Performance Analysis for FMIPv6 considering Probability of Predictive Mode Failure

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Abstract

Mobile IPv6 (MIPv6) is a protocol to support mobility for IPv6. Fast Handovers for MIPv6 (FMIPv6) have been studied, since in MIPv6 handover latency is long, and all packets are lost during handover. FMIPv6 provides seamless handover by minimizing handover latency, and prevents packet loss through buffering and tunneling. FMIPv6 uses anticipation based on layer 2 trigger information, and consists of two modes such as predictive mode and reactive mode. Several works have been done to evaluate the performance of FMIPv6 in different network environments. However, the previous works did not consider probability of predictive mode failure that classifies the two modes. Also, in the most previous works the two modes of FMIPv6 are evaluated separately. In this paper, FMIPv6 combining the two modes is analyzed through probability of predictive mode failure, since FMIPv6 is just a protocol. We investigate probability of predictive mode failure to find important elements in network environment. Then, FMIPv6 is analyzed by these elements for performance evaluation with respect to various metrics like signaling cost, delivery cost, and buffering cost. Numerical results show a trade-off between performance and system parameters. Then, we shows methods to optimize FMIPv6 using probability of predictive mode failure and layer 2 trigger time.

1. Introduction

As the advancement of wireless communication, requirements on the wireless Internet and mobility support are increasing. To support mobility, Mobile IPv6 (MIPv6) [1] has been proposed by the Internet Engineering Task Force (IETF). In MIPv6, when a mobile node (MN) moves to other sub network, it needs certain process, a handover, which causes long latency problem. To solve these problems, Fast Handover for Mobile IPv6 (FMIPv6) [2] has been studied in IETF. FMIPv6 provides seamless handover by minimizing handover latency, using anticipation based on layer 2 trigger information to reduce handover latency and packet loss. FMIPv6 consists of two modes such as predictive mode and reactive mode. The two modes are classified by the time required to process additional signaling before layer 2 handover. If the above time is larger than the time between layer 2 trigger and link down, FMIPv6 will be reactive mode. In this case, predictive mode is failed, and then we call this status as predictive mode failure.

Several studies have been done to evaluate the performance of FMIPv6 in different network environments [3] [4]. In [3], the authors compared various metrics of different IP mobility management schemes. FMIPv6 supports a faster handover procedure compared with MIPv6, while HMIPv6 provides an approach allowing for different hierarchies of mobility agents. In the paper, the authors proposed analytical framework in order to provide depth analysis of the overall performance of various protocols. However, the paper did not consider network elements for probability of predictive mode failure that is crucial to analyze FMIPv6. Network elements are radius of a cell and velocity of an MN. In [4], an enhanced FMIPv6 scheme was proposed. In the scheme, registration delay was reduced by performing registration process in advance. The scheme and FMIPv6 were analyzed to evaluate performance. However, predictive mode was only analyzed. That is, FMIPv6 in this paper was not analyzed completely.

The previous works neither consider probability of predictive mode failure, nor use various network elements for probability of predictive mode failure. Also, in the most previous papers the two modes in FMIPv6 are evaluated separately. It is required to analyze the total performance of a protocol, to evaluate performance of the protocol. In this paper, FMIPv6 combining the two mode is analyzed through probability of predictive mode failure, since FMIPv6 is just a protocol. Probability of predictive mode failure is affected by radius of a cell, velocity of mobile nodes, and layer 2 triggering time. Probability of predictive mode failure is investigated using these elements for performance evaluation.
with respect to various metrics like signaling cost, delivery cost, and buffering cost. Numerical results show a trade-off between performance and system parameters, and layer 2 triggering time to optimize FMIPv6.

The rest of this paper is organized as follows: in section 2, FMIPv6 is described. Analytical model is in section 3. In section 4, numerical results based on this analytical model is then investigated. Finally, we conclude discussion with future study.

