latency of HP-PMIPv6 (equation 3.) and the required buffer space of the proposed predictive mode (equation 4.) can be expressed as follows.

$$T_{Preposed\ scheme} = \psi \cdot T_{Predictive} + (1-\psi) \cdot T_{Reactive} \quad (3)$$

$$BS_{Predictive} = \lambda_S \cdot E(S) \cdot T_{Predictive} \quad (4)$$

4.2 Packet Loss

Packet loss is defined as the number of packets lost during the handover. In HP-PMIPv6, the reactive mode does not prevent packet loss while the predictive mode does unless the buffer space in the nMAG is enough to handle incoming packets. Thus, we need to present the Formula for both of the cases where packet loss occurs and where packet loss does not occur.

In Figure 2, packets are lost during the time from when the LMA receives the DeReg-PBU message to when the MN receives the RA message from the nMAG. Operating in the reactive mode, HP-PMIPv6 cannot prevent packet loss during handover because it does not use buffering. The packet loss in the reactive mode is presented in Formula 5, which is equal to that of PMIPv6.

$$P_{Reactive} = \lambda_S \cdot E(S) \cdot T_{Reactive} \quad (5)$$

Operating in the predictive mode, no packet is lost in HP-PMIPv6 unless the incoming packets exceeds the buffer size in the nMAG. The packet loss of the predictive mode is described as follows in Formula 6.

$$P_{Predictive} = \max(BS_{Predictive} - B, 0) \quad (6)$$

B is defined as the buffer size in the MAG and $BS_{Predictive}$ is the required buffer space. If the B is larger than $BS_{Predictive}$, packet loss will not occur. If the $BS_{Predictive}$ is larger than B, then packet loss occurs. Thus, the packet loss of HP-PMIPv6 is

$$P_{Proposed\ scheme} = \psi \cdot P_{Predictive} + (1-\psi) \cdot P_{Reactive} \quad (7)$$

4.3 Total Signaling Cost

The total signaling cost C_T is the sum of the binding update cost and packet delivery cost during the handover time. The total signaling cost is described as follows:

$$C_T = C_{BU} + C_{PD} \quad (8)$$

C_{BU} is the binding update cost which is the control signaling message for the handover and C_{PD} means the packet de-livery cost during the time of handover.

4.3.1 Binding Update Signaling Cost

The transmission cost of control packets between X and Y in the wire link is $C_{X,Y} = \tau \cdot d_{X,Y}$. Also, the transmission cost of control packets is $C_{X,Y} = \kappa \cdot \tau \cdot d_{X,Y}$ between X and Y in the wireless link. The τ is the unit of transmission cost over a wired link and κ is a weighting factor for the wireless link. The binding update signaling cost of PMIPv6 and the reactive mode in HP-PMIPv6 is

$$C_{BU}^{Reactive} = C_{BU}^{PMIPv6} = 4C_{MAG,LMA} + 4C_{LMA,AAA} + 2C_{MAG,MN} \quad (9)$$

The predictive mode requires $2C_{MAG,LMA}$ because the tunnel is established using the HBU and HBA messages. However, since the MN-ID that has been authenticated is piggybacked on the HBU message, $2C_{LMA,AAA}$ is not therefore required. The binding update signaling cost is given by

$$C_{BU}^{Predictive} = 6C_{MAG,LMA} + 2C_{LMA,AAA} + 2C_{MAG,MN} \quad (10)$$

The binding update signaling cost in HP-PMIPv6 considered both in reactive mode and predictive mode is as follows.

$$C_{BU}^{Proposed\ scheme} = \psi \cdot C_{BU}^{Prsdictive} + (1-\psi) \cdot C_{BU}^{Reactive} \quad (11)$$

4.3.2 Packet Delivery Cost

The cost of packet delivery is defined as the linear combination of the packet tunneling cost and packet loss cost. The packet deliver cost is

$$C_{PD} = \alpha \cdot C_{tun} + \beta \cdot C_{loss} \quad (12)$$

α is the weighting factor of the tunneling effect and β is the weighting factor of the dropping effect. And $\alpha + \beta = 1$. C_{tun} is the packet tunneling cost and C_{loss} is the packet loss cost.

