On Secure-Smart Mobility Scheme in Proxy Mobile IPv6 Networks

Jae-Young Choi
College of Information and Communication Engineering
Sungkyunkwan University
Suwon, Republic of Korea
E-mail: jaeychoi@skku.edu

Jun-Dong Cho and Jongpil Jeong
Department of Human ICT Convergence
Sungkyunkwan University
Suwon, Republic of Korea
E-mail: {jdcho, jpjeong}@skku.edu

***Abstract*—IPv6-based mobility management techniques for Proxy Mobile IPv6 (PMIPv6) system are proposed to improve the performance of a variety of Fast Handover of Proxy MIPv6 (F-PMIPv6). However, F-PMIPv6 cannot be better than PMIPv6 in all scenarios. Therefore, selecting a proper mobility management scheme between PMIPv6 and F-PMIPv6 is an interesting issue, for its potential in enhancing the capacity and scalability of a system. We developed an analytical model to analyze the applicability of PMIPv6 and F-PMIPv6. Based on this model, we designed a Secure Smart Mobility (SSM) scheme that selects the better alternative between PMIPv6 and F-PMIPv6 for user according to changing mobility and service characteristics. When F-PMIPv6 is adopted, SSM chooses the best mobility anchor point and regional size to optimize the system performance. Numerical results illustrate the impact of key parameters on the applicability of PMIPv6 and F-PMIPv6. SSM has been proven to show better results than both PMIPv6 and F-PMIPv6.**

Keywords-PMIPv6; F-PMIPv6; Secure Smart Mobility.

I. INTRODUCTION

Proxy Mobile IPv6 (PMIPv6) [1] lets Mobile Nodes (MNs) connect to the PMIPv6 domain with various interfaces at the same time, and supports inter-equipment handover. Even though PMIPv6 reduced the handover delay time compare to Mobile IPv6 (MIPv6) [2] and its extensions, it is inferior in regard to applications with requirements for real-time communications such as Voice of IP (VoIP). Moreover, the handover interrupt time of the vertical handover process is longer than that of a horizontal handover process, because a Duplicate Address Detection (DAD) process has to occur the new interface of the MN receives the packet. For these reasons, Fast Handover for PMIPv6 (F-PMIPv6) [3] and Fast Handover for Hierarchical MIPv6 (FH-PMIPv6) [4] is proposed to improve the handover performance of PMIPv6.

PMIPv6 allows for maintaining the existing connection even if MIPv6 is not applied. It is a network-based mobility management technique to manage node mobility. Also, PMIPv6 supports multiple interfaces. Handover needs to be considered when Mobile Access Gateways (MAGs) have different interfaces. PMIPv6 must also go through a Local Mobility Anchor (LMA). If a Corresponding Node (CN) and MN are in the same area, packets inefficiently have to go through the LMA. Due to the network-based nature of PMIPv6, interfaces of the terminals can be known. Thus, additional signaling processes and MAGs have to be proceeded. If an MN connects through a new interface, the PMIPv6 domain does not have the information about the intensions of the MN regarding whether its connection is for undergoing handovers or multi-roaming. In the PMIPv6 domain, packets converge to LMA and cause a bottleneck state. Additional LMAs with an inter-LMA redirection function can help with load balancing and network stabilizing. Therefore, the establishment of a protocol for inter-LMA redirection is needed.

Based on [5]-[9], our SSM scheme is proposed to resolve two of the existing problems. It chooses the better alternative between PMIPv6 and F-PMIPv6 according to its mobility transitions and service conditions. When F-PMIPv6 is chosen, SSM selects the optimized mobility anchor point and its regional size, as well as the better protocol by analyzing the applications of PMIPv6 and F-PMIPv6. This paper proposes a reference analysis model based on two functions. First, Internet architectures are modeled using an MIP network. The MIP network is based on the cellular architecture used in Personal Communication System (PCS). PCS is region-oriented, while the Internet is space-oriented. In a region-oriented network, the distance between two terminals is measured by their physical spaces. Therefore, the Internet architecture is suitable for an abstract MIP network. The proposed analysis model considers both registration and packet transmission capabilities. Previous research preferred statistics about delayed handovers according to a registration record of the mobility management. However, packet transmission capability is also an important statistic in delay-sensitive services like mobile networks. Thus, considering both registration and packet transmission capability is important in analysis research.

