

Analysis of Vertical Handover Latency for IEEE 802.21-enabled Proxy Mobile IPv6

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Abstract— Low handover latency and IP session continuity are envisioned to be important factors for realizing next-generation all-IP heterogeneous wireless networks. To meet these constraints of the next generation networks, Proxy Mobile IPv6 (PMIPv6) has been considered as one of the IP mobility management protocols in recent years. Much research about the performance analysis of PMIPv6 has been done. However, a PMIPv6-based vertical handover and its performance analysis for heterogeneous wireless networks have not been considered yet. In this paper, we present a performance analysis of vertical handover latency for IEEE 802.21-enabled PMIPv6. Results of the performance evaluation show that the handover latency of PMIPv6 can be reduced with the IEEE 802.21.

Keywords— IEEE 802.21; proxy mobile IPv6; vertical handover; heterogeneous wireless networks; handover latency

I. INTRODUCTION

As the number of mobile devices is growing rapidly and demands for supporting real-time applications of mobile nodes (MNs) in broadband wireless access systems are increasing more and more, low handover latency and IP session continuity have become more crucial in mobile environments [1]. Moreover, industries also want to reduce signaling costs in wireless links for efficient use of wireless resources.

To support these requirements, Proxy Mobile IPv6 (PMIPv6) has been developed by IETF network-based localized mobility management (NETLMM) working group. PMIPv6 provides network-based IP mobility management support to an MN without the participation of MN in any IP mobility-related signaling in wireless links [2]. As opposed to host-based mobility management protocols such as Mobile IPv6 (MIPv6) [3], hierarchical MIPv6 (HMIPv6) [4], and MIPv6 fast handovers (FMIPv6) [5], PMIPv6 does not need any mobility support on MNs. Results in [6] and [7] show that handover latency of PMIPv6 is much smaller than that of other mobility management protocols.

All MNs of the next-generation wireless networks are assumed to support multi-interface [8]. However, a few problems for PMIPv6 should be addressed to support MNs with multi-interfaces [9]. One of the problems, which will be covered in this paper, is vertical handover [10]. The vertical handover with PMIPv6 should be considered for the nodes to switch from one access network to another successfully.

As one of the solutions to support the vertical handover with PMIPv6, IEEE 802.21 has emerged recently. IEEE 802.21 specifies media access-independent mechanisms that optimize handovers between heterogeneous wireless communication systems [11]. Thus, it is possible for MNs to perform seamless handover by using the IEEE 802.21 where the network environment supports it.

In this paper, we present a performance analysis of vertical handover latency for IEEE 802.21-enabled PMIPv6. The remainder of this paper is organized as follows. Background and previous works about PMIPv6 and IEEE 802.21 are described in Section II. After we analyze the vertical handover latency of IEEE 802.21-enabled PMIPv6 in Section III, the results of a performance evaluation are shown in Section IV. Conclusions with further works are made in Section V.

II. BACKGROUND AND PREVIOUS WORKS

A. PMIPv6

PMIPv6 has been introduced to solve well-known problems in using a global mobility management protocol, such as update latency, signaling overhead, and location privacy [12]. In PMIPv6 domain where the mobility of an MN is managed, a mobile access gateway (MAG), which is an MN's first-hop access router that handles the mobility-related signaling for MN [1], participates in the signaling instead of MNs. Therefore, MNs require no specialized mobility management software [13].

The PMIPv6 signaling procedures are as follows. After completing link layer handover, the newly attached MAG (n-MAG) updates the local mobility anchor (LMA), which is a home agent for an MN in a PMIPv6 domain [1], about the current location of MN by sending a proxy binding update (PBU) message. LMA then sends a proxy binding acknowledgment (PBA) message, creates the binding cache entry, and sets up its endpoint of the bidirectional tunnel to MAG. On receiving the PBA message, MAG sends a route advertisement (RA) message and the process ends with a successful address configuration of MN.

A number of works have been done to analyze the handover performance of PMIPv6 with other IPv6 mobility management protocols, such as MIPv6, HMIPv6, and FMIPv6 [6], [7], [14]–[16]. However, all these works assume that every MN has only one interface so the vertical handover for MNs with multiple interfaces have not been considered.