The packet tunneling cost means the cost that the packets are transferred through the tunnel during the handover. The predictive mode makes the tunnel to prevent packet loss by exchanging the HBU and HBA messages. Thus, the packet tunneling cost of the predictive mode is

$$C_{tun}^{Predictive} = \lambda_S \cdot E(S) \cdot C_{CM}^{t} \cdot T_{Predictive} \quad (13)$$

S_c and S_d are the average size of control packets and data packet, respectively $\eta = S_d / S_c$. $C_{CM}^{t} = \eta \cdot (C_{CN,LMA} + C_{LMA,MAG} + C_{MAG,MN})$ is the cost of transferring data packets from the CN (Correspondent Node) to the MN. The PMIPv6 and proposed reactive mode do not make the tunneling so there is no forwarding of packets during the handover. Thus, $C_{tun}^{Reactive} = C_{tun}^{PMIPv6} = 0$. The predictive mode prevents packet loss by buffering packets in the handover procedure. However, if the value of t_{LS} -t_{HS} is higher than the time for HBU and HBA messages, since the MN moves fast, packet loss occurs without a tunnel. $C_{CM}^{f} = \eta \cdot (C_{CN,LMA} + C_{LMA,MAG} + C_{MAG,MN})$ is the cost of transferring data packets from CN to MN. The packet loss cost of the proposed predictive mode is given by

$$C_{loss}^{Predictive} = \lambda_S \cdot E(S) \cdot C_{CM}^{f} \cdot \max((t_{HBU} + t_{HBA}) - (t_{LS} + t_{HS}), 0) \quad (14)$$

The reactive mode does not use buffering, so packet loss occurs. The handover latency of PMIPv6 and the HP-PMIPv6 reactive mode are identical. Thus, the packet loss cost is also identical. The packet loss cost of the reactive mode in HP-PMIPv6 is given by

$$C_{loss}^{Predictive} = \lambda_S \cdot E(S) \cdot C_{CM}^{f} \cdot T_{Reactive} \quad \textbf{(15)}$$

When the MN moves to another MAG rather than the predicted nMAG, HP-PMIPv6 performs in reactive mode and packet loss occurs. On the other hand, if the MN moves to the nMAG, the proposed scheme performs in predictive mode and there is no packet loss unless the buffer is overflowed. Then, the packet loss cost in HP-PMIPv6 is

$$C_{loss}^{Proposed\ scheme} = \psi \cdot C_{loss}^{Predictive} + (1-\psi) \cdot C_{loss}^{Reactive} \quad \textbf{(16)}$$

5 Numerical and Simulation Results

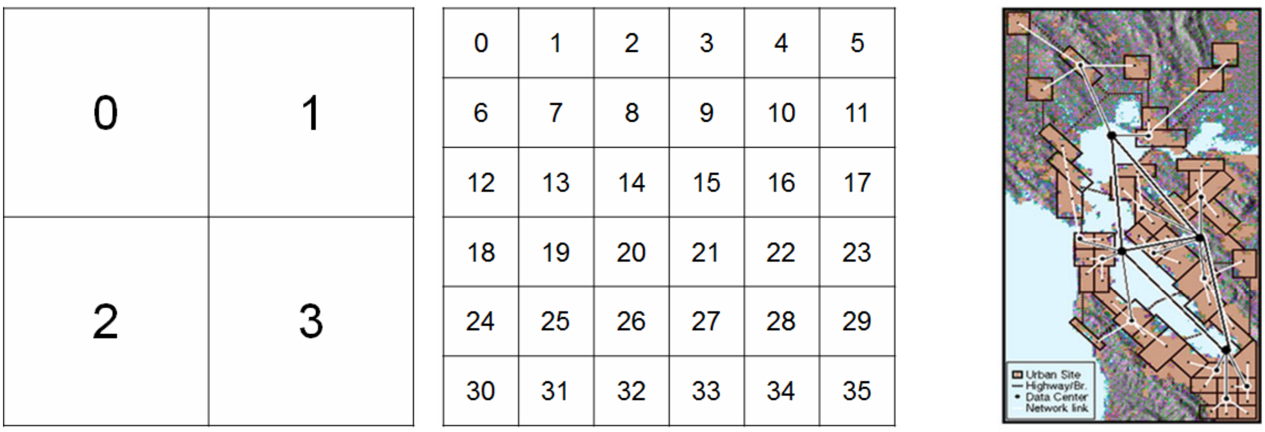
In this section, we show the superiority of our proposed scheme to the PMIPv6 using mathematical analysis. Also, we present the performance of the proposed scheme in the real-world environment through simulation of the mobility dataset. First, we explain the simulation environments and mobility dataset and show the handover latency, packet loss, and the total signaling costs using mathematical analysis and simulation based on the mathematical analysis and simulation of the mobility dataset.