The rest of the paper is organized as follows. Section 2 of this paper covers the handover techniques of PMIPv6 and F-PMIPv6. Section 3 proposes SSM and explains the security certification processes. Section 4 presents the numerical values and results, and Section 5 summarizes and concludes the study.

 ISBN: 978-1-61208-353-7

II. RELATED WORK

A. Handover of Network-based Mobility Protocols

To resolve the problems of the existing host-based mobility protocols, PMIPv6 [1] is proposed. When mobile terminal equipment tries to perform a handover, PMIPv6 deals with the situation on the network, without concern for any of the IPv6 mobility protocol-related signals. In the current state of MIPv6, when mobile terminal equipment tries to do a handover, it has to register its location. But, in the case of PMIPv6, internet application services are available only with the IPv6 stacks.

F-PMIPv6 [3] was proposed to reduce the packet losses from the MAG-LMA handover delay. Like the existing FMIPv6, F-PMIPv6 sets tunnels between the Previous MAG (PMAG) and destination NMAG to reduce the packet loss before the mobile terminal equipment moves to a new network.

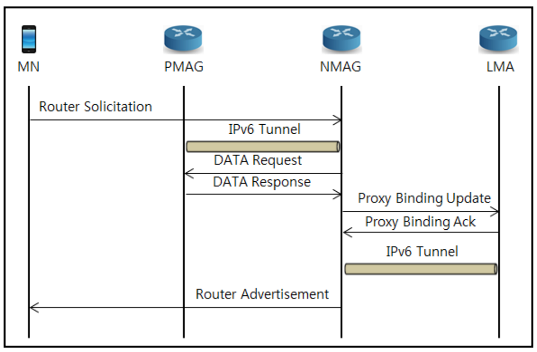

Figure 1. Handover of F-PMIPv6.

Fig. 1 shows the handover process of F-PMIPv6. Through tunneling, packets can be transmitted between PMAG and NMAG, even if the link is separated. However, this simultaneously overloads the network since the tunnel exchanges only the tunnel-related signals are exchanged between the MAGs, with no transmission of BU to LMA. Also, the transmission of BU from the MAG to the LMA to achieve Routing Optimization (RO) can cause order disturbance of packets.

B. Security Certification Process

Major operations of the security certification process are the initial registration process and the certification process. To join a regional mobile domain, an MN has to register at the AAA server and carry out a certification process to connect to the internet through the MAG [10].

III. SECURE-SMART MOBILITY (SSM) SCHEME

In this section, the Secure-Smart Mobility (SSM) method is proposed. SSM resolves the two following issues. It selects the better alternative between PMIPv6 and F-PMIPv6 for the users. And, when F-PMIPv6 is selected, SSM optimizes the LMA and system performance by choosing a proper regional size. Fig. 2 shows the structure of SSM and the operation of SSM. SSM is made up of four parts: LMA, MAG, MN, and a certifier AAA server. LMA and MAG are connected through a bi-directional tunnel using Proxy CoA. In SSM, a MAG does not have to be in the control of one LMA.

SSM is a protocol that supports mobility in a limited domain without the additional functional modification of MNs. The MN in a relevant domain can be distinguished from its MN-ID. If MN operates in the domain, connection certification is performed, and when it is completed, the MN receives a Home Network Prefix (HNP). The network supports mobility by maintaining the HNP of the MN statically, so that the MN can operate as if it is in the same Layer 3 wherever it is. LMA acts as a kind of home domain of the MN in the domain. It is usually located in the gateway location in the domain, and assigns HNP and sends it to the MN. LMA ensures the connection by maintaining the location and address information of every terminal of its range of management. Every packet sent from outside of the domain to inside is designed to be received by the LMA, and the packets are sent to the MN through the tunnel with the MAG. In contrast, packets sent from inside to outside of the domain are tunneled from MAG to LMA, and LMA sends those to the outside.

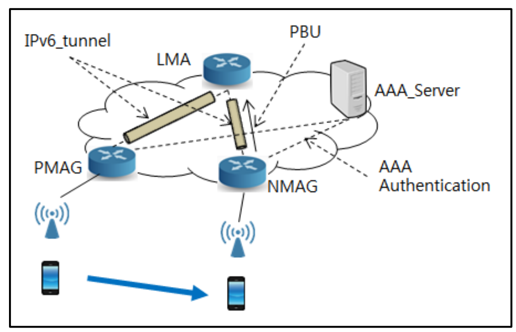

Figure 2. Operation of SSM.

