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Analytical Approach of New Random-walk Based Mobility Management Scheme in IP-based Mobile Networks

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Abstract

In next-generation wireless networks, provisioning of IP-based network architecture and seamless transmission services are very important issues for mobile nodes. For this reason, a mobility management mechanism to support global roaming is highly regarded. These technologies bring a broader life by using a global roaming account through the connection of multiple devices or technology to mobile users; they also provide real-time multimedia services. This paper presents a comprehensive performance analysis of fast handover for hierarchical mobile IPv6 (F-HMIPv6), hierarchical mobile IPv6 (HMIPv6), Proxy Mobile IPv6 (PMIPv6), and fast Proxy Mobile IPv6 (FPMIPv6) using the fluid-flow model and random-walk model. As a result, the location update cost of the PMIPv6 and FPMIPv6 is better than that of HMIPv6 and F-HMIPv6. These results suggest that the network-based mobility management technology is superior to the hierarchical mobility management technology in the mobility environment.

Keywords: *Mobility model; PMIPv6; FPMIPv6; HMIPv6; F-HMIPv6; Mobility Management.*

1. Introduction

Mobility management protocols can be divided into two varieties: host-based and network-based mobility management protocols. Mobile IP v6 (MIPv6) [1], fast handover for IPv6 (FMIPv6) [2], hierarchical mobile IPv6 (HMIPv6) [3], and fast handover for hierarchical mobile IPv6 (F-HMIPv6) [4] are typical host-based mobility protocols, whereas Proxy Mobile IPv6 (PMIPv6) [5] and fast Proxy Mobile IPv6 (FPMIPv6) [6] are network-based mobility management protocols. The existing Internet network identifier and host identifier consist of the assigned IP address. The network identifier is the only information indicating that the network is connected to the host, while the host identifier is the only information identifying the host within its own networks. The host creates the socket using the IP address and port number of the transport layer, and sets up a connection to another host using this socket address. While the host connects with other hosts, its IP address should remain the same. If the host moves to another network, the IP address, as the network identifier, must change. Because changing the IP address means changing the socket address, there is a disadvantage in that the existing connection is disconnected and must be connected again. Various mobility management schemes are presented to solve these problems; nevertheless, the problems are still difficult to

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solve.

To improve the mobility management protocol, some literature regarding the IPv6-based mobile mobility protocol introduced evaluation results; however, the protocol has some disadvantages and is based on a simple principle theory. In this paper, HMIPv6, F-HMIPv6, PMIPv6, and FPMIPv6 are evaluated in a cellular network for efficiency, and some models are compared to calculate the cost of signaling and packet transmission. The evaluation results of each protocol are also analyzed based on the new random walk model.

The hierarchical structure protocol, analyzed by the new random walk model, reduces the inconvenience when each of the MNs performs a binding update; it shows the cost efficiency through the prediction of a fast handover structure. Additionally, through the network-based PMIPv6 and when FPMIPv6 is applied to the new random walk, the cost-efficiency is analyzed by comparing the protocol of the hierarchical structure and the fast handover protocol. In addition, the efficient result of the new random walk model is presented in comparison with the fluid mobility model.

This paper is organized as follows. Section 2 presents related research, and introduces the location update process of F-HMIPv6, PMIPv6 and FPMIPv6 as well as the fluid mobility model and random walk mobility model. Section 3 presents a random walk model, applied to each protocol for analysis. Section 4 performs the evaluation and cost analysis for the proposed model. Section 5 describes the conclusions.

2. Related Work

2.1 Mobility support protocols

In the IPv6-based network, if the MN, which is not a function of MIPv6, tries to handover, it should shut down and establish a new connection. To prevent this, a PMIPv6 protocol is proposed in order to keep the existing connections without MIPv6 functionality [7, 8]. The PMIPv6 consists of a local mobility anchor (LMA) and a Mobile Access Gateway (MAG), and authentication, authorization of accounting (AAA) servers. When the MN comes close to the first domain and connects to the access link which is connected with the MAG, the MAG detects this and gets the MN’s information through the certification process using a unique key value [2]. The MAG sends the Proxy Binding Update (PBU) message to the LMA using the MN's information. The LMA receives the PBU message, and connects the tunnel with the MAG using the information in the PBU message. The LMA then sends the Proxy Binding Acknowledgement (PBAck) message to the MAG to indicate that the tunnel setup and PBU have completed. The MAG sets up the tunnel with the LMA, and sends the RA message in order to set the IP address of the MN. The procedures for the PMIPv6 performance are referred to in Figure 1.