5.1 Simulation Environment

We conduct the simulation using Java for the total signaling cost, handover latency, and packet loss in PMIPv6 and HP-PMIPv6. The MN, AAA, MAG and LMA are independent objects. They create messages and send them in accordance with the signaling procedure. Table 2 shows the size and transmission delay of each message. We assume that the MN is always connected to one MAG. The AAA server and the LMA are connected through wired link. Also many MAGs are connected with the LMA and AAA server through wired link. There are 6 neighboring MAGs around a MAG.

5.2 Sumatra

Stanford University released the Stanford University Mobile Activity Traces (SUMATRA) [28], which is a dataset for the study on user mobility and data traffic. SUMATRA consists of SULAWESI-1, SULAWESI-2, BALI-1, and BALI-2. The topology of SULAWESI-1 is shown in Figure 6 (a). The dataset consists of 4 areas and 25 people's mobility and calls for 30 minutes. The topology of SULAWESI-1 is shown in Figure 6 (b). The dataset consists of 36 areas and 50,000 people's mobility and calls for 4 hours. The topology of BALI-1 and BALI-2 are shown in Figure 6 (c). The BALI-1 dataset consists of 90 areas and 33,600 people's mobility and calls for 1 hour and the BALI-2 dataset consists of 90 areas and 1,100 people's mobility and calls for 24 hours.



(a) (b) (c)

Figure 6. Sumatra zone layout

In HP-PMIPv6, the nMAG is chosen according to the movement history of the MN stored in the AAA server. We use the SUMATRA dataset to determine the movement history of the MN in the real environment. We calculate the movement probability from one area to other area by analyzing the SUMATRA mobility dataset. For example, the movement probability is 0.75 from area 0 to area 1 and is 0.25 from area 0 to area 2. Table 3 shows the movement probability of SULAWESI-1. In SULAWESI-2, the movement probability is almost identical from one area to another area. In BALI-1 and BALI-2, the movement probability from one area to another is a diverse pattern. Considering the movement probability from one area to another area, simulations are performed using SUMATRA. For example, when the MN assumes that the MN moves from area 0 to other areas in the SULAWESI-1, at this time we generate a random number between 1 and 100. If the random number is under 75, we assume that the MN moves to area 1. In the other case, the MN moves to area 2.

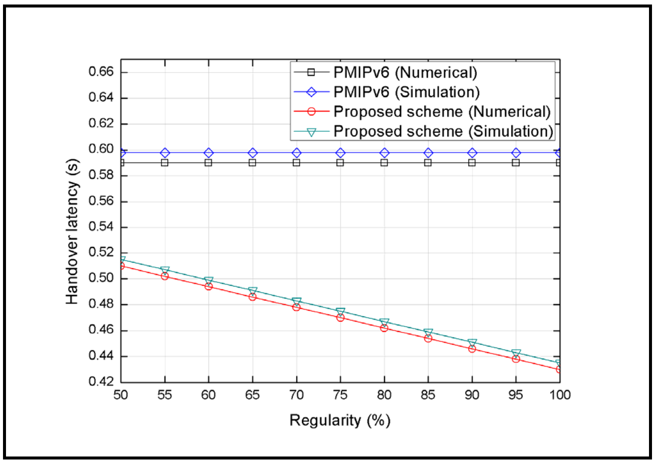
Table 3. SULAWESI-1 movement probability

