The Impacts of Signaling Time on the Performance of Fast Handovers for MIPv6 ⋆

Seung-Hee Hwang[1] Youn-Hee Han[2] Jung-Hoon Han[1] and Chong-Sun Hwang[1]

[1] Dept. of Computer Science and Engineering, Korea University, Seoul, Korea, shhwang@disys.korea.ac.kr, frajung@disys.korea.ac.kr, hwang@disys.korea.ac.kr
[2] i-Networking Lab., Samsung Advanced Institute of Technology, Yongin, Kyungki-do, Korea, yh21.han@samsung.com

Abstract. A Fast Handover protocol (FMIPv6) in IETF working group is proposed to reduce the handover latency in Mobile IPv6 standard protocol. The FMIPv6 proposes some procedures for fast movement detection and fast binding update to minimize the handover latency. Additionally, to reduce the lost packets caused by a handover, this protocol introduces buffers in access routers. However, the handover latency or the amount of lost packets are affected by the time to send signals such as Fast Binding Update message for the fast handover. In this paper, we inspect the impacts of the signaling time on packet loss and handover latency in FMIPv6 through the numerical analysis, we propose the optimal signaling time to improve the performance of FMIPv6 in terms of the handover latency and lost packets.

1 Introduction

In mobile network, a mobile user should communicate with its correspondent nodes via its IP address regardless of its location. However, the IP address is some location-dependent, so its IP address may be changed at its location change, and its communication also may be disconnected at its new location. To solve this problem, Mobile IP is proposed [1].

In MIPv6, MN has a home IP address (HoA) for identification and a temporal IP address for routing information. When MN moves to a new subnet, that is, it may disconnect with the current link and connect with a new link in link layer, and it should obtain a new temporal address called Care-of-Address (CoA) through stateless or stateful (e.g. DHCPv6) address auto-configuration [2] according to the methods of IPv6 Neighbor Discovery [8]. Then MN should register the binding its new CoA with its HoA to its home agent (HA) and its CNs. Therefore MN can maintain the connectivity with CNs regardless of its movement.

On the other hand, when MN in MIPv6 conducts these procedures which are called a *handover*, there is a period the MN is unable to send or receive packets; that is, the *handover latency* is defined as a duration from reception of last packet

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via previous link to reception of first packet via new link. This handover latency results from standard Mobile IPv6 procedures, namely movement detection, new Care of Address configuration and confirmation, and Binding Update, as well as link switching delay, and these procedures are time consuming tasks, so it is often unacceptable to real-time traffic such as VoIP.

To reduce the handover latency, Fast handovers for Mobile IPv6 (FMIPv6) [3], has been also proposed in IETF. FMIPv6 supports a fast handover procedure allowing starting handover in advance a movement [3]. In this proposal, MN obtains the new CoA (NCoA) before actual movement to new subnet through newly defined messages: *Router Solicitation for Proxy* (RtSolPr) and *Proxy Router Advertisement* (PrRtAdv). It also register its NCoA to previous AR (PAR) to indicate to forward the packets to its NCoA, so as soon as MN moves to the new subnet and connect with a new link, it can receive the forwarded packets from PAR. If feasible, buffers may exist in PAR and NAR for protecting packet loss. Therefore this proposal reduces the service disruption duration as well as the handover latency [3]. However, the various signaling in FMIPv6 makes it complicated to analyze the performance, which should be investigated, so we analyze the signaling time of FMIPv6 on the performance in terms of handover latency, packet loss, and required buffer size.

This paper is organized as follows: we will describe FMIPv6 protocol in Setion 2; we will expain the analytic models and calculate the performance functions for the handover latency, the number of lost packets, and the required buffer size, and then we will show the numerical results in Section 3; we will inspect of signaling time on the performance of FMIPv6 and propose the optimal signaling time for more effective FMIPv6 in Section 4; and we will conclude this paper with some words in Section 5.