MAG is the first hop that is directly connected to the MN, and instead of the MN, it undergoes mobility support signaling. Also, MAG performs the network connecting and routing functions of the MN. If the MN connects to the MAG, the MAG sets for the connection with LMA using the information of MN, and receives packets from the LMA for MN. Policy profiles include the address and its setup method of the LMA in charge, HNP information of the MN, the service policy, etc. MAG and LMA can be informed about the HMP information of the MN, and complete MN certification through these profiles.

SSM concerns every factor related to the network and MN. The most important factor so far is reflected on LMA, which affects the values of A, B, and δ. The discovery of a mobile LMA needs an LMA option of the router advertisement propagated into the MN from the LMA by a specific router interface. The LMA option includes a *preferences* field which is utilized in reflecting loads in LMA, and it ranges from 0 to 15. Another important network factor is the average distance between an LMA and its reachable MAG($l_{LMA \rightarrow MAG}$). $l_{LMA \rightarrow MAG}$ is made manually

 ISBN: 978-1-61208-353-7

in the LMA, and can be included in the extended LMA option offered to the MN. To obtain the number of hops to deliver the packets or signals, an MN or LMA can use the TTL field in the IP header. Then, the average number can be used when calculating C_T. The most important MN-related factors are the average time (T) that an MN stays in the MAG, and the average ratio of packet arrival (α). These parameters can be collected regularly by each MN using statistical analysis.

Suppose that the regional size of the MN's relocation is K. When K has an increasing value, F-PMIPv6 can obtain more average registration while the average packet transmission expense is increasing. However, K cannot be increased unlimitedly because of the bottleneck phenomenon of LMA. The overall average packet processing delay occurs due to $\alpha \cdot (A\omega K + BlgK + \delta)$, and can be differentiated by its load [9]. Thus, the optimized K which minimizes the overall cost C_T can be represented as K_{opt}, and it optimizes the overall performance of F-PMIPv6 compared to PMIPv6.

$$\min\ C_T(K)$$
$$s.t.\ \ \alpha \cdot (A\omega K + BlgK + \delta) < \varphi \qquad K \in Z^+ \quad (1)$$

where ψ is a constant which limits the overall packet process delay of LMA.

$C_{FPIMPv6}$, the cost function of F-PMIPv6, represents the absolute performance of F-PMIPv6 in view of the average registration and packet transmission delay.

$$C_{FPMIPv6} = n_1 + \frac{(m-1)D_{intra} + D_{inter}}{mT} + n_2 \cdot T_{PH} \quad (2)$$

Due to the restriction of $\alpha \cdot (A\omega K + BlgK + \delta) < \psi$, C_T and $C_{FPIMPv6}$ are minimized which lets K_{opt} represent the absolute performance and the relative performance.

$$C_{FPMIPv6} = C_T + n1 \cdot D + n2 \cdot T_{PM} \quad (3)$$

Since it is independent of K, $C_{FPMIPv6}$ moves through the Y axis by C_T in the scale of $C_T + n_1 \cdot D + n_2 \cdot T_{PM}$. Consequently, the K value that minimizes C_T and $C_{FPMIPv6}$ is from the restriction $\alpha \cdot (A\omega K + BlgK + \delta) < \psi$. Therefore F-PMIPv6 can achieve both its absolute performance and its relative performance. Since (1) is too complex, it needs to be simplified. Since K is not limitless, suppose the maximum value is N, the same as the number of MAGs that MN can relocate. As K increases, the following will occur:

Case 1: If the differential function of C_T, C_T', shows the trend of $C_T'(N) > 0$ on the site of its first origination from C_T, then $C_T(K)$ increases instead of decreasing. In this case, $C_T(1)$ is the minimum.

Case 2: In the case of $C_T'(K)$, the increasing and decreasing domain of $C_T(K)$ is first altered from over zero to below zero. $C_T'(K)$ is the minimum when $K' = K{:}min(C_T(K{=}1), C_T(K{=}Kmax)$. This analysis simplifies the solution of K_{opt}, as shown below.