Transition	Probability
0 → 1	0.75
0 → 2	0.25
1 → 0	0.63
1 → 2	0.34
2 → 0	0.34
2 → 3	0.63
3 → 1	0.50
3 → 2	0.50

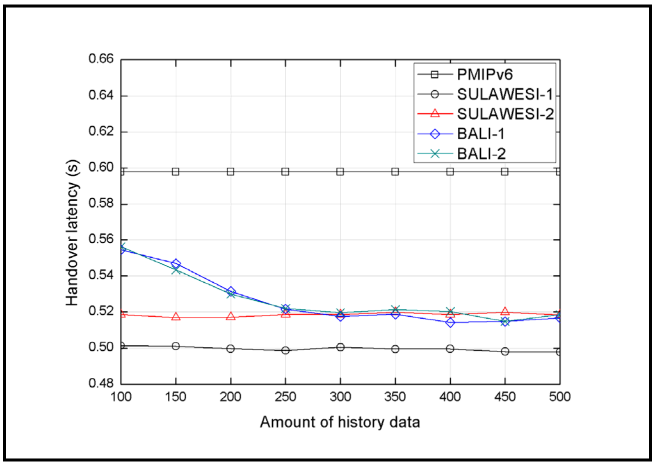
5.3 Results

In this section, we show results of the handover latency using the SUMATRA and regularity. Figure 7 represents the performance evaluation of mathematical analysis using regularity and of simulation results using SUMATRA. Figure 7 (a) is the handover latency depending on the regularity. The results show that the handover latency of the PMIPv6 is much higher than that of HP-PMIPv6. The reason is that if people have regularity, the operation probability of the predictive mode is increased in the proposed scheme. Figure 7 (b) shows the handover latency using SUMATRA and it conducts an experiment based on the amount of history information in the AAA server. The BALI-1 and BALI-2 of handover latency are stable, if the amount of history information is more than 300. These datasets have a topology consisting of 90 areas and consist of diverse patterns from one area to another area. Therefore, the amount of history information would be over a certain amount. On the other hand, handover latencies of SULAWESI-1 and SULAWESI-2 are consistent even with a small amount of history information because the topology is not big. As we can see from Table 3, all the probabilities that the MN moves from an area to another are different, except the case when MN moves from area 3 to area 1 or area 2 in SULAWESI-1. However, the averages of the handover latencies of the MN are different because the probabilities that the MN moves from an area to another are almost identical.

The experiments for the packet loss are separated into two cases based on regularity and SUMATRA dataset. Figure 8 represents the packet loss. First, Figure 8 (a) shows the result based on the the average packet length. The packet loss in HP-PMIPv6 is less than that in PMIPv6 because the predictive mode prevents packet loss using the buffering mechanism during handover. And since the regularity is 0.72, the probability of operation in the predictive mode is also 0.72. Figure 8 (b) shows the packet loss result based on regularity. When the regularity is 100%, packet loss