2 FMIPv6

FMIPv6 is proposed to reduce the handover latency of MIPv6 by providing a protocol to replace MIPv6 movement detection algorithm and new CoA configuration procedure. Providing FMIPv6 is operated over IEEE 802.11 network, the new AP is determined by the scanning processes. The new associated subnet prefix information is obtained through the exchange of the *Router Solicitation for Proxy* (RtSolPr) and *Proxy Router Advertisement* (PrRtAdv) messages. Although the sequential L2 handover processes of scanning, authentication, and re-association are performed autonomously by firmware in most existing IEEE 802.11 implementations, these processes should not be executed autonomously in FMIPv6 to exchange RtSolPr and PrRtAdv messages, and *Fast Binding Update* (FBU) and *Fast Binding Acknowledgement* (FBAck) messages.

In FMIPv6 operated over IEEE 802.11 network, MN firstly performs a scan to see what APs are available. The result of the scan is a list of APs together with physical layer information, such as signal strength. And then, MN selects one or more APs by its local policy. After the selection, MN exchanges RtSolPr and PrRtAdv to get the new subnet prefix. In fact, there may or may not some delay

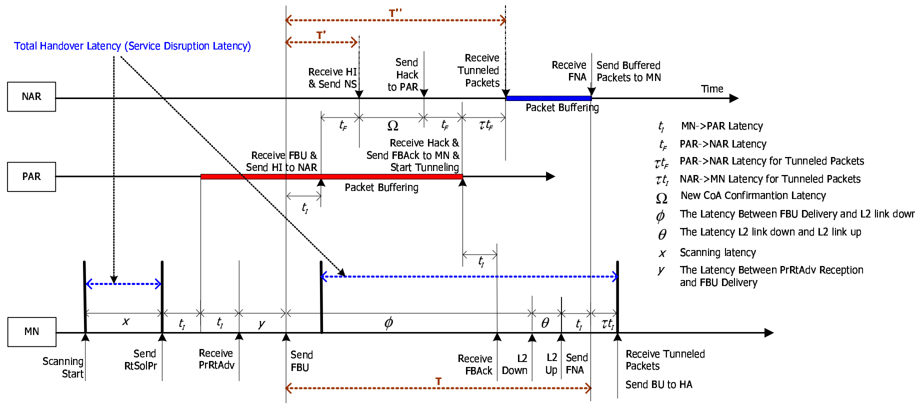


Fig. 1. Origin FMIPv6 handover procedure and timing diagram in case of receiving FBAck via the previous link

between scanning and sending RtSolPr; that is, MN can execute scanning at any time and may not do scanning for RtSolPr delivery, we assume that MN may scan available APs and select one or more APs just before sending RtSolPr in this paper. After receiving PrRtAdv, MN itself configures its prospective new CoA (NCoA) based on the new subnet prefix. And then, MN sends FBU to PAR to tell a binding of previous CoA (PCoA) and NCoA. At this point, the MN should wait FBAck message, if feasible, when it still presents on the previous subnet. If the MN receives FBAck in the previous subnet, it should move to NAR as soon as possible. If the MN does not receive FBAck in the current subnet and becomes under unavoidable circumstances (e.g., signal strength is very low) forcing it to move to NAR, MN should move to NAR without waiting more FBAck.

Fig.1 and Fig.2 describe FMIPv6 handover procedure and its timing diagram in the case that MN receives FBAck on the previous subnet. They also show the different time for buffering. When PAR in Fig.1 receives RtSolPr with buffering option from MN, it should start buffering according to [3], whereas PAR starts to store the packets destined for MN's PCoA into its buffer after receiving FBU from MN in Fig.2. In fact, if PAR starts buffering after receiving RtSolPr and finishes after processing FBU according to [3], that may cause needless buffering before reception of FBU, since the PAR delivers and also stores the packets in its buffer for the duration from receiving RtSolPr to receiving FBU 1. Therefore we assume PAR starts buffering at the reception of FBU like that in Fig.2. From this time, MN cannot receive packets and thus the service disruption time is measured. Then PAR sends *Handover Initiation* (HI) with NCoA to NAR. On receiving HI, NAR should confirm the NCoA and respond with *Handover Acknowledge* (HAck) message to PAR. At this time, the tunnel between PAR and the new location of MN is setup and the buffered packets are tunneled to NCoA. NAR must intercept the tunneled packets and store them into its buffer until it receives *Fast Neighbor Advertisement* (FNA) message from MN. FNA is