Clearly, K_{opt} can optimize the performance of F-PMIPv6. Yet, $C_T(K_{opt}) > 0$ indicates that the optimized performance of F-PMIPv6 is still poorer than that of PMIPv6. Therefore, PMIPv6 is the most adequate alternative if $C_T(K_{opt}) > 0$. However, F-PMIPv6 is more adequate when there are many MAGs in LMA. Since $C_{FPMIPv6}$ represents the absolute performance of F-PMIPv6 and K_{opt} minimizes both C_T and $C_{FPMIPv6}$, LMA should be designated as an optimized regional mobility management entity with the minimization of $C_T(K_{opt})$, and K_{opt} should be the optimized regional size.

IV. PERFORMANCE EVALUTION

A. Cost analysis of PMIPv6 and F-PMIPv6

This section compares the register performance and defines the average registration profit D_R as the average registration time using F-PMIPv6 instead of PMIPv6. If D_R has a positive value, the average registration delay of PMIPv6 is shorter than that of F-PMIPv6. Independent from the handover delay time, the MN does not consider the regular binding update, which refreshes and delivers its binding record when analyzing CN or LMA. The major symbols of the subdivided section are displayed in Table 1.

TABLE I. PARAMETERS FOR REGISTRATION ANALYSIS

Parameter	Description
D_{RM}	The Average Registration Delay of PMIPv6
D_{LMA1}	The Average Delay of Registration Signaling through LMA Before Handover
D_{LMA2}	The Average Delay of Registration Signaling through LMA After Handover
D_{MAG}	The Average Delay of Registration Signaling through MAG
D_{intra}	The Average Delay of Registration Process during intra-LMA Handover
D_{inter}	The Average Delay of Registration Process during inter-LMA Handover
$D_{LMA1\rightarrow MAG}$	The Average Delay of Registration Signaling from LMA to MAG
$D_{LMA2\rightarrow LMA1}$	The Average Delay of Registration Signaling from the new LMA to the previous LMA After Handover
$D_{MAG\rightarrow MN}$	The Average Delay of Registration Signaling from MAG to MN
$l_{LMA\rightarrow MAG}$	The Average Distance between LMA and MAG
$l_{MAG\rightarrow MN}$	The Average Distance between MN and MAG
μ	The Signaling Cost per Unit distance of Wired Link
$\frac{MinInt + MaxInt}{2}$	The Average Delay of RA (Router Advertisement) Transmission

While calculating D_R, it is hypothesized that the signal transmission delay of the uplink and downlink is the same for simplicity. The registration of PMIPv6 includes home registration. However, in F-PMIPv6, when the MN tries roaming to another region, the process includes regional registration as well as home registration.

As such, D_{RM}, D_{intra}, D_{inter} can be calculated with (4)-(6).

$$D_{RM} = \frac{MinInt + MaxInt}{2} + 2D_{MAG} + 2D_{LMA1\rightarrow MAG} \quad (4)$$

$$D_{intra} = \frac{MinInt + MaxInt}{2} + 2D_{MAG} + 2D_{LMA1} + 2D_{LMA1\rightarrow MAG} \quad (5)$$

$$D_{inter} = D_{intra} + D_{LMA1} + D_{LMA2} + 2D_{LMA2\rightarrow LMA1} \quad (6)$$

The number of handovers required in moving an MN, $m(m \geq 1)$ means that the MN relocates to a new area on the m^{th} handover trial. Therefore, the overall average delays D_{FPT} and D_{PT} from the m^{th} handover of MN in F-PMIPv6 and PMIPv6 are given in (7)-(8).

$$D_{FPT} = (m-1)D_{intra} + D_{inter} \quad (7)$$

$$D_{PT} = mD_{RM} \quad (8)$$

D_R can be calculated as follows (9).

$$D_R = \frac{(D_{FPT} - D_{PT})}{mT} = \frac{((m-1)D_{intra} + D_{inter} - mD_{RM})}{mT} \quad (9)$$

Suppose that the average signal transmission delay of a wired link is proportional to the measured distance between the moving numbers of a hop. Let the cost of the unit distance signal transmission be μ, which includes the unit distance propagation delay and cuing delay of each hop. Since the wireless bandwidth is usually narrow, suppose the average signal transmission delay of a wireless link is $\theta \cdot \mu$ when $a > 1$. The average signal transmission delay is different between the core network and the access network. To simplify the analysis, μ reflects the average level of a signal in the core network and the access network. Therefore, D_R can be altered to (10).