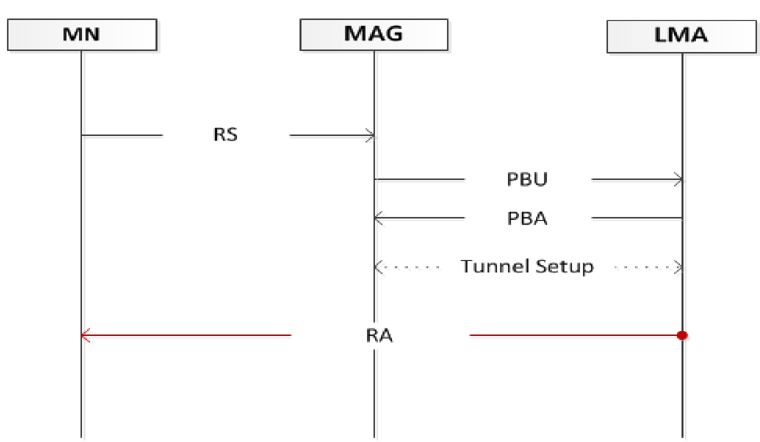

Figure 1. Location Update Procedure for PMIPv6.

FPMIPv6 involves the same technology as PMIPv6. The MN in the FPMIPv6 domain follows the procedures of the handover process in the PMIPv6. It consists of an nAR, the previous AR, the new MAG, the previous MAG, and the LMA.

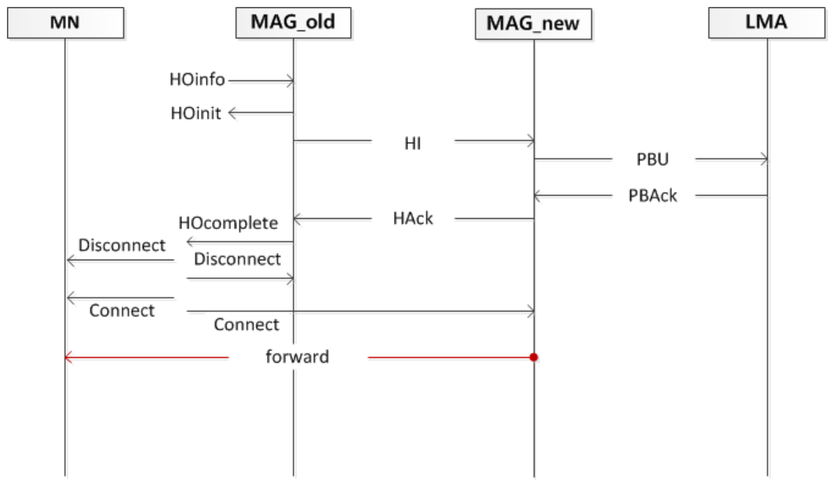

Figure 2. Location Update Procedure for FPMIPv6.

The goal of FPMIPv6 is to have the lowest handover latency and minimal packet loss in the network layer. First, it is possible to predict handover [9]. According to the results, the new MAG sends a PBU to the LMA, and through this act, the LMA sends a ready signal to the new MAG to be predicted. When the downlink traffic reaches the previous MAG, the MN stops communicating with the previous MAG and redirects a buffer to the new MAG. The key of the proposed handover is the role of the MAG. The nAR, pAR, and MAG determine the initialization of the handover information according to the MN's information. A newly-set MAG commands that a proxy binding update message is sent to the LMA. This message from the LMA will receive a response in a short period of time and the new MAG will receive approval from the previous MAG. The previous MAG shares a new MAG's information with the current AR, MN, and will set up its own information for the new AR in accordance with the floor area ratio of the interface. The important issues of FPMIPv6 are the timely handover timing and the exact predictability of the handover [10]. The basic process and procedure of FPMIPv6 are referred to in Figure 2. The previous MAG received timely information about the handover from the AR connected with the MN. If it can predict that the handover time will be coming soon, the MN sends an HOinfo message to the previous MAG using the AR information, and changes the path to a new AR. The previous MAG sends the HI message, the initial message of the handover, to the new MAG. The new MAG receiving the HI message sends a PBU message to the LMA, and the LMA prepares a new binding and sends the proxy-binding response message to the new MAG. The MN's packet will be forwarded to the new MAG, and the MAG receiving the Proxy Binding Response message transmits the handover response message to the MAG. In this process, buffering traffic occurs in the MN. This buffering keeps going until the MN completes the connection with the new MAG. When the traffic is forwarded to the MN, the previous MAG will receive the completion message and stop the connection with the MN.

2.2 Mobility Modeling

A personal communications service (PCS) system can be used as a wireless-based device, and the areas where radio signals can be processed are called cells. If a mobile device moves to another cell, most of the PCS performs a movement procedure in the network map formed hexagonal cells as shown in Figure 3. An IPv6-based wireless cellular network is suitable to evaluate the performance of the roaming user; the mobile service area is divided into the same size as each cell. Each cell has a hexagonal shape and is surrounded by the ring forms. The center cell is "0" and the surrounding cells are defined as 1, 2, 3, etc. based on the distance. Each cell in Figure 3 is managed by the MAG (AR); the LMA (MAP) domain is composed of six rings [11].