2. Fast Handover for Mobile IPv6 (FMIPv6)

Fast Handover for Mobile IPv6 (FMIPv6) uses anticipation based on layer 2 trigger information to reduce handover latency and packet loss. There are two modes in FMIPv6, such as predictive mode and reactive mode. The two modes are classified by the time required to process additional signaling before layer 2 handover. If the above time is larger than the time between layer 2 trigger and link down, FMIPv6 will be reactive mode. In this case, predictive mode is failed, and then we call this status as predictive mode failure.

In FMIPv6, several portions of the layer 3 handover are performed prior to the layer 2 handover. In other words, the MN performs the layer 3 handover while it is connected to a PAR, and in this case, the PAR must have known information about an NAR. Through a router solicitation for proxy (RtSolPr) and a proxy router advertisement (PrRtAdv) messages, the MN obtain information of the NAR. The MN request tunneling sending a fast binding update (FBU) message in predictive mode. The PAR establishes a tunnel between itself and the NAR, and then verifies the MN’s new CoA by exchanging a handover initiate (HI) message and a handover acknowledge (HAck) message. Packets that arrive at previous care-of address (PCoA) are forwarded to the NAR through an established tunnel during the handover, and the NAR buffers the packets. In reactive mode, the FBU message is sent from the new network encapsulated in a fast neighbor advertisement (FNA) message. When FMIPv6 is completed, the buffered packets are forwarded to the MN. Figure 1 shows flows of FMIPv6.

3. Analytical Models

In IPv6-based wireless networks, QoS may be defined by signaling overhead, handover latency, and packet loss [3]. Additionally, in FMIPv6 probability of predictive mode failure is an important element to evaluate FMIPv6 with MNs’ velocity, radius of a cell, and layer 2 trigger time. Analytical framework using probability of predictive mode failure for evaluating performance of FMIPv6 is proposed in this section. We define that handover is begun from layer 2 trigger epoch and is ended at which the MN receives the first packet in new network.

3.1. Mobility Modeling

We assume that mobile service area are partitioned into Location Areas (LAs) of the same size, and each cell is surrounded by rings of cells as shown in Fig. 2(a) [6]. The innermost cell "0" is called the center cell; cells labeled "1" form the first ring around cell "0" and so forth. Each ring is labeled according to its distance from the center such that ring $r_1$ refers to the cells in the first ring away from cell "0." In general, $r_k (k = 1, 2, \ldots)$ refers to the $k$th ring away from the center cell. The number of cells in $k$th ring is $6 \cdot k$. Then, the number of cells $N(K)$ is calculated as

$$N(K) = \sum_{k=1}^{K} 6 \cdot k + 1 = 3(K + 1) \cdot K + 1 \quad (1)$$

where $K$ denotes the outermost ring within the LA [7].

Given that the cell radius is $r$, we can observe that the perimeter of the center cell is $6r$ and the perimeter of the first ring is $18r$. The radius $r$ is determined based on the number of MNs and bandwidth allocation schemes. The perimeter $L(K)$ and the coverage area $S(K)$ are

$$L(K) = (12K + 6) \cdot r \quad (2)$$

$$S(K) = \{3K \cdot (K + 1) + 1\} \cdot 2.6 \cdot r^2$$

,where $2.6 \cdot r^2$ is the area of each cell [7].
We use fluid-flow model for mobility model, referring to [8] and [9]. Under the fluid-flow model in [7], the direction of an MN’s movement in the LA is uniformly distributed in the range of $(0, 2\pi)$. Let $v$ be average speed; $S(K)$ and $L(K)$ be area and perimeter of the LA, respectively. The average handover rate $\mu_h$ is equal to the average number of crossings of the boundary of the LA per unit time, then

$$\mu_h = \frac{vL(K)}{\pi S(K)}. \quad (3)$$

### 3.1.1. Probability of Predictive Mode Failure

In FMIPv6, additional signaling messages may be exchanged between an MN and an PAR, while the MN is in the overlapped area of cells in the PAR and the NAR. Predictive mode will be failed due to the MN leaving the overlapped area between two cells, before the additional signaling for FMIPv6 can be completed. Figure 2(b) shows the overlapped area of boundary cells. In this section, we now calculate the probability of predictive mode failure.