$$D_R = \frac{\mu(2\theta + 2ml_{LMA \to MAG}) - 2(\left(\frac{MinIn + MaxInt}{2}\right)(m-1) + mD_M}{mT} \quad (10)$$

Using (10), high registration profit from the distance between the MN and MAG and the distance between the LMA and MAG can be obtained from F-PMIPv6. When $D_R < 0$, higher average registration profit can be obtained from F-PMIPv6. According to (9)-(10), m has to satisfy the following (11) to achieve $D_R < 0$.

$$m > \frac{D_{inter} - D_{intra}}{D_{RM} - D_{intra}} = \frac{2\mu\left(\theta + \frac{MinInt + MaxInt}{2}\right) + D_L}{2\mu\left(l_{LMA \to MAG} - \frac{MinInt + MaxInt}{2}\right) + D_L - D_M} \quad (11)$$

The value of m has a close relation with the size of the region. Suppose each MN transfers to a random LMA, and the regional size is K.

When MN always roams in the assigned area, F-PMIPv6 has better performance than PMIPv6 in registration, and the average registration profit can be calculated as $|2\mu \cdot (l_{LMA \to MAG} - (MinInt + MaxInt)/2|$. $K \geqslant N$ when MN roams in its region. If F-PMIPv6 is selected, the number of handovers of intra-LMA and inter-LMA are m-1 and 0, respectively. However, if PMIPv6 is selected, the number of handovers would be m-1. Therefore, D_R can be calculated as below.

$$D_R = \frac{(m-1)D_{intra} - (m-1)D_{RM}}{m-1} = 2\mu\left(l_{LMA \to MAG} - \frac{MinInt + MaxInt}{2}\right) + D_M \quad (12)$$

Generally, $l_{LMA \to MAG} - (MinInt + MaxInt)/2 < 0$, and there are no big differences between MAG and MN in the average registration signal process delay time. In this case, D_R can be simplified as $2\mu \cdot (l_{LMA \to MAG} - (MinInt + MaxInt)/2$. Since $2\mu \cdot (l_{LMA \to MAG} - (MinInt + MaxInt)/2 < 0$, F-PMIPv6 has better performance than PMIPv6 in registration. Also, the average registration profit is related to $|2\mu \cdot (l_{LMA \to MAG} - (MinInt + MaxInt)|$.

When MN roams between indifferent areas, D_R is dependent on the regional area K, and their relations are arranged in (13). Also, F-PMIPv6 can achieve average registration profit only when (14) is satisfied.

$$D_R = \frac{(2\mu \cdot \theta \cdot D_H) \cdot (2N - 2K - 1) + 2\mu \cdot l_{LMA \to MAG} \cdot (1 - 2K)}{(2N-2) \cdot T} + \frac{4\mu \cdot (N-1) \cdot \frac{MinInt + MaxInt}{2} + 2D_M(N-1)(D_M - D_L)}{(2N-2)T} \quad (13)$$

$$\frac{2N-2}{2N-2K-1} > \frac{2\mu(\theta + l_{LMA \to MAG}) + D_L}{2\mu(l_{LMA \to MAG} - \frac{MinInt + MaxInt}{2} + D_L - D_M} \quad (14)$$

When MN roams between indifferent areas, $K < N$. In this case, when condition I indicates an MN which enters LMA$(i = 1, 2, \ldots, N)$, the movement of a roaming MN through different MAGs can be modeled by a Markov chain. As in Fig. 3, it is predicted that the MN can move in each direction (except for the boundary MAGs) with a probability of 1/2.

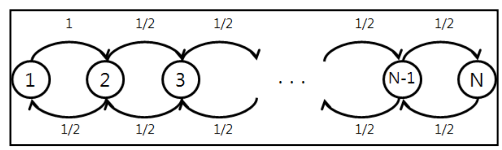

Figure 3. State transmission diagram.