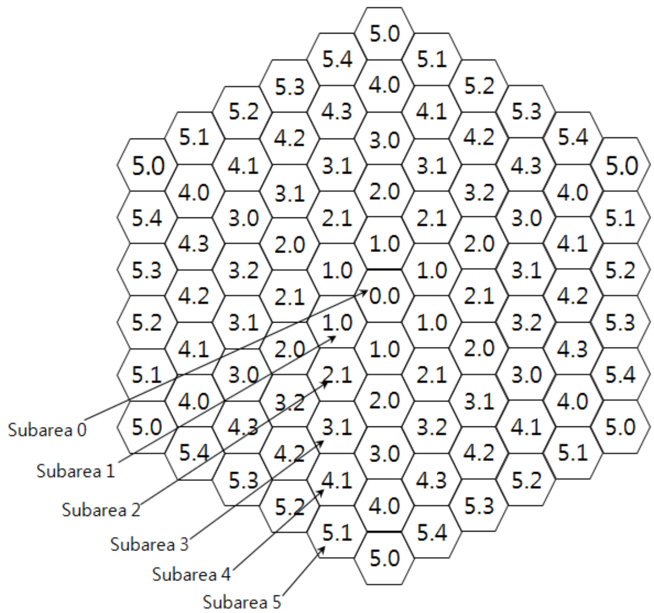

Figure 3. LMA (MAP) Domain Configuration.

3. Mathemathical Modeling of Hierarchical Mobility Managmenet Protocols

A 2-D random walk model consists of a cluster of six subareas formed into a hexagon [12]. The cell located in the center is defined as subarea-0 and the surrounding area (x-1) is defined as the subarea x cell.

As in Figure 4, subarea x, except subarea-0, consists of 6x. The probability that the MN moves to the adjacent cell is 1/6, and the number of moves is k. Figure 4 depicts the cluster of 6 subareas, and ●, based on line-1 - line-3, is distributed in the same relative position in each area and belongs to the same group; the properties are also the same. Each cell has a property such as (x,y) type; the property of subarea-0 is $(0,0)$.

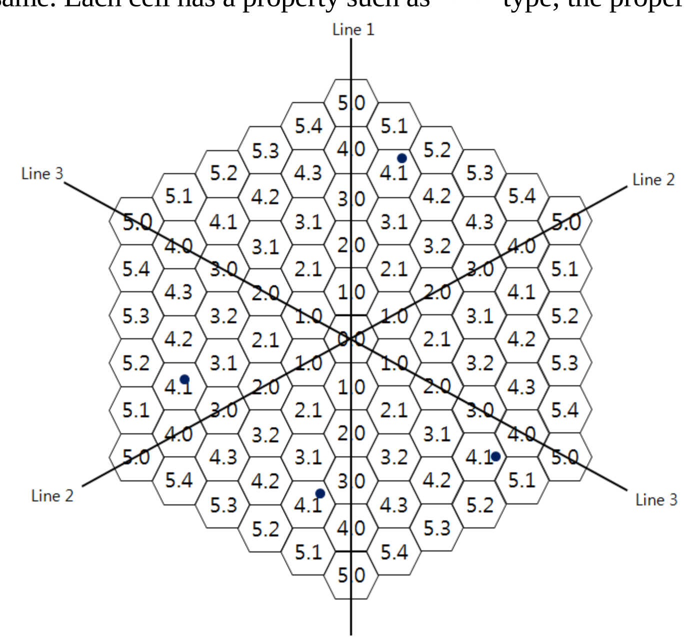

Figure 4. The Structure Diagram of a 6-area Cluster.

Subarea-1 cells $(1,0)$, consisting of six properties, are a close neighbor of the cell $(0,0)$, and have three borders. Subarea-2 in the cluster has the neighboring cells of $(2,1),(2,0)$, etc., which have two or three boundaries. In this way, it can be expressed until Subarea-5 and be explained in the following ways. The neighboring cells of $(2,0)$ are $(1,0),(3,0),(3,1),(3,2),(2,1),(2,1)$ and can be represented with the same group. The moving probability of each cell for the subarea-n cluster (n = 6) is shown in Figure 5.