Let $T$ be a random variable for the time from layer 2 trigger epoch to link down (i.e., pending L2 handover). The probability that the MN leaves the overlapped area before the required time for additional signaling in FMIPv6, $T_{fast}$, is:

$$P_{rf} = \begin{cases} \Pr(T < T_{fast}) & , \text{if } T_{fast} \leq T_{trigger} \\ 1 & , \text{if } T_{fast} > T_{trigger} \end{cases} \quad (4)$$

If we assume that $T$ is exponentially distributed, then the probability becomes

$$P_{rf} = 1 - e^{-\lambda T_{fast}} \quad (5)$$

where $\lambda$ is the arrival rate of MNs into the overlapped area [10]. For an MN whose direction of travel is uniform on the interval $[0, 2\pi)$, we find that the arrival rate, $\lambda$, of the MN into the overlapped area is given by:

$$\lambda = \frac{2vL}{\pi S} \quad (6)$$

where $L$ is the length of the perimeter of the overlapped area, and $S$ is the overlapped area. We can obtain $L = 2 \cdot \left(\frac{1}{6} 2\pi r\right) = \frac{2\pi r}{3}$ and $S = 2 \cdot \left(\frac{1}{6} \pi r^2 - \frac{\sin(\pi/3)}{2} r^2\right) = \frac{4v}{\pi (\pi - \sin(\pi/3))},$ referring to Fig. 2(b). Then,

$$\lambda = \frac{4v}{\pi (\pi - \sin(\pi/3))} \quad (7)$$

### 3.2. Total Cost

Performance analysis of wireless networks should consider total cost induced by mobility management and packet delivery. We calculate costs during handover, since FMIPv6 is a protocol that enhances MIPv6 handover. Signaling cost and packet delivery cost are occurred during handover. Thus, total cost could be considered as the sum of signaling cost and packet delivery cost:

$$C_{total} = \alpha \cdot C_{signal} + \beta \cdot C_{PD} \quad (8)$$

where $\alpha$ and $\beta$ are weight factors of signaling cost and packet delivery cost to adjust weights of two costs ($\alpha + \beta = 1$).

### 3.3. Signaling Cost

Signaling cost of FMIPv6 consists of predictive mode and reactive mode cost.

$$C_{FMIPv6}^{predict} = (1 - P_{rf}) \cdot C_{signal}^{predict} + P_{rf} \cdot C_{signal}^{react} \quad (9)$$

where $P_{rf}$ is probability of predictive mode failure. In FMIPv6, signaling costs of predictive mode and reactive mode can be calculated referring to Fig. 1. Signaling costs of predictive mode and reactive mode consist of costs of exchanging messages among the MN, the PAR, and the NAR during handover as follows,

$$C_{signal}^{predict} = \mu_h \cdot l_c \cdot (C_{RS-RA} + C_{pred}^{predict} + C_{pred}^{react}) \quad (10)$$

$$C_{signal}^{react} = \mu_h \cdot l_c \cdot (C_{RS-RA} + C_{react}^{reactive}) \quad (11)$$

where $C_{RS-RA} = 2 \cdot \omega_l$, $C_{pred}^{predict} = 2 \cdot \omega_l + 3 \cdot \omega_d \cdot h_{PN}$, $C_{react}^{reactive} = \omega_l + C_{new}^{reactive} = 2 \cdot \omega_l + 2 \cdot \omega_d \cdot h_{PN}$. ($l_c$ is average length of a control packet, $\omega_l$ and $\omega_d$ are weight factors of wireless and wired link, respectively, and $h_{PN}$ is average hops between a PAR and an NAR.)