The normal condition probability of condition I is defined as $\pi(I = 1, 2, \ldots, N)$. By Fig. 4, the balance equation of the Markov chain is given as follows.

$$\begin{cases} \pi_1 = \pi_2 \times \frac{1}{2} \\ \pi_2 = \pi_1 + \pi_3 \times \frac{1}{2} \\ \pi_i = (\pi_{i-1} + \pi_{i+1} \times \frac{1}{2} & i = 3,4,\ldots,N-2 \\ \pi_{N-1} = \pi_{N-2} \times \frac{1}{2} + \pi_N \end{cases} \quad (15)$$

(16) can be recreated repeatedly as follows.

$$\begin{cases} \pi_1 = 0.5 \times \pi_2 \\ \pi_2 = \pi_{i+1} & i = 3,4,\ldots,N-2 \\ \pi_N = 0.5 \times \pi_{N-1} \end{cases} \quad (16)$$

By $\sum_{i=1}^{\infty} \pi = 1$, the normal condition probability is calculated as follows.

$$\begin{cases} \pi_1 = \pi_N = 1/(2 \times (N-1) \\ \pi_i = \frac{1}{N-1} \end{cases} \quad (17)$$

This gives the probability of the MN's regional roaming.

$$P_{intra} = \sum_{i=1}^{K} \pi_i = \frac{2K-1}{2N-2} \qquad K < N \quad (18)$$

Therefore, the regional roaming probability is $P_{inter} = 1 - P_{intra}$. The regional relocation probability after the m^{th} handover (P_{out}^{in}) is expected as below.

$$P_{out}^{m} = {P_{intra}}^{m-1} \times P_{inter} = (\frac{2K-1}{2N-2})^{m-1} \times (1 - \frac{2K-1}{2N-2}) \quad (19)$$

$$E(m) = \sum_{m=1}^{\infty} m\, P_{out}^{m} = \frac{2N-2}{2N-2K-1} \quad (20)$$

With (20), (10) and (11) can be converted to (13) and (14), respectively. Clearly, D_R is dependent on the regional size by (13). A high K value indicates a high average registration profit. Also, the average registration profit of F-PMIPv6 can be obtained only in case if (14) is satisfied.

The packet transmission performance is compared and defined. The average packet transmission cost T_P is defined as the average consumed time to deliver packets from CN to MN through F-PMIPv6 instead of PMIPv6.

TABLE II. PARAMETERS FOR PACKET DELIVERY ANALYSIS

Parameter	Description
T_{PM}	The Average Packet Delivery Latency of MIPv6
α	The Average Packet Arrival Rate
$T_{CN\to LMA}$	The Average Latency for Packet Delivery from CN to LMA
$T_{LMA\to MAG}$	The Average Latency for Packet Delivery from LMA to MAG
T_{PF}	The Average Packet Delivery Latency of PMIPv6
T_L	The Average Packet Processing Delay of LMA
T_M	The Average Packet Processing Delay of MAG
$l_{LMA\to MAG}$	The Average Distance Between LMA and MAG

The major symbols used in analyzing T_P are shown in Table 2. In PMIPv6 and F-PMIPv6, packets can be delivered in two modes. One is transmitting packets through the MAG. In this mode, the MAG receives every packet instead of the MN and delivers it to the MN. In the other mode, packets are directly delivered to the MN. In the following analysis, the average packet transmission cost is modeled by the former mode, but its implied method is the latter. The average delay of packet transmission from CN to MN through PMIPv6 and F-PMIPv6 can be depicted as follows.

$$T_{PM} = \alpha \cdot (T_L + T_{CN\to LMA} + T_{LMA\to MAG} + T_{MAG\to MN} \quad (21)$$

$$T_{PF} = \alpha \cdot (T_L + T_M + T_{CN\to LMA} + T_{LMA\to MAG} + T_{MAG\to MN} \quad (22)$$

The average packet transmission cost is as below.

$$T_P = T_{PF} - T_{PM}$$
$$= \alpha \cdot (T_M + T_{CN\to LMA} + T_{MAG\to MN} - T_{LMA\to MAG}) \quad (23)$$

The average processing delay of LMA(T_M) is established in a similar way to that in the previous study. Since the average number of regional MN is ωK, suppose that the MAG can provide an average ω of MN. Therefore, the complexity of finding the binding cash in LMA is proportional to ωK. Also, since an inquiry of an IP routing table is generally based on the corresponding longest prefix, it is realized using a Patricia Trie [9]. The complexity of an IP routing table inquiry is proportional to the length of the routing table log. The average delay of packet encapsulation in LMA is δ. So, when A and B are clearly defined coefficients, T_M can be calculated by (24).