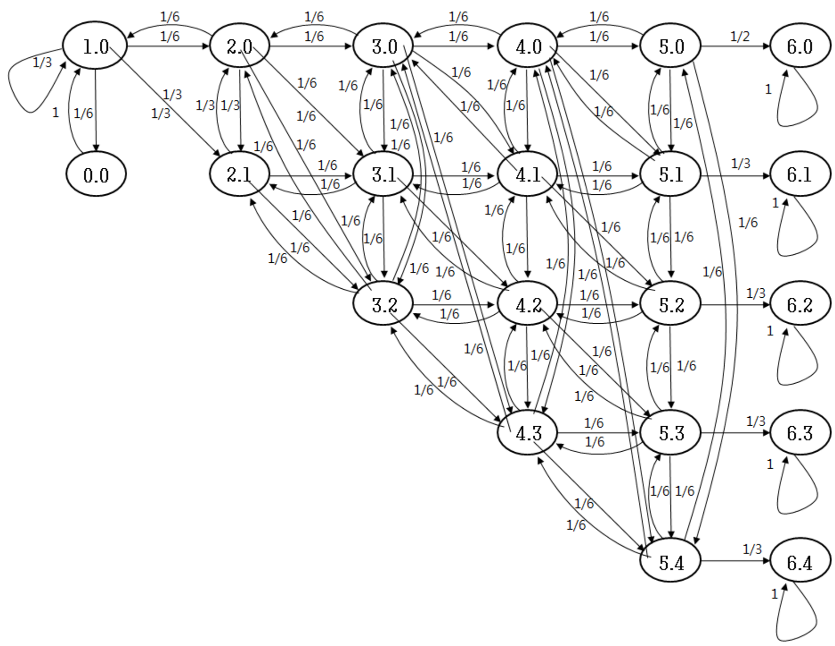

Figure 5. The State Diagram of a 6-subarea Cluster.

$P(x,y)(x',y')$ is defined as (x',y') moves from (x,y). The probability that (0,0) moves to (0,1) is P(0,0)(1,0)=1, and the probability $P(1,0)(0,0) = 1/6$ when (1,0) moves to (0,0). If (1,0) moved to its own (1,0), the probability is $P(1,0)(1,0) = 1/3$. $0 \le j < n-1$, $P(n-1,j),(n,j)$ is defined as the probability that the MN moves from $(n-1,j)$ to the neighboring cell, and when (n,j) moves to itself, the probability is $P(n-1,j),(n,j) = 1, 0 \le j < n-1$. $S(n)$ is the total number of subarea in the subarea-n clusters. If $S(1) = 2, n > 1$, $S(n)$ is defined as the following formula.

$$S(n) = \frac{n(n+1)}{2}$$

In the matrix consisting of $S(n) \times S(n)$, the probability of moving into each subarea can be represented as matrix $P = \left(p(x,y),(x',y')\right)$ and is expressed as shown in Figure 6.

$$P = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1/6 & 1/3 & 1/3 & 1/6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1/3 & 0 & 1/3 & 1/3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1/6 & 1/3 & 0 & 1/3 & 1/6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1/6 & 1/6 & 1/6 & 1/6 & 1/6 & 1/6 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/6 & 1/3 & 0 & 0 & 1/3 & 1/6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/3 & 0 & 0 & 1/3 & 0 & 1/3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/6 & 1/6 & 1/6 & 0 & 1/6 & 1/6 & 1/6 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/6 & 0 & 1/3 & 0 & 0 & 1/3 & 1/6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1/6 & 1/6 & 0 & 1/6 & 1/6 & 0 & 1/3 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/6 & 1/6 & 1/6 & 0 & 1/6 & 1/3 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/6 & 0 & 1/3 & 0 & 1/2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}_{S(n) \times S(n)}$$

Figure 6. Moving Probability Matrix for Each Subarea.

$y_i^{(k)}$ is the resulting number of processing times that represent the times to process the area S_j until the k level. $M_i\left[y_i^{(k)}\right]$ is the number of times that represent the number of steps from the area S_i to S_j [13]. This is represented by the following formula.

$$M_i\left[y_j^{(k)}\right] \rightarrow \left(z_{ij} - \pi_j\right) + k\pi_j$$

U_{BU} is the analytical model for the average number of update times. U_{nBU} is represented as the number of update times from subarea S_i to subarea 1*,2*, 3* as follows.

$$U_{BU} = M_i\left[y_{1*}^{(k)}\right] + M_i\left[y_{2*}^{(k)}\right] + M_i\left[y_{3*}^{(k)}\right] + M_i\left[y_{4*}^{(k)}\right]$$

$$U_{BU} = \sum_{n=1}^{4} M_i\left[y_n^{(k)}\right]$$

$$U_{nBU} = \sum_{n=1*}^{N*} M_i\left[y_n^{(k)}\right]$$

The mobility ratio for the intra-domain and within-domain is represented as the following formula.

$$R_{inter} = \frac{\kappa - U_{BU}}{\kappa}, \quad R_{intra} = \frac{U_{BU}}{\kappa}$$

The following section covers the performance analysis of F-HMIPv6, PMIPv6 and FPMIPv6, and calculates the location update cost and packet delivery cost.