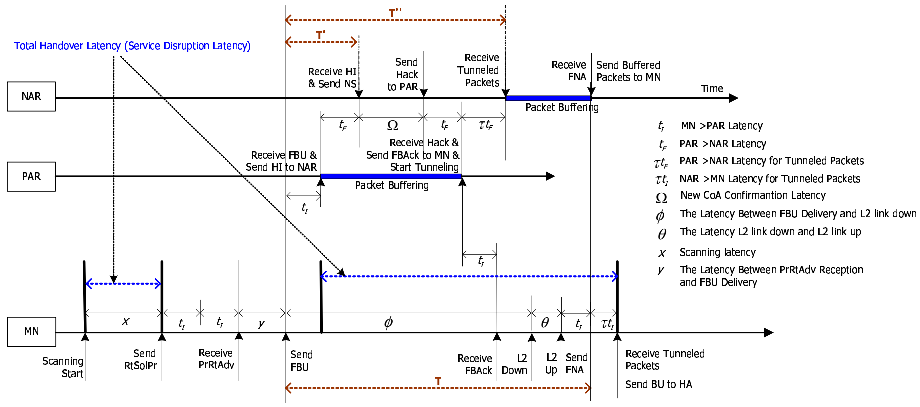


Fig. 2. FMIPv6 handover procedure and timing diagram in case of receiving FBAck via the previous link

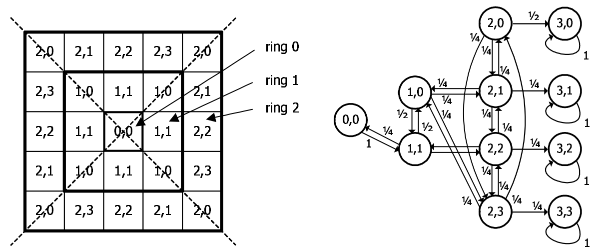
the first message delivered from MN when it completes re-association with new AP. The reception of FNA allows NAR to release the buffered packets to MN. It means the end of service disruption time.

On the other hand, in the case the MN does not receive FBAck on the previous subnet, some different procedures are performed. MN moves to new AP area earlier than the reception of FBAck and, at this time, MN sends FNA immediately after attaching to new AP. It is noted that this FNA should encapsulate FBU in order to allow NAR to first check if NCoA is valid. When receiving such a FNA, NAR may not receive the tunneled packets delivered from PAR. In this case, NAR just forwards the tunneled packets to MN when the tunneled packets arrive at NAR.

3 Performance Analysis

3.1 Packet Level Traffic Model

IP traffic is characterized as connectionless transmission. Each packet has its destination address and is routed individually to the destination. In terms of IP traffic, we define a session or *session time* as a duration that packets with same source and same destination are been generating continuously, and *idle time* as a duration that packets are not generated until a new session starts. Generally today's Internet traffic is characterized as self-similar by nature. Therefore, recent research describes that a session time follows the Pareto distribution (or the Weibull distribution) which presents the self-similar property [6]. On the other hand, a session is arrived by the Possion process with a rate λ_c. In this paper, let a session time be t_{st}. For t_{st}, its probability density function $f_{st}(t)$ is defined



(a) 3-layer subnet structure

(b) State diagram of two-dimensional random walk model in 3-layer subnet structure

Fig. 3. Network system model and random walk model

from [6] as follows:

$$f_{st}(t) = \begin{cases} \frac{\alpha k^{\alpha}}{t^{\alpha+1}} & , t \geq k \\ 0 & , otherwise \end{cases} \quad (1)$$

where α is the shape parameter and k is the location parameter. If $\alpha \leq 2$, then the distribution has infinite variance, and if $\alpha \leq 1$, then it has infinite mean. The mean is as follows.

$$E_{st}[t] = \int_0^{\infty} t f_{st}(t) dt = \frac{\alpha \cdot k}{\alpha - 1}, \quad \alpha > 1 \quad (2)$$

For all examinations, we will use $\lambda_c = 0.002$ (so, the mean inter-session arrival time is 500 seconds.), $\alpha = 1.1$, and $k = 30$ as being similar to [6]. (so, the mean session time is 330 seconds.)