B. IEEE 802.21

Recently, as demands for handover solutions that can seamlessly and securely maintain ongoing user sessions in wireless heterogeneous networks have been increased, standard activities to support seamless handovers between heterogeneous access networks are being established [17]. The IEEE 802.21 working group has developed standards to enable media independent handover (MIH) in heterogeneous networks and published the standard in January 2009. IEEE 802.21 provides a framework that enables service continuity while an MN moves between heterogeneous wireless access technologies [11]. The framework consists of the following elements:

- MIH function (MIHF): MIHF facilitates handovers between different access links [11]. MIHF provides three types of services, the media independent event service (MIES), the media independent command service (MICS), and the media independent information service (MIIS) [17].
- MIH service access points (MIH_SAPs): MIH_SAPs provide MIH users with access to the services of MIHF [11].
- MIH users: MIH users can make a handover decision by using the services provided by MIHF [11]. PMIPv6 can be one of the candidates for MIH users.

C. Previous Works related to PMIPv6, IEEE 802.21, and vertical handover

To enhance the performance of the PMIPv6 protocol, such as handover latency and packet loss rate, researchers have suggested PMIPv6-based mobility management schemes supported by IEEE 802.21 and analyzed their performances [18]-[20]. Magagula [18], [19] and Kim [20] showed that IEEE 802.21-enabled PMIPv6 reduces the handover latency. However, none of these papers considered vertical handover.

Le [21] investigated the handover latency occurred during vertical handover in PMIPv6. Because the current PMIPv6 protocol does not specify the operations for vertical handover of an MN with multiple interfaces, they proposed a preliminary binding solution to eliminate delay and packet loss during vertical handover. The effectiveness of the proposed solution was demonstrated by an experimental performance evaluation but there was no numerical analysis in the paper.

III. ANALYSIS OF VERTICAL HANDOVER LATENCY

In this section, we analyze the vertical handover latencies of PMIPv6, Proxy-based FMIPv6 (PFMIPv6) [14], and IEEE 802.21-enabled PMIPv6. Because we only focus on network-based mobility management protocols that can solve the deployment issues, the vertical handover latency analysis of MIPv6, HMIPv6, FMIPv6, and their IEEE 802.21-supported protocols has not been done in this paper. These host-based protocols change IP stacks of MNs so that they cannot be widely deployed. The previous work [6] also shows that PMIPv6 outperforms host-based mobility management protocols in view of handover latency. We first show a

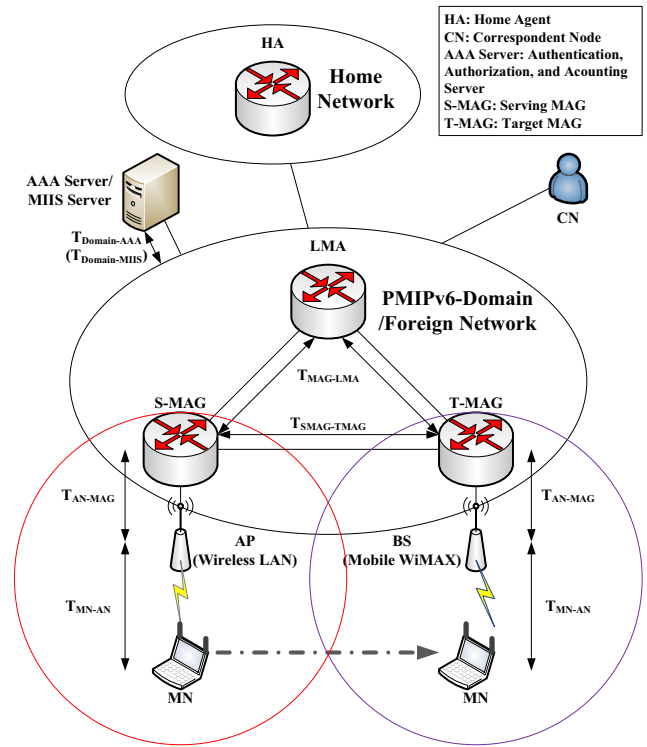


Figure 1. Network Model

TABLE 1. NOTATIONS FOR DELAYS BETWEEN ENTITIES

Notation	Meaning
T_{MN-AN}	Delay between MN and AP/BS
T_{AN-MAG}	Delay between AP/BS and MAG
$T_{MAG-LMA}$	Delay between MAG and LMA
$T_{S-MAG-T-MAG}$	Delay between S-MAG and T-MAG
$T_{Domain-AAA}$ ($T_{Domain-MIIS}$)	Delay between entities in PMIPv6-Domain and AAA/MIIS Server
T_{L2}	Delay from when MN is detached from WLAN to when MN is attached to Mobile WiMAX.

network model and assumptions. Based on the network model and the assumptions, the vertical handover latencies of the protocols mentioned above are analyzed.