3.1 F-HMIPv6

In general, the location update cost is differed between intra-domain and inter-domain, and the procedure shows a different picture depending on the characteristics of each domain. In case of Inter-domain, the operation is same as F-HMIPv6 while Intra-domain case includes the operation procedure of Inter-domain. F-HMIPv6 signaling can be expressed using the following formula if it can be assumed that F-HMIPv6 is optimized in the path of the routing, and PAR and NAR , MAP and MAP have the equal distance, respectively.

$$S_{intra}^{F-HMIPv6} = 5\kappa + 7\tau \times d_{AR-MAP}$$

$$S_{inter}^{F-HMIPv6} = S_{intra}^{F-HMIPv6} + S_{MIPv6,RO}^{F-HMIPv6}$$

$$S_{MIPv6,RO}^{F-HMIPv6} = 2\kappa + 2\tau \times d_{AR-MAP} + N_{CN} \times S_{BU}$$

In case that mobility model applied here, the location update cost is as follows.

$$C_l^{F-HMIPv6} = \frac{R_d S_{inter}^{F-HMIPv6} + (N_{AR} \times R_{intra} - R_{inter}) S_{intra}^{F-HMIPv6}}{\rho \times A_d}$$

The conversion of RCoA and LCoA about MN of MAP's binding cache table in F-HMIPv6 is same as the binding techniques between HoA and CoA of HA.

$$C_p^{F-HMIPv6} = P_{MAP} + P_{HA} + C_T$$

All packets are passed to the MN by LCoA of the tunneled MN in MAP. The lookup cost is proportional to the size of binding cache table and the number of MN belongs to the MAP domain. In addition, the routing cost is proportional to the number of AR in MAP domain.

$$P_{MAP} = \lambda_s \times \left[\alpha \times N_{AR} \times \rho \times A_c + \beta \times \log_2 (N_{AR}) \right]$$

λ_s means the packets per second as the session arrival rate, and α shows the relationship of binding cache table according to the cost and size of MAP's lookup. β represents the relationship between the number of AR in the MAP domain and the routing cost, and A_C means the area of the cell (m^2), ρ means density of the user state ($/m^2$) belongs to a cell, and N_{AR} is the number of AR in the MAP domain. F-HMIPv6 is suitable to solve the problem of route optimization. Transmission of the packet is routed directly to the MN's new location.

$$P_{HA} = \lambda_p \times \theta_{HA}$$

λ_p is the packet arrival rate, and θ_{HA} is the cost of the packet processing to HA. λ_s and λ_p are the session arrival rate and packet arrival rate, respectively. The packet transmission cost, C_T , can be calculated as follows.

$$C_T = \kappa \times \lambda_s + C_{direct} + C_{indirect}$$

C_{direct} is the delivery cost which of transmitted packets from CN to MN. This can be expressed using the following formula.

$$C_{direct} = \tau \left(\lambda_s - \lambda_p \right) \left(d_{CN-MAP} + d_{MAP-AR} + d_{pAR-nAR} \right)$$

In addition, $C_{indirect}$ means the cost of packet transmission via HA of the triangular structure as follows.

$$C_{indirect} = \tau \lambda_p \left(d_{CN-HA} + d_{HA-MAP} + d_{MAP-AR} + d_{pAR-nAR} \right)$$

3.2 PMIPv6 and FPMPv6

In the network-based mobility management techniques, the signaling is the sum of the costs needed to move in the inter-domain, the cost of moving out of the domain and the cost of the BU. The cost of moving PMIPv6 in the registered domain is simple and inexpensive.

$$S_{intra}^{PMIPv6} = 2\kappa + 2\tau \times d_{MAG-LMA} + 2\tau \times d_{MAG-AAA}$$

$$S_{inter}^{PMIPv6} = S_{intra}^{PHMIPv6} + 2\tau \times d_{nLMA-pLMA}$$

FPMIPv6 is similar to the FMIPv6; its signaling cost is represented by the following formula when the MN is located at the current MAG (pMAG) and when the pMAG sends the MN's information to the new MAG (nMAG) successfully and sends/receives the HI and HAck message with nMAG.

$$S_{intra}^{FPMIPv6} = 2\kappa\ ,\ S_{inter}^{FPMIPv6} = S_{intra}^{FPMIPv6}$$

In the case of the mobility model applied here, the location update cost is as follows.