$$T_M = A\omega K + BlgK + \delta \quad (24)$$

Suppose that the average packet transmission delay of a wired link is proportional to the number of relocated hops with coefficient η. Then, (23) can be converted to (25).

$$T_P = \alpha \cdot (A\omega K + BlgK + \delta$$
$$+\eta(l_{CN\to LMA} + l_{LMA\to MAG} - \frac{MinInt+MaxInt}{2}) \quad (25)$$

From $l_{CN\to LMA} + l_{LMA\to MAG} \geq \frac{MinInt+MaxInt}{2}$, it is clear that (25) represents the average packet transmission cost T_P. $T_P < 0$ indicates that the average packet transmission delay of F-PMIPv6 is higher than that of PMIPv6. This is based on the fact that the regional propagation of LMA is the result of a triangle routing problem. The route of packet transmission is converted from PMIPv6 to an outer network to the outer network of an MN F-PMIPv6 and then the LMA, and finally, the MN.

The overall cost function expressed as C_T describes the general performance of F-PMIPv6 compared to PMIPv6 in every point of view, including registration and packet transmission. n_1 and n_2 are coefficients defined in (26).

$$C_T = n_1 \cdot D_R + n_2 \cdot T_P \quad (26)$$

It reflects the application of F-PMIPv6 and PMIPv6. When $C_T < 0$, F-PMIPv6 is applied rather than PMIPv6 or F-PMIPv6 is more adequate.

B. Numerical Results

The numerical analysis of several major parameters of F-PMIPv6 and PMIPv6 is shown. SSM, PMIPv6, and F-PMIPv6 are compared. The values of parameters used here are shown in Table 3.

TABLE III. PARAMETER VALUES USED IN PERFORMANCE ANALYSIS

Parameter	Value	Parameter	Value
μ	0.008	n_1	10
η	0.008	n_2	1
θ	2	D_{LMA1}	0.008
ω	15	D_{MAG}	0.008
N	30	A	0.00003
D_{LMA2}	0.005	$MinInt$	1
B	0.00007	$MaxInt$	5
δ	0.00005	T_L	0.008
$l_{CN\to LMA}$	18	φ	0.015

The registration delay in PMIPv6 or F-PMIPv6 affects the handover delay directly. This is an important statistic to evaluate the quality of service in the network. $n_1 > n_2$ due to the importance of handover delay.

Suppose that the MN does not relocate the access point more frequently than once every second. So, $T \geqslant 1$. The TTL field of the IP header is generally 32 or 64. That is, the limit of the number of hops through which packets can be transmitted is 32 or 64. $l_{CN\rightarrow LMA} = 25$ and $l_{LMA\rightarrow MAG} = 10$.

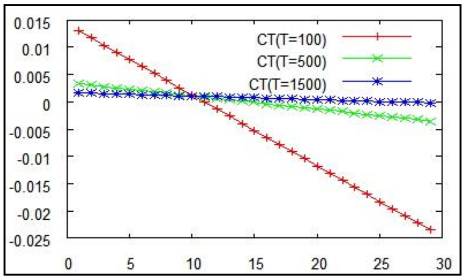

Figure 4. Impact of T on C_T.

Fig. 4 explains the relations between C_T and T. In this scenario, α = 0.05 and $l_{LMA\rightarrow MAG} = 6$. C_T is less than zero when $K > 9$, and it decreases with T since T reflects the velocity of MN. In a small region ($K \leqslant 9$), the MN moves fast, and the ratio of MNs that show fast relocation is high. Due to the double registration in F-PMIPv6 would cause a long registration delay. In this case, F-PMIPv6 cannot deliver the average registration profit. As the MN movement becomes faster, the F-PMIPv6 registration performance is more degenerated. On the other hand, when K is high enough ($K \geqslant 9$), the probability of an N that moves outside of the region is low, even if the MN is moving fast. In other words, most of the mobility is micro mobility. In this case, F-PMIPv6 can yield the average registration profit.

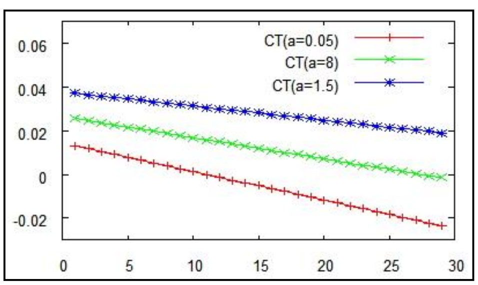

Figure 5. Impact of α on C_T.