### 3.4. Packet Delivery Cost

Packet delivery cost of FMIPv6 consists of predictive mode and reactive mode cost.

$$C_{FMIPv6}^{delivery} = (1 - P_{rf}) \cdot C_{delivery}^{predict} + P_{rf} \cdot C_{delivery}^{react} \quad (12)$$

In terms of the packet delivery cost, we consider the costs associated with packet forwarding, packet loss, and packet buffering. In FMIPv6, packets from correspondent nodes are forwarded to the MN through tunneling between the PAR and the NAR. Before the MN connect to the NAR, the forwarded packets are buffered in the PAR or the NAR. However, if layer 2 trigger is not occurred, the packets are lost during handover. Then, $C_{delivery}^{predict}$ and $C_{delivery}^{react}$. For $C_{delivery}^{predict}$, the first equation is for $T_{trigger} > 0$ and the second one is for $T_{trigger} \leq 0$ are.

$$C_{delivery}^{predict} = \mu_h \cdot l_d \cdot C_{packet} \cdot (T_{HL} - T_{pre}) \quad + \epsilon \cdot \mu_h \cdot C_{NAR} \cdot (T_{HL} - T_{pre}) \quad (13)$$

$$C_{delivery}^{react} = \begin{cases} \mu_h \cdot l_d \cdot C_{buffer} \cdot T_{HL} \\ + \epsilon \cdot \mu_h \cdot \lambda_p \cdot C_{PAP} \cdot T_{HL} \\ + \mu_h \cdot l_d \cdot \gamma \cdot C_{loss} \cdot T_{HL} \end{cases} \quad (14)$$
where \(\lambda\) is packet arrival rate, \(l_d\) is average length of a data packet, and \(\epsilon\) and \(\gamma\) are weight factors of buffering in AR and packet loss, respectively. \(C^\text{packet}_{\text{forward}}\) is a cost of forwarding a packet \((w_d \cdot h_{AN} + w_d \cdot h_{PN} + w_l)\), \(C^\text{buffer}_{\text{AR}}\) is a cost of buffering in the xAR \((\lambda_p \cdot l_d)\), \(BF_{AR-th}\) is threshold of buffer memory in an AR. If packet buffering exceeds \(BF_{AR-th}\), the rest of forwarded packets is lost. \(T_{HL}\) is handover latency, \(T_{pre}\) is a delay between layer 2 triggering and link down epoch. We divide handover latency into three components: \(T_{pre}\), \(t_{L2}\) (L2 handover latency), and \(T_{new}\) (a delay between link up epoch and receiving the first packet in the new network). Referring to Fig. 1, we calculated the handover latencies:

\[
T_{HL}^{\text{predict}} = T_{pre} + t_{L2} + 2 \cdot t_{wl} \quad (15)
\]

\[
T_{HL}^{\text{fast}} = T_{pre} + t_{L2} + 2 \cdot t_{wl} + 2 \cdot t_{ud} \cdot h_{PN} \quad (16)
\]

, where \(T_{pre}\) (the first equation is for \(T_{fast} > T_{trigger}\) and the second one is for \(T_{fast} \leq T_{trigger}\)) is calculated using Eq. 4 and 5, as follows

\[
T_{pre} = \begin{cases} 
T_{fast} & T_{trigger} \\
T_{pre} & T_{trigger} < T_{fast} 
\end{cases}
\]

\[
T_{pre} = \int_{T_{trigger}}^{T_{fast}} T \cdot \lambda e^{-\lambda T} dT \cdot \frac{1}{Pr(T<T_{fast})} \quad (17)
\]

, where \(T_{fast}\) is a processing time of signal messages before layer 2 handover in FMIPv6. Also, wireless transmission delay \((t_{wl})\) and wired transmission delay \((t_{ud})\) are calculated referring to [3]:

\[
t_{wl}(l) = \frac{1 + q}{1 - q} \left( \frac{l}{BW_{l}} + 1 \right) \quad (18)
\]

\[
t_{ud}(l) = \frac{l}{BW_{d}} + 1 + \omega_q \quad (19)
\]

, where \(l\) is a packet length, \(q\) is the probability of wireless link failure, \(\omega_q\) is the average queuing delay at each router in the Internet [11], \(BW_l\) (resp. \(BW_d\)) the bandwidth of wireless (resp. wired) link and \(L_{wl}\) (resp. \(L_{ud}\)) wireless (resp. wired) link delay.