$$C_l^{PMIPv6} = \frac{R_{inter} S_{inter}^{PMIPv6} + (N_{MAG} \times R_{intra} - R_{inter}) S_{intra}^{PMIPv6}}{\rho \times A_d}$$

$$C_l^{FPMIPv6} = \frac{R_{inter} S_{inter}^{FPMIPv6} + (N_{MAG} \times R_{intra} - R_{inter}) S_{intra}^{FPMIPv6}}{\rho \times A_d}$$

The process is finalized at the sending and receiving of the PBU and PBA in PMIPv6 and FPMIPv6.

$$C_p^{PMIPv6} = P_{LMA} + C_T\ ,\ C_p^{FPMIPv6} = P_{LMA} + C_T$$

All packets are passed to the MN by the LCoA of the tunneled MN in the LMA. The lookup cost is proportional to the size of the binding cache table and the number of MN belonging to the LMA domain. In addition, the routing cost is proportional to the number of MAG in the LMA domain.

$$P_{LMA} = \lambda_s \times \left[\alpha \times N_{MAG} \times \rho \times A_c + \beta \times \log_2(N_{MAG}) \right]$$

λ_s means the packets per second as the session arrival rate, and α shows the relationship of the binding cache table according to the cost and size of the LMA's lookup. β represents the relationship between the number of MAG in the LMA domain and the routing cost, A_C means the area of the cell (m^2), ρ means the density of the user state ($/m^2$) belonging to a cell, and N_{MAG} is the number of MAG in the LMA domain. λ_s and λ_p are the session arrival rate and packet arrival rate, respectively.

The packet transmission cost in PMIPv6, C_T, can be calculated as follows.

$$C_T = \kappa \times \lambda_s + \tau(\lambda_s - \lambda_p)(d_{CN-LMA} + d_{LMA-MAG})$$

The packet transmission cost in FPMIPv6, C_T, can be calculated as follows.

$$C_T = \kappa \times \lambda_s + (\lambda_s - \lambda_p)(d_{CN-LMA} + d_{LMA-MAG} + d_{pMAG} - d_{pMAG-nMAG})$$

4. Performance Evaluation

This section describes the session arrival rate in accordance with the user mobility ratio and the total cost by applying the cost of a location update via the user density. Additionally, the fluid-flow model using the location update cost and packet transmission cost is described, along with the two-dimensional random walk model according to the user density, the moving speed, and cell residence time.

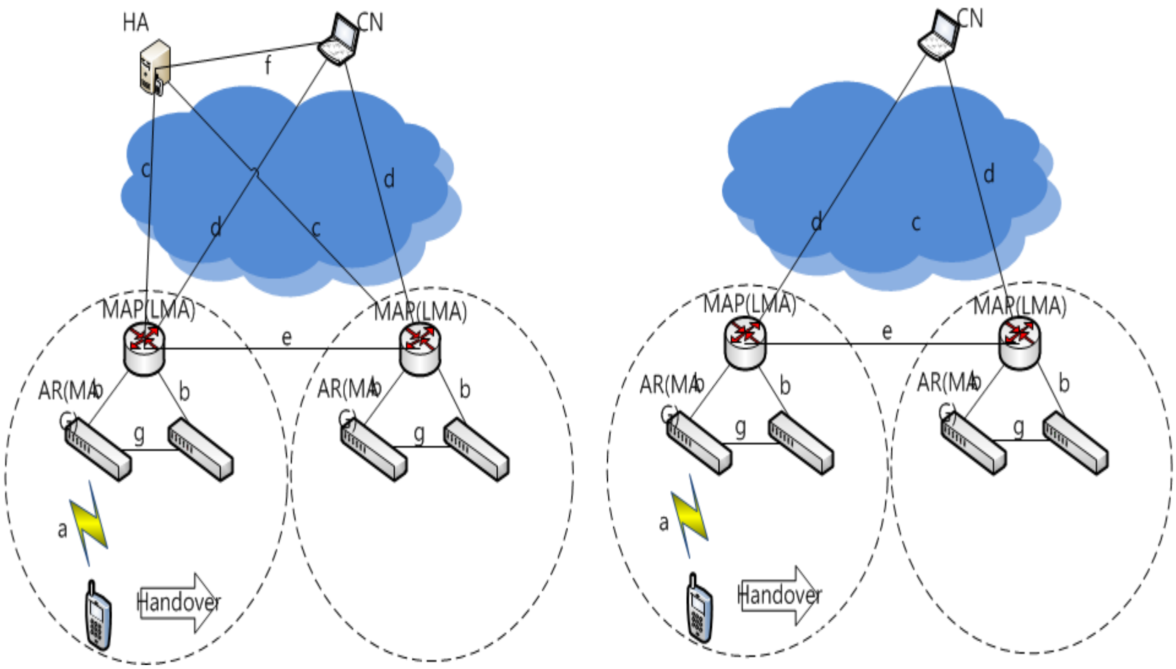

Figure 7. Performance Analysis of the Network Topology; Left (HMIPv6, F-HMIPv6), Right (PMIPv6, F-PMIPv6).