(a) Handover latency with regularity

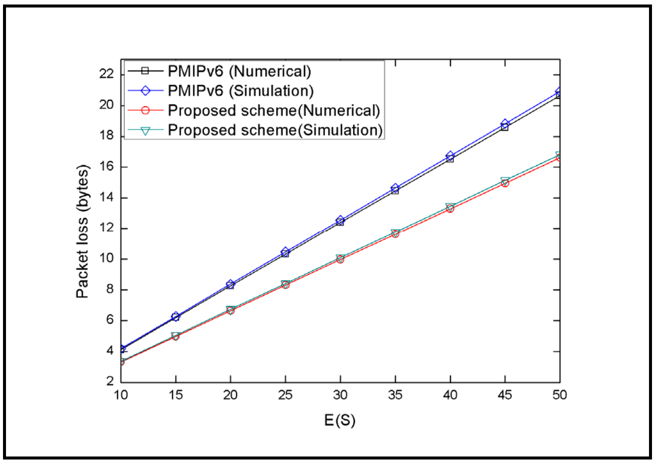


(b) Handover latency with SUMATRA

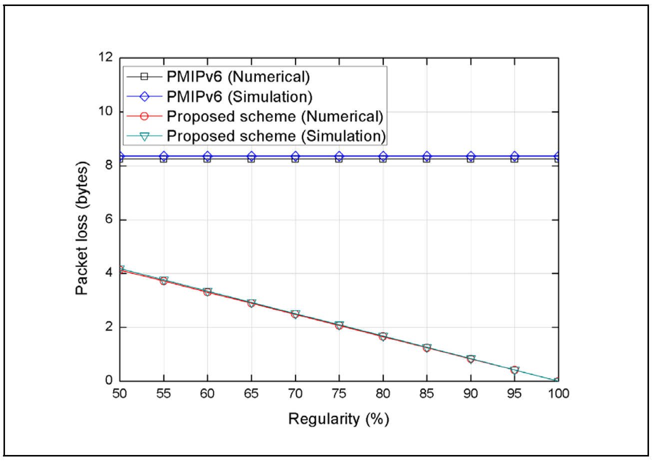
Figure 7.

does not occur by using the buffering mechanism in the proposed scheme. However, in PMIPv6, packet loss does occur during the handover. Figure 8 (c) is the result when the amount of history information is 300 in SUMATRA. The packet loss is incurred lowest in SULAWESI-2. The packet losses of SULAWESI-1, BALI-1, and BALI-2 are almost identical. The reason for this is that the handover latency is almost identical in those datasets, when the amount of history information is 300.

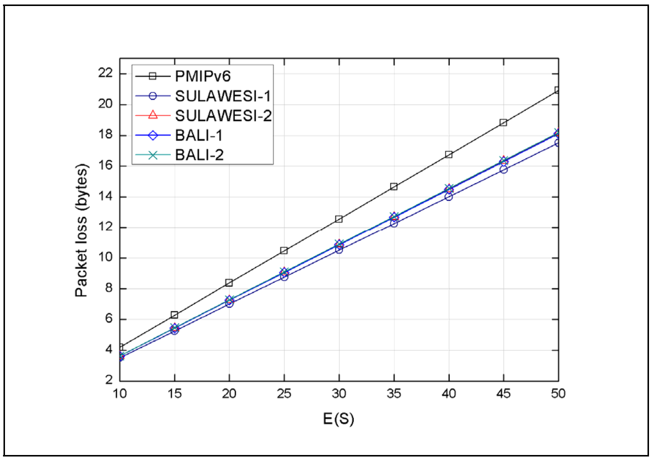
Figure 9 shows the handover signaling costs of the PMIPv6 and proposed scheme. The total signaling cost is calculated as the sum of transmission delays for each message. The binding update cost of the proposed scheme is higher than that of PMIPv6, as the predictive mode of the proposed scheme makes a tunnel by exchanging the HBU and HBA messages between the LMA and nMAG. However, the packet delivery cost of the proposed scheme is lower than PMIPv6, as the predictive mode of the proposed scheme prevents packet loss using the buffering mechanism. Consequently, the results show that the signaling cost of the PMIPv6 are higher than that of HP-PMIPv6.



(a) Handover latency with session rate



(b) Packet loss with regularity



(c) Packet loss with SUMATRA

Figure 8.