3.2 Network system model and mobility model

We assume that each subnet also consists of more than one wireless AP areas. We assume that the homogeneous network of which all AP areas in a subnet have the same shape and size. We describe a two-dimensional random walk model for mesh planes in order to compute the domain and subnet residence time density functions. The mesh plane is drown as Fig.3 in which each 25 small squares and the entire square represents each AP areas and one subnet area, respectively.

A subnet is referred to as an *n-layer subnet* if it overlays with $N = 4n^2 - 4n + 1$ AP areas. For instance, Fig.3 (a) shows $3 - layer$ subnet, and the number of overlayed AP areas is $4 \times 3^2 - 4 \times 3 + 1 = 25$. The AP area in the center in Fig.3 (a) is called as *ring* 0, and the set of AP areas that surround ring 0 is called as *ring* 1, and so on. In general, the set of AP areas which surround the ring $x - 1$ is called as *ring* x. Therefore, an n-layer subnet consists of AP areas from ring 0 to ring $n - 1$. Especially, the AP areas that surround the ring $n - 1$ are referred to as *boundary neighbors*, which are outside of the subnet.

We assume that MN resides in an AP area for a period and moves to one of its four neighbors with the same probability, i.e., with probability 1/4. According to this equal moving probability assumption, we classify the AP areas in a subnet into several *AP area types*. An AP area type is represented as the form $<x, y>$, where x indicates that the AP area is in the ring x and y represents the $y+1$th type in the ring x. Each type in each ring is named sequentially from 0, and the number 0 is assigned to APs in a diagonal line. For example, in Fig.3 (a), The AP type $< 2, 1 >$ represents that this AP is in the ring 2 and it is the AP of 2nd type in ring 2.

In the random walk model, a state (x, y) represents that the MN is in one of the AP areas of type $<x, y>$. The absorbing state (n, j) in $n - layer$ subnet represents that an MN moves out of the subnet from state $(n-1, j)$, where $0 \leq j \leq 2n-3$ (For example, $j \in \{0, 1, 2, 3\}$ for 3-layer subnet). The state diagram of the random walk for 3-layer subnet is shown in Fig.3 (b).

Let t_p and t_s be i.i.d. random variables representing the AP area residence time and the subnet residence time, respectively. Let $f_p(t)$ and $f_s(t)$ be the density function of t_p and t_s, respectively. We assume that the AP area residence time of an MN has the Gamma distribution with mean $1/\lambda_p$ ($=E[t_p]$) and variance ν. The Gamma distribution is selected for its flexibility and generality. The Laplace transform of the Gamma distribution is $f_p^*(t) = \left(\frac{\gamma\lambda_p}{t+\gamma\lambda_p}\right)^\gamma$, where $\gamma = \frac{1}{\nu\lambda_p^2}$. Also, we can get the Laplace transform $f_s^*(t)$ of $f_s(t)$ and its expected subnet residence time $E[t_s]$ from [10, 11].

From [10, 11], during a session time t_{st}, the probabilities $\Pi_p(K)$ and $\Pi_s(K)$ that the MN moves across K AP areas and K subnets, respectively, can be derived as follows:

$$\Pi_p(K)=\begin{cases} 1-\frac{E_{st}[t]}{E[t_p]}(1-f_p^*(\frac{1}{E_{st}[t]})) & ,K=0 \\ \frac{E_{st}[t]}{E[t_p]}(1-f_p^*(\frac{1}{E_{st}[t]}))^2(f_p^*(\frac{1}{E_{st}[t]})^{K-1} & ,K\geq 1 \end{cases} \tag{3}$$

$$\Pi_s(K)=\begin{cases} 1-\frac{E_{st}[t]}{E[t_s]}(1-f_s^*(\frac{1}{E_{st}[t]})) & ,K=0 \\ \frac{E_{st}[t]}{E[t_s]}(1-f_s^*(\frac{1}{E_{st}[t]}))^2(f_s^*(\frac{1}{E_{st}[t]})^{K-1} & ,K\geq 1 \end{cases} \tag{4}$$

3.3 Performance functions

At first, we introduce some parameters used for performance functions as follows:

- η: packet delivery delay in wireless path between AP and MN.
- ϵ: packet delivery delay per hop in wired path.
- Ω: NCoA confirmation latency in FMIPv6.
- τ: additional weight for tunnelled packets.
- a: #hops between AP and AR.
- b: #hops between PAR and NAR.
- $t_I(=\eta+\epsilon a)$: packet delivery delay between MN and AR.
- $t_F(=\epsilon b)$: packet delivery delay between two ARs.
- ϕ: latency between FBU transmission and L2-down trigger.
- θ: AP area switching latency (new AP re-association and authentication latency).