Table 1. Parameter Values Used in Performance Evaluation.

Parameter	Value	Explanation
α	0.1	Weight factors in wired link
β	0.2	Weight factors in wireless link
λ_s	1	Session arrival rate
λ_p	0.1	Packet arrival rate
θ_{HA}	20	Packet processing cost
τ	1	Transmission costs in wired link
κ	2	Transmission costs in wireless link
N_{CN}	2	Packet processing cost in CN
L_c	120m	Cell residence time
k	20	Number of cell movements or steps

A_d	40	Area of MAP domain
$d_{HA-CN} = f$	6	Distances unit of hops between HA and CN
$d_{CN-MAP} = d$	4	Distances unit of hops between CN and MAP
$d_{HA-MAP} = c$	6	Distances unit of hops between HA and MAP
$d_{AR-MAP} = b$	2	Distances unit of hops between AR and MAP
$d_{AR1-AR2} = d_{pAR-nAR}$	2	Distances unit of hops between ARs

Table 1 lists the values of the parameters used in the performance evaluation [14], [15]; the network topology for the analysis of mobility management can be expressed as in Figure 7. The distance between the HA and CN is f, the distance between the CN and MAP (LMA) is d, the distance between the HA and MAP is c, the distance between the AR (MAG) and MAP (LMA) is b, and the distance between the pAR (pMAG) and nAR (nMAG) is defined the same. In addition to these, each distance is defined as f = 6, d = 4, c = 6, b = 2; the distance between the pAR (pMAG) and nAR (nMAG) equals 2. As shown in Figure 7, the left topology shows HMIPv6 and F-HMIPv6, while the right one depicts PMIPv6 and FPMIPv6.

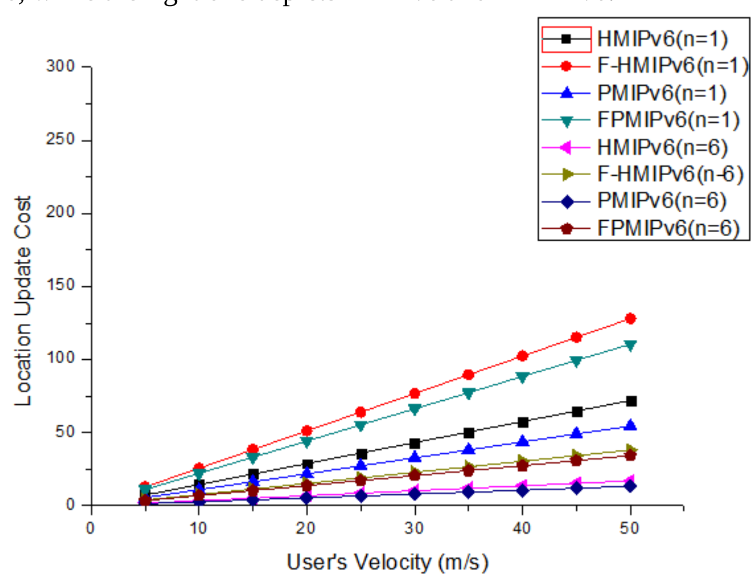

Figure 8. Location Update Cost in Accordance with User's Velocity in Fluid-flow Model.

Figure 8 shows the relationship between the location update cost and the average moving speed of the user when the number of rings for the MAP domain is one, and when number of rings is six in cases using the fluid flow mobility model. The degree of the concentration of users is assumed to be 0.0002; the results, which are a low percentage of the cost of the cells and the intersection of a low-speed mobile user, are obtained as well as a lower location update cost. In addition, the F-HMIPv6 signaling requires more overhead than the HMIPv6 did. F-HMIPv6 has a greater location update cost when n = 6 and n = 1 compared to FMIPv6. Comparing the two pictures demonstrates that the larger the size of the MAP (LMA) is, the less the cost of the location update of the HMIPv6 and F-HMIPv6 will be. The reason is that the movement of the MN is similar in the MAP (LMA) and the small size of the inter-domain. In addition, increasing the size of the domain did not affect FMIPv6. FPMIPv6 and PMIPv6, compared with F-HMIPv6 and HMIPv6, show a lower rate of cost with the small wireless interval and wired one.