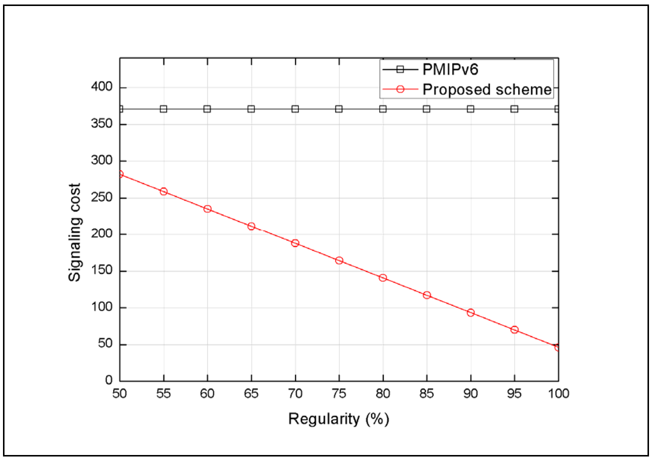
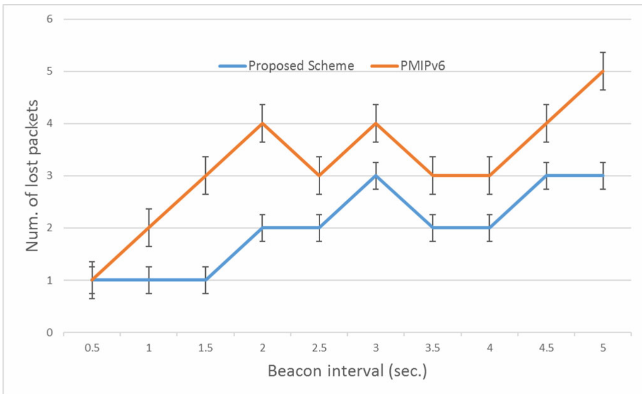
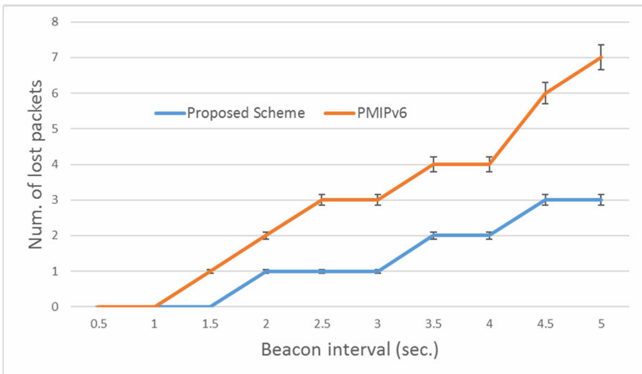


Figure 9. Total signaling cost based on regularity

In order to verify the efficiency of the proposed scheme, we simulated false rate under the two mobility models such as random way-point and smooth way-point model. In random way-point model (see Figure 10(a)), two algorithms show the similar packet loss rate. The average error rate resulted around 2. However, in Figure 10(b), proposed algorithm shows lower packet loss rate under the smooth way-point model.



(a) False rate under random way-point model



(b) False rate under smooth way-point model

Figure 10.

The results of the numerical analysis, simulation, and SUMATRA simulation show that our proposed scheme is superior to the PMIPv6 in terms of performance. In particular, the proposed scheme prepares the handover by predicting the nMAG using the movement history of the MN to prevent packet loss and to reduce the handover latency. It also reduces the total signaling cost by preventing packet loss.

6 Conclusions

Studies on human mobility patterns found out that people have a limited mobility pattern what is reproducible in a daily life. Based on the fact, the schemes are proposed to find the location of an MN in the cellular network. In this study, we apply the regularity in human mobility to PMIPv6 and propose a fast handover without aggravating the role of the MN.

The PMIPv6 has problems with handover latency and packet loss during the handover [29]. To solve those problems, the NPMIPv6 and FPMIPv6 are proposed. However, those schemes support fast handover by allowing the MN to participate in the handover signaling procedure by sending the information of the nMAG. This supports fast handover by the participation of the MN in the handover signaling; however it has problems compared with PMIPv6 such as signaling overhead in the wireless link and energy consumption. In addition, the role of the MN is aggravated by performing the scanning procedure.

To confirm the performance, we compare with the PMIPv6 and proposed scheme through mathematical modeling, simulation using mathematical analysis and simulation using real world datasets, SUMATRA. The proposed scheme shows improvements in handover latency, packet loss, and total signaling cost using the buffering mechanism as well as fast handover. It reduces the MN load by using the movement history and provides reliable services by reducing the handover latency. For the next work, we will test our scheme more complex real test-bed environments.

Acknowledgements

This work was supported by the G-ITRC Program under Grant IITP-2015R6812-15-0001, the NRF Research Fellow program under Grant NRF-2016R1A6A3A11934080, and the NRF Korea under Grant 2010-0020210.

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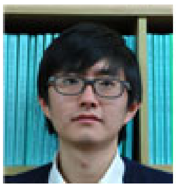

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