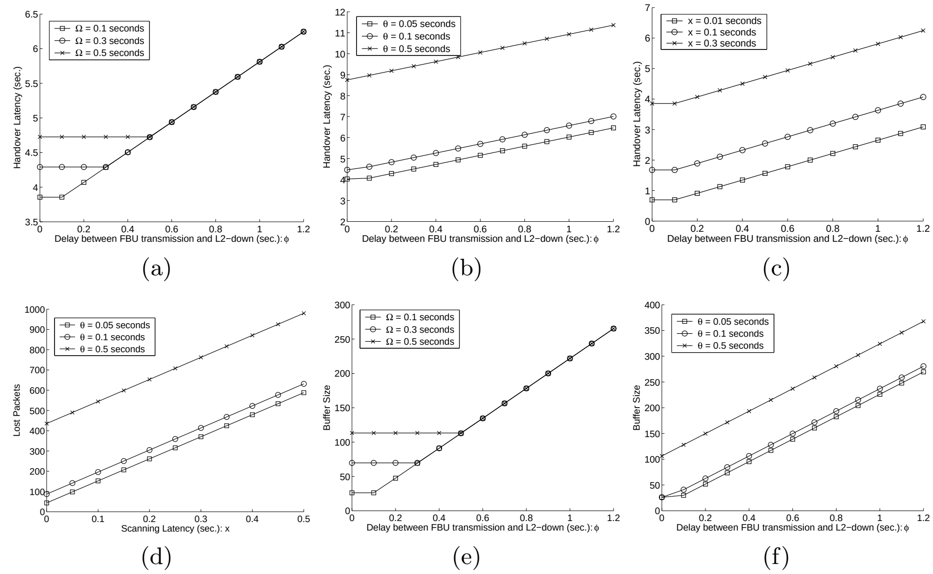


Fig. 4. Numerical Results I

- x: AP Scanning latency.
- y: latency between PrRtAdv reception and FBU transmission. MN receives the packets from PAR in this duration.

Irrespective of whether MN receives FBAck on the previous subnet or not, the handover procedure of FMIPv6 is divided into two independent procedures; P_I, the procedure to be executed by MN itself, and P_{II}, the procedure to be executed by only both PAR and NAR in order to establish the bidirectional tunnel and send the tunneled packets. The two separated procedures will start when MN sends FBU to PAR, and combine into one when NAR receives FNA from MN. We assume that NAR has already received at least HI from PAR, when it receives FNA from MN. Processing FNA is also assumed to be executed after the completion of tunnel establishment between NAR and PAR. Until the two procedures P_I and P_{II} combine into one, the completion times of each procedure are defined as follows:

- $C_{P_I} = \phi + \theta + t_I$.
- $C_{P_{II}} = t_I + (2 + \tau)t_F + \Omega$.

If $C_{P_I} > C_{P_{II}}$, NAR has buffered the packets tunneled from PAR and forwards them to MN when it receives FNA. Otherwise, NAR waits the packets which will be tunneled from PAR (or runs its NCoA confirmation procedure and sends FBU encapsulated in FNA to PAR) when it receives FNA.