A. Network Model

Fig. 1 shows a network model considered in this paper. MN is equipped with two network interface cards (NICs): IEEE 802.11-based wireless LAN (WLAN) and Mobile WiMAX. MN connected to WLAN moves towards the Mobile WiMAX network. Because MN has ongoing traffic sessions, seamless vertical handover should be supported for session continuity. The delays between each entity are summarized in table I.

B. Assumptions

Before starting to analyze the vertical handover latency, some assumptions should be given in this paper [6].

- We do not consider an initial MN attachment phase.
- Only the power of the NIC connected to the current network is turned on. The other NIC is turned off to reduce power consumption.
- Both WLAN and Mobile WiMAX networks are assumed to be in the PMIPv6 domain.
- The processing and queuing delays are considered to be negligible.
- When vertical handover occurred, the NIC for the target network get the same IP address to allow session continuity.
- MIIS and AAA servers are co-located.

C. Performance Analysis

Vertical handover latency can be defined as the disrupted time interval from when MN detaches from the serving network to when the first data packet is communicated between MN and CN [22]. Before comparing the vertical handover latency of PMIPv6 with the vertical handover latency of PFMIPv6 and IEEE 802.21-enabled PMIPv6, we define three notations, D_{PMIPv6} , $D_{PFMIPv6}$, and $D_{802.21}$. The meanings of the notations are presented in table II.

1) PMIPv6: Fig. 2 shows PMIPv6 handover procedures between WLAN and Mobile WiMAX [2]. We assume that MN tries to attach to Mobile WiMAX right after MN is detached from WLAN and S-MAG simultaneously sends PBU with the lifetime value of zero to LMA. The vertical handover latency of PMIPv6, D_{PMIPv6} , is caused by four factors: the layer 2 attachment process, the AAA process for MN at T-MAG and LMA, the binding process, and the RA process. By using the notations described in table I and II, D_{PMIPv6} can be expressed as

$$D_{PMIPv6} = 2T_{MAG-LMA} + T_{L2} + 4T_{DOMAIN-AAA} + T_{MN-AN} + T_{AN-MAG}. \quad (1)$$

2) PFMIPv6: Predictive PFMIPv6 handover procedures are presented in Fig. 3. We do not show reactive PFMIPv6 handover procedures in this paper because the performance of predictive handover is always better than the performance of reactive one. To reduce the handover latency, PFMIPv6 utilizes the bi-directional tunnel between S-MAG and T-MAG [14]. This tunnel is used for sending and receiving handover initiate (HI) and handover acknowledge (HACK) messages. In fact, to realize the bi-directional tunnel, information transfer between MAGs in different wireless networks should be guaranteed. So we assume that the information transfer is possible between MAGs in different networks for the performance analysis of vertical handover latency. Comparing with PMIPv6, the delay factor caused by the AAA process at T-MAG is not applied to the calculation of $D_{PFMIPv6}$ because T-MAG can authenticate and authorize MN before the detachment from WLAN. $D_{PFMIPv6}$ can be expressed as

$$D_{PFMIPv6} = 2T_{MAG-LMA} + T_{L2} + 2T_{DOMAIN-AAA} + T_{MN-AN} + T_{AN-MAG}. \quad (2)$$

TABLE 2. NOTATIONS FOR HANDOVER LATENCY

Notation	Meaning
D_{PMIPv6}	The total vertical handover latency of PMIPv6 between WLAN and Mobile WiMAX.
$D_{PFMIPv6}$	The total vertical handover latency of PFMIPv6 between WLAN and Mobile WiMAX.
$D_{802.21}$	The total vertical handover latency of IEEE 802.21-enabled PMIPv6 between WLAN and Mobile WiMAX.