### 4. Performance Evaluations

In this section, we provide some numerical evaluation to demonstrate the the performance of FMIPv6 using the results from the previous section.

<table>
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<th>Symbol</th>
<th>Value</th>
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<td>(w_d)</td>
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Parameters and default values used in performance evaluation are given Table 1. Most parameters used in this analysis are set to typical values found in [12], [5], and [13].

The signaling cost is depicted in Fig. 3 as a function of \(T_{fast}\). \(T_{fast}\) is a processing time for signal messages before layer 2 handover in FMIPv6. We observe that signaling cost of FMIPv6 decreases proportionally with \(T_{fast}\), while costs of predictive mode and reactive mode are not affected with \(T_{fast}\). This is because \(T_{fast}\) is an important element to calculate the probability of predictive mode failure (\(Pr_f\)). Signaling cost of reactive mode is smaller than that of predictive mode, since additional signal messages are required in predictive mode before layer 2 handover. When \(T_{fast}\) is large, signaling cost of FMIPv6 approaches to that of reactive mode, as \(Pr_f\) increases proportionally with \(T_{fast}\). Figure 4 represents the effect of \(T_{fast}\) on packet delivery cost, and shows that packet delivery costs of all schemes increase as \(T_{fast}\) increases. When \(T_{fast}\) is small, packet delivery costs of predictive is similar to that of reactive mode. However, packet delivery cost of reactive mode is smaller than that of predictive mode, when \(T_{fast}\) is large. This is because packet delivery cost depends on handover latency and \(T_{pre}\) is calculated by Eq. 17. That is, packet delivery cost of predictive mode is directly influenced by \(T_{fast}\). Also, when \(T_{fast}\) is large, packet delivery cost...
Generally, when \( T \) is large. Then to minimize total cost of FMIPv6, \( T \) should be as small as possible. Also, the optimized layer 2 triggering time (\( T_{\text{trigger}} \)) in FMIPv6 is more important. That is, layer 2 trigger event should be occurred and \( T_{\text{trigger}} \) should be almost zero to minimize the total cost of FMIPv6.

In conclusion, to enhance FMIPv6, transmission time of messages should be reduced and layer 2 triggering time should exactly be occurred right before layer 2 handover.

5. Conclusion

Several studies have been done, to evaluate the performance of FMIPv6 in different network environments. The previous works did not consider probability of predictive mode failure, or did not use various network elements for probability of predictive mode failure with combination of the two modes of FMIPv6. FMIPv6 is greatly influenced by probability of predictive mode failure which consists of radius of a cell, velocity of mobile nodes, and especially layer 2 triggering time. Also, in the previous papers two modes in FMIPv6 are evaluated separately. It is required to analyze the total performance of a protocol, to evaluate performance of the protocol. In this paper, FMIPv6 combining the two mode is analyzed through probability of predictive mode failure, since FMIPv6 is just a protocol.

We calculate signaling cost and packet delivery cost using \( T_{\text{fast}} \), since \( T_{\text{fast}} \) is an important element in FMIPv6. Generally, when \( T_{\text{fast}} \) is high, total cost of FMIPv6 may be large. Then to minimize total cost of FMIPv6, \( T_{\text{fast}} \) should be as small as possible. Also, the optimized layer 2 triggering time (\( T_{\text{trigger}} \)) in FMIPv6 is more important. Figure 5. Total cost as a function of layer 2 trigger time.

![Figure 5. Total cost as a function of layer 2 trigger time.](image)

### References