After announcing its attachment to NAR and receiving the tunneled packets, MN registers its new CoA to HA, and to CNs sequentially. In FMIPv6, the handover latency HL_F in a session time is define as follows (see Fig.2):

$$HL_F = \sum_{K=0}^{\infty} K\Pi_p(K)(x+\theta) + \sum_{K=0}^{\infty} K\Pi_s(K)(MAX\{C_{P_I}, C_{P_{II}}\} - t_I - \theta + \tau t_I). \quad (5)$$

Since FMIPv6 supports packet buffer function, packet losses does not occur during MN's subnet movement. Therefore, the number of lost packets PL_F in a session time is defined as follows.

$$PL_F = \lambda \sum_{K=0}^{\infty} K\Pi_p(K)(x+\theta) - \lambda \sum_{K=0}^{\infty} K\Pi_s(K)\theta. \quad (6)$$

The required buffer size is represented by the sum of the buffer sizes required at both PAR and NAR. The required buffer size BS_F in a session time is represented as follows:

$$BS_F = \lambda \sum_{K=0}^{\infty} K\Pi_s(K)(\Omega + 2t_F) + \lambda \sum_{K=0}^{\infty} K\Pi_s(K) \cdot MAX\{C_{P_I} - C_{P_{II}}, 0\}. \quad (7)$$

, where λ is the average packet arrival rate.

3.4 Numerical results

For examinations, the following fixed parameters are used: $\eta = 0.01 sec.$, $\epsilon = 0.005 sec.$, $\tau = 1.2$, $a = 1$, $b = 2$, $n = 3$ (subnet layer is 3), $\lambda_p = 0.033$ (that is, the mean of AP area residence time is 30 seconds), $\nu = 1$, $\lambda = 100$ $packets/sec.$, $y = 0.01 sec.$. As the target of investigation, we select the following changeable parameters and their default values:$x = 0.3 sec.$, $\theta = 0.03 sec.$, $\Omega = 0.1 sec.$, and $\phi = 0.02 sec.$. While we select one parameter and change its value, the remaining parameters values are set to their default values during the following investigation.

Fig.4 explains the handover latency, the number of lost packets, and the required buffer size in FMIPv6. As the latency ϕ between FBU transmission and L2-down trigger increases, the handover latency and required buffer size also increase. Therefore, ϕ should be as small as possible. In addition, when Ω, θ and x are low, the performance of FMIPv6 is high. The number of lost packets depends on only Layer 2 handover latency, that is θ and x.

From Fig.4 (a), we can find that the handover latency in FMIPv6 is unchanged as lowest when ϕ is so low (e.g. for $\phi = 0 \sim 0.3 sec.$ and $\Omega = 0.3 sec.$). It is resulted from that the handover procedure of FMIPv6 is divided into two independent procedures; P_I and P_{II}. If $C_{P_I} > C_{P_{II}}$, the performance depends largely on ϕ. Otherwise, ϕ does not affect the performance and Ω plays a important role of changing the performance.

4 Impacts of Signal Time on FMIPv6

Lots of research has already shown that the FMIPv6 has less handover latency (and less packet loss) than MIPv6 [4, 5, 9]. In this paper, therefore, we focus on the effect of signaling time on FMIPv6 performance rather than the performance comparisons between MIPv6 and FMIPv6.

As we discussed in the above section, the handover latency and the required buffer size depend largely on ϕ (the latency between FBU transmission and L2 down event) and Ω (address confirmation latency). For the exchange of FBU and FBAck to be completely done in the previous link, ϕ should be high and thereby C_{P_I} will be larger than $C_{P_{II}}$. It means the performance of FMIPv6 will depend largely on ϕ. MN can send FBU early in the overall handover duration to receive FBAck. In this case, however, the more buffering is required at PAR and NAR. If the packet arrival rate λ is very high, the buffers at PAR and NAR will be overflowed and packets will be lost. Therefore, the duration between FBU transmission and FBAck reception (and thereby ϕ) should not be too long.