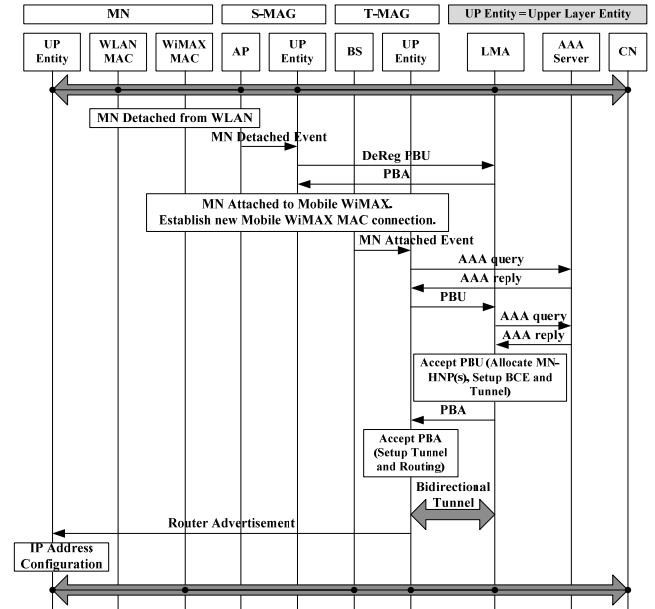


Figure 2. PMIPv6 handover procedures between WLAN and Mobile WiMAX

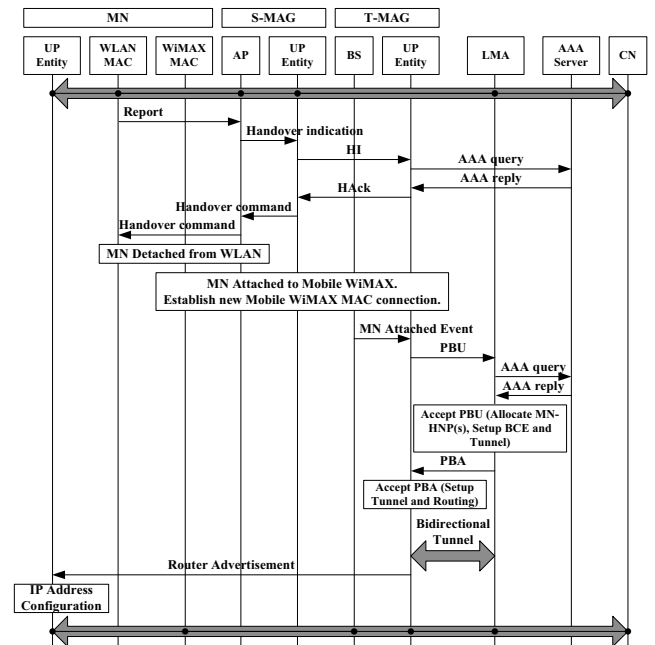


Figure 3. PFMIPv6 handover procedures between WLAN and Mobile WiMAX

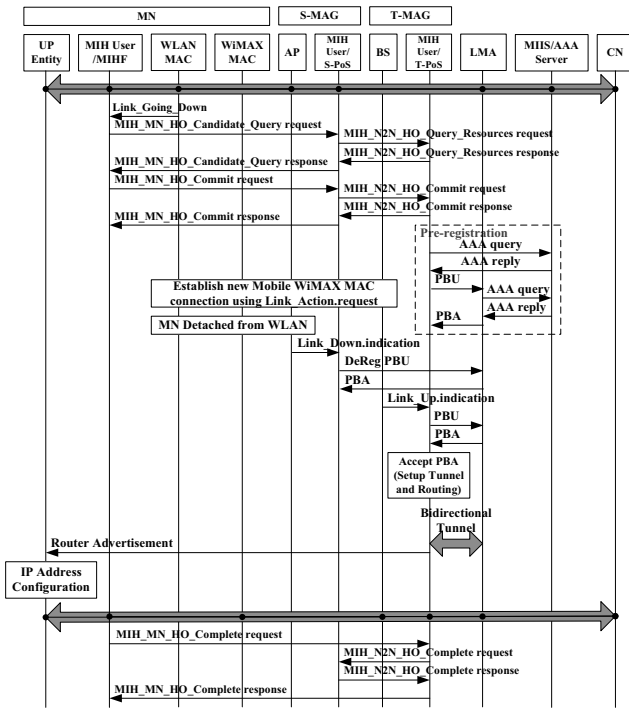


Figure 6. IEEE 802.21-enabled PMIPv6 handover procedures between WLAN and Mobile WiMAX

3) **IEEE 802.21-enabled PMIPv6:** Fig. 4 shows IEEE 802.21-enabled PMIPv6 handover procedures between WLAN and Mobile WiMAX [2], [11]. Instead of using bi-directional tunneling between MAGs described in PFMIPv6, the IEEE 802.21 framework is used to reduce a handover disruption time. When MN receives a Link_Going_Down trigger event, MN queries target networks and notifies S-MAG of the decided T-MAG information. S-MAG then reserves the resource at T-MAG and T-MAG can start to perform the AAA process and the layer 2 attachment process prior to the detachment event of MN in WLAN. As shown in Fig. 4, the handover latency is more reduced when compared with PMIPv6 and PFMIPv6 because the layer 2 attachment process and the AAA process at T-MAG and LMA occurred before MN is detached from WLAN. $D_{802.21}$ can be expressed as

$$D_{802.21} = 2T_{\text{MAG-LMA}} + T_{\text{MN-AN}} + T_{\text{AN-MAG}}. \quad (3)$$

IV. PERFORMANCE EVALUATION

Based on the analysis in Section III, we evaluate the performance of PMIPv6, PFMIPv6, and IEEE 802.21-enabled PMIPv6 in view of handover latency. To evaluate the vertical handover latency, the delay cost of each link is decided based on the previous work [6]. Table III shows the delay costs of links in Fig 1.