Fig. 5 depicts the effect of α on C_T. In this scenario, T = 100 and $l_{LMA\rightarrow MAG} = 6$. It shows the proportional trend of C_T and α. The fact that the average packet transmission cost increases as α increases leads to an increasing value of C_T.

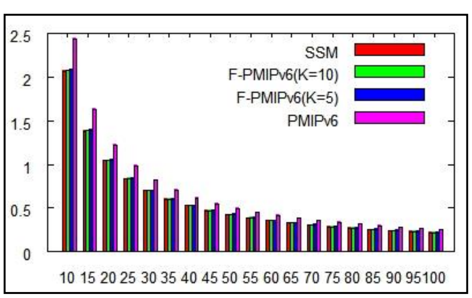

Figure 6. Cost *vs*. *T*.

In Fig. 6, the cost is a combination of the registration delay and packet transmission delay. The Cost of PMIPv6 can be calculated as $n_1 \cdot D_{RM} + n_2 \cdot T_{PM}$.

V. CONCLUSION

Both PMIPv6 and F-PMIPv6 are the mobility management solutions for IPv6 networks. However, F-PMIPv6 is an extension of PMIPv6, and surpasses PMIPv6 in some aspects, not every aspect. This study proposed an analytical model for an improved protocol, F-PMIPv6, and compared it to PMIPv6. Based on this analytical model, the SSM method selects the most adequate protocol and MAG. The mathematical results explain the effects of several key parameters based on the application ranges of PMIPv6 and F-PMIPv6. With the SSM method, an adequate protocol between PMIPv6 and F-PMIPv6 is chosen. Also, SSM showed better performance compared to PMIPv6 or F-PMIPv6.

ACKNOWLEDGEMENT

This research was supported by the Ministry of Trade, Industry and Energy (MOTIE), KOREA, through the Education Support program for Creative and Industrial Convergence (Grant Number N0000717) and Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2010-0024695). Also, this research was supported by Next-Generation Information Computing Development Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (No.2010-0020737).

Corresponding author: Jongpil Jeong.

REFERENCES

[1] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and Patil, B., “Proxy Mobile IPv6”, IETF RFC 213, August 2008.

[2] D. Johnson, C. Perkins, J. Arkko, “Mobility Support in IPv6”, IETF RFC 3775, June 2004.

[3] H. Yokota and R. Koodli, “Fast Handovers for Proxy Mobile IPv6”, IETF RFC 5949, September 2010.

[4] M. C. Chuang and J. F. Lee, “FH-PMIPv6: A fast handoff scheme in Proxy Mobile IPv6 networks”, IEEE Consumer Electronics, May 2011, pp. 1297-1300.

[5] Guan, J. Zhou, H. Yan, Z. Qin, Y. and Zhang, H., “Implementation and analysis of proxy MIPv6”, Wireless Communications and Mobile Computing, vol.11, April 2011, pp. 477-490.

[6] N. Neumann, J. Lei, X. Fu, G. Zhang, “I-PMIPv6 : An Inter-Domain Mobility Extension for Proxy-Mobile IP”, IWCMC’ 09, June 2009.

[7] G. Kim, “Low latency cross layer handover scheme in proxy mobile IPv6 domain”, NEW2AN 2008, pp. 110-121, September 2008.

[8] S. Yoo and J. Jeong, “Analytical Approach of Fast Inter-Domain Handover Scheme in Proxy Mobile IPv6 Networks with Multicasting Support”, Journal of Korea Information Processing Society, vol. 19-C, no. 2, April 2012, pp. 153-166.

[9] S. Han and J. Jeong, “Intelligent Hierarchical Mobility Support Scheme in F-PMIPv6 Networks”, Jornal of the Korean Institute of Communications and Information Sciences”, vol. 38A, no. 04, April 2013, pp. 337-349.

[10] I. Im, Y. Cho, J. Choi, and J. Jeong, “Security-Effective Fast Authentication Mechanism for Network Mobility in Proxy Mobile IPv6 Networks,” ICCSA 2012, vol. 4, June 2012, pp. 543-559.