On the other hand, thinking about the case that MN does not receive the FBAck, there are two reasons: one reason is that FBU is delivered to PAR, but MN moves to a new area before receiving FBAck, and the other is that FBU itself is lost or that FBU is delivered to PAR, yet sequential HI is not delivered to NAR. In any case, if MN does not receive FBAck in previous link, MN should resend FBU, which is encapsulated in FNA, via new link since MN does not know whether or not FBU was delivered to PAR. If FBU is lost, then the anticipated fast handovers are not feasible. So we assume in this paper if FBU is not lost, then NAR receives at least HI when NAR receives the FNA. When NAR receives FNA encapsulating FBU, if NAR is still confirming NCoA presented by HI, it reserves the FNA encapsulating FBU in its local memory. If the confirmation procedure is a success, then NAR sends HAck to PAR and waits for the tunneled packets from PAR. After then NAR processes the FNA in temporal storage, and forwards the tunneled packets to MN's NCoA. If the confirmation of NCoA is failed, then NAR assigns new CoA and include it HAck. However, if FBU is lost, so NAR does not receive HI from PAR and NAR receives FNA with FBU, then NAR forwards FBU to PAR to setup tunnel between PAR and NAR. From the observation, we can separate the handover processing duration of FMIPv6 as three parts as follows: Let assume T the duration between FBU transmission and FNA delivery, it is same with C_{P_I}, T' the duration between FBU transmission and HI delivery, and T'' the duration between FBU transmission and NAR's reception of the first packet tunneled from PAR, it is same with $C_{P_{II}}$.

Theorem: When $T' < T < T''$, the handover latency in FMIPv6 has the minimal value.

Proof: From the Fig.2, each duration T, T', and T'' is represented as follows:

$$
\begin{aligned}
T &= C_{P_I} = \phi + \theta + t_I \\
T' &= t_I + t_F \\
T'' &= C_{P_{II}} = t_I + (2+\tau)t_F + \Omega.
\end{aligned}
$$

For $S = \{\phi, \theta, \Omega, t_F, t_I, \tau\}$, we define a function $C(S)$ indicating the duration between MN's FBU transmission and MN's reception of the first tunneled packet in the new link.

$$C(S)=\begin{cases} T' + (4+\tau)t_F + \Omega + \tau t_I, & for\ T \leq T' \quad (a) \\ T'' + \tau t_I, & for\ T' < T < T'' \quad (b) \\ T + \tau t_I, & for\ T \geq T'' \quad (c) \end{cases} \tag{8}$$

The handover latency is determined by this function $C(S)$ and L2 scanning duration x. From Eq.8, the handover latency HL_F should be re-defined as follows:

$$HL_F=\begin{cases} \sum_{K=0}^{\infty} K\Pi_p(K)(x+\theta) \\ \quad + \sum_{K=0}^{\infty} K\Pi_s(K)\{T' + (4+\tau)t_F + \Omega - t_I - \theta)\}, \\ \qquad\qquad\qquad\qquad for\ T \leq T' \\ \sum_{K=0}^{\infty} K\Pi_p(K)(x+\theta) \\ \quad + \sum_{K=0}^{\infty} K\Pi_s(K)\{T'' - t_I - \theta\}, \\ \qquad\qquad\qquad\qquad for\ T' < T < T'' \\ \sum_{K=0}^{\infty} K\Pi_p(K)(x+\theta) \\ \quad + \sum_{K=0}^{\infty} K\Pi_s(K)\{T - t_I - \theta\}, \\ \qquad\qquad\qquad\qquad for\ T \geq T'' \end{cases} \tag{9}$$

By using the above parameters definitions, we can infer the following inequalities for ϕ, which make the FMIPv6 handover latency distinct.

i) $T < T'$
$\equiv \phi + \theta + t_I < t_I + t_F$
$\equiv \phi \leq t_F - \theta$

ii) $T' \leq T \leq T''$
$\equiv t_I + t_F < \phi + \theta + t_I < t_I + (2+\tau)t_F + \Omega$
$\equiv t_F - \theta < \phi < (2+\tau)t_F + \Omega - \theta$

iii) $T \geq T''$
$\equiv \phi + \theta + t_I \geq t_I + (2+\tau)t_F + \Omega$
$\equiv \phi \geq (2+\tau)t_F + \Omega - \theta$

Let the minimal value of $C(S)$ be $C_{min}(S)$. The minimal $C_{min}(S)$ is found from the above equation as the followings.

$$\begin{aligned} & Eq.8(a) - Eq.8(b) \\ &= \{T' + (4+\tau)t_F + \Omega + \tau t_I\} - \{T'' + \tau t_I\} \\ &= 3t_F > 0. \\ &\therefore Eq.8(a) > Eq.8(b). \end{aligned} \tag{10}$$