Fig. 5 shows the impact of the delay between MN and AP/BS on the handover latency. As the delay between MN and the access networks is increased, we can observe that the

TABLE 3. DELAY COSTS OF LINKS

Parameter	Value	Parameter	Value
$T_{\text{MN-AN}}$	10 ms or variable	$T_{\text{Domain-AAA}}$ ($T_{\text{Domain-MHS}}$)	20 ms
$T_{\text{AN-MAG}}$	2 ms	T_{L2}	100 ms or variable
$T_{\text{MAG-LMA}}$	20 ms		

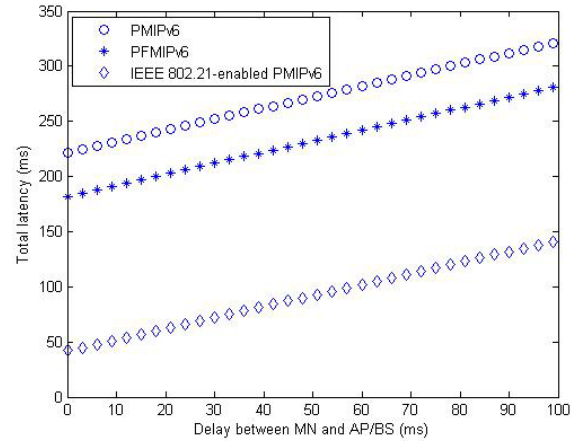


Figure 4. Total latency of PMIP, PFMIPv6, and IEEE 802.21-enabled PMIPv6 versus delay between MN and AP/BS

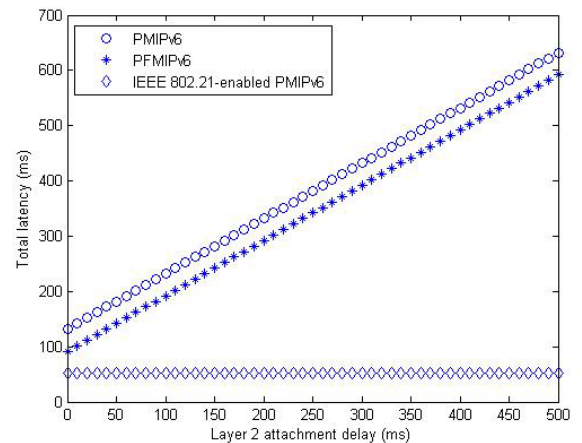


Figure 5. Total latency of PMIP, PFMIPv6, and IEEE 802.21-enabled PMIPv6 versus layer 2 attachment delay

vertical handover latencies of PMIPv6, PFMIPv6, and IEEE 802.21-enabled PMIPv6 are also increased. However, IEEE 802.21-enabled PMIPv6 outperforms PMIPv6 and PFMIPv6 in latency regardless of the variation of the wireless link delay. This result is due to the fact that the pre-registration process such as the layer 2 attachment and AAA can be performed before MN is detached from the serving network.

The impact of the layer 2 attachment delay is also shown in Fig. 6. In this paper, because we only consider the handover from WLAN to Mobile WiMAX, the layer 2 attachment delay varies depending on the target network. The figure shows that IEEE 802.21-enabled PMIPv6 outperforms PMIPv6 and

PFMIPv6. From the figure, we can realize that one of the most benefits of the IEEE 802.21 framework is that the total vertical handover latency is not dependent on the layer 2 attachment delay if the layer 2 attachment can be completed before MN is detached from WLAN.

V. CONCLUSIONS

In this paper, we analyze a vertical handover latency of IEEE 802.21-enabled PMIPv6. The network model used in this paper and the procedure of the performance analysis are explained. The results of the performance evaluation show that the handover latency of PMIPv6 can be reduced by conforming to the IEEE 802.21. With IEEE 802.21, we do not need to use access technology-dependent mobility-related signaling method as used in PFMIPv6.

Further research will include performance evaluation of the analysis by using network simulation tools, such as OPNET or NS-2. Optimized handover decision algorithms for multi-radio MNs, IEEE 802.21-based multi-radio power management, and PMIPv6-based network mobility support for automotive networking [23] will also be considered as further works.

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