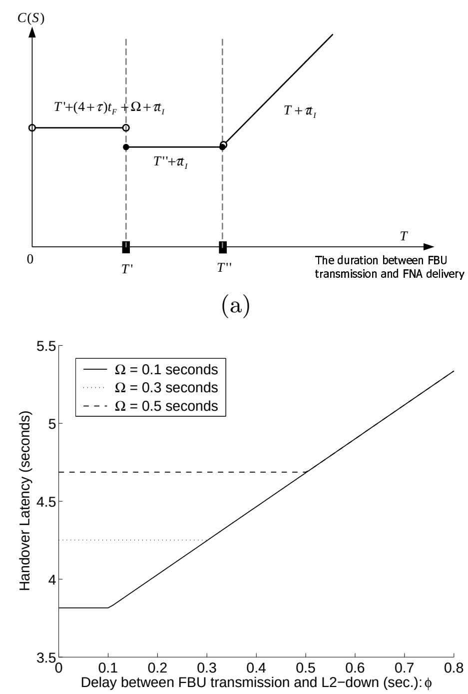
$$\begin{aligned} & Eq.8(c) - Eq.8(b) \\ &= T + \tau t_I - T'' - \tau t_I \\ &= \phi + \theta - \Omega - (2+\tau)t_F \end{aligned}$$

$$= \phi + \theta - \Omega - (2+\tau)t_F > 0$$
$$(\because\ \phi > (2+\tau)t_F + \Omega - \theta\ from\ iii))$$
$$\therefore Eq.8(c) > Eq.8(b). \tag{11}$$

Therefore, Eq.8 (b) is the lowest value of $C(S)$. So $C_{min}(S)$ is derived as followings:

$$C_{min}(S) = T'' + \tau t_I, \qquad for\ T' < T < T''. \tag{12}$$

Therefore, when $T' < T < T''$, the $C(S)$ is lowest as shown in Fig.5(a) and consequently, the handover latency will be lowest.



(a)

(b)

Fig. 5. The time to send FBU and Ω to minimize the handover latency

Corollary 1) For lowest handover latency in FMIPv6, FBAck should not always be delivered in previous link.

From Theorem, $C_{min}(S)$ is lowest for $T' < T < T''$. $T' < T < T''$ means that FBU should be delivered in previous link and NAR should receive HI until FNA is delivered to NAR. Therefore FBack reception on previous link is not necessary condition for effective handover in FMIPv6.

Corollary 2) If the delivery latency between PAR and NAR t_F is lower than link switching latency θ, when $0 < \phi < (2+\tau)t_F + \Omega - \theta$, the C(S) has the minimal value $C_{min}(S) = T'' + \tau t_I$ and consequently the handover latency is the smallest.

In Theorem, $T' < T < T''$ is represented as follows

$$\begin{aligned} & T' < T < T'' \\ \equiv\ & t_I + t_F < \phi + \theta + t_I < t_I + (2+\tau)t_F + \Omega \\ \equiv\ & t_F - \theta < \phi < (2+\tau)t_F + \Omega - \theta \\ \equiv\ & 0 < \phi < (2+\tau)t_F + \Omega - \theta \\ & (\because \textit{assuming} \ \ t_F < \theta \ \ \textit{in most cases}). \end{aligned} \tag{13}$$

Since $t_F < \theta$, when $0 < \phi < (2+\tau)t_F + \Omega - \theta$, the handover latency has the minimal value as shown Fig.5 (b). This implies that even if HI is not delivered and FNA is delivered to NAR, the handover latency in FMIPv6 shows lowest value.

5 Conclusions

Fast Handovers for IPv6 (FMIPv6) protocol is proposed to reduce the handover latency in Mobile IPv6 standard protocol. In this paper, we inspected the mechanism of FMIPv6 protocol over IEEE 802.11 wireless network in detail, and analyzed numerically the performance of FMIPv6 in terms of handover latency, packet loss, and required buffer size using proposed models. From the numerical results, we found that the performance is very different according to the signals delivery time of FMIPv6, especially FBU. To make FMIPv6 more effective, we calculated the optimal time for FBU delivery, such as $0 < \phi < (2+\tau)t_F + \Omega - \theta$ under condition that FBU is not lost. In addition, there needs not any buffer in NAR.

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