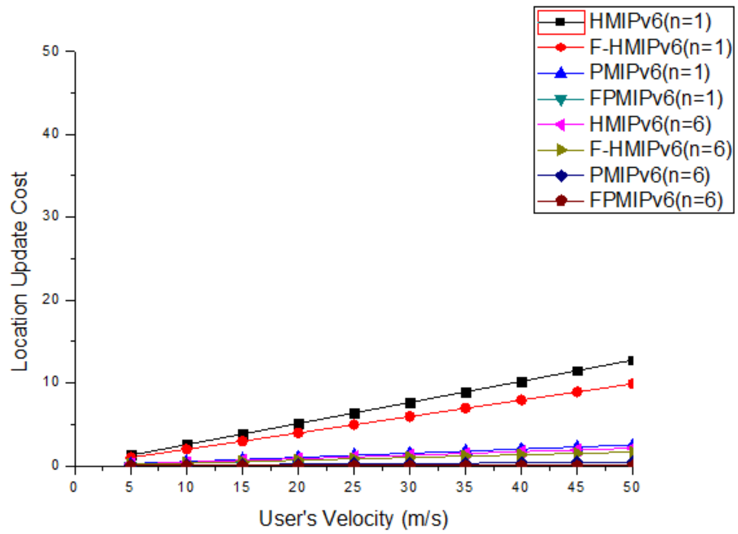

Figure 9. Location Update Cost in Accordance with User's Velocity in Random Walk Model.

Figure 9 shows the relationship between the location update cost and the average moving speed of the user when the number of rings for the domain is one, and when number of rings is six in cases using the two-dimensional random walk model. The form of increasing seems like the flow of fluid. In the case of F-HMIPv6, it calculates the highest cost of the location update, and it consists of less wired and wireless intervals than HMIPv6. HMIPv6, however, has a slightly higher cost for the location update because of the moving cost between the AR and HA of HMIPv6 for the BU, and the moving cost between the AR and MAP of F-HMIPv6. FPMIPv6 and PMIPv6, with a simple procedure, consist of wired and wireless intervals, and have a low location update cost via the low moving cost between the pLMA and nLMA. The cost is highly required when the size of the domain and cell are large or the number of ones is increased.

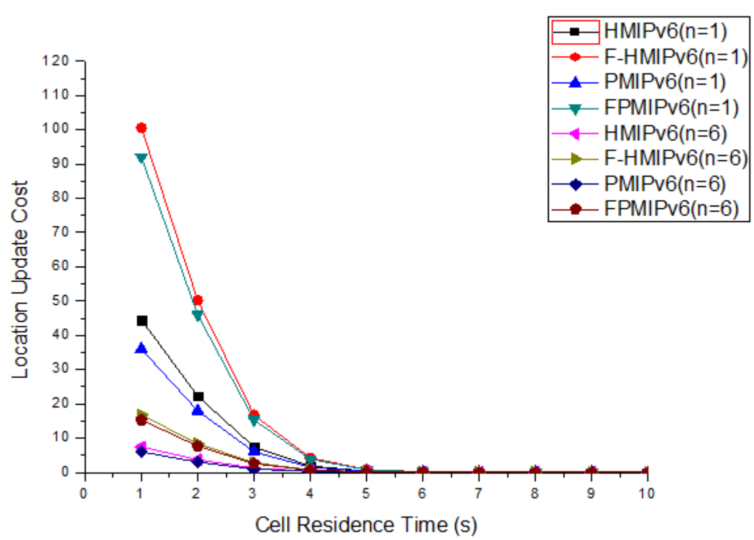

Figure 10. Location Update Cost in Accordance with Cell Residence Time.

Figure 10 shows the relationship between the location update cost and the average cell residence time when the number of rings for the MAP domain is one, and when number of rings is six in cases using the random walk mobility model. The number of the MAP domains has a powerful effect when estimating cost; the HMIPv6 and F-HMIPv6 protocols were largely affected. The low cost of the location update is required when the MN stays in the current cell a long time. This is called the minimum movement of the MN in a subnet.

5. Conclusion

PMIPv6 is the proposed protocol to complement the shortcomings of the host-based mobility protocol and the network-based protocol in order to enable the handover of mobile hosts. HMIPv6 has a lower signaling cost than other protocols, and is suitable for the design of hierarchical mobility management. In addition, PMIPv6 requires the simple procedure of moving, and is also suitable for the design of mobility management. A mobility management scheme for mobile networks has been continually developed in several ways. In this paper, the cost is analyzed according to the circumstances of each protocol (HMIPv6, F-HMIPv6, PMIPv6, and FPMIPv6) using the fluid-flow model and the 2-D random walk model. In addition, what function or case affects the protocol is evaluated. FPMIPv6 requires a higher cost of packet transmission by packet buffering. F-HMIPv6 involves greater cost for location update than other protocols; the result for the cost of packet transmission is the same as HMIPv6. F-HMIPv6 is suitable for the inter-domain. PMIPv6 and FPMIPv6 require a lower rate of cost than F-HMIPv6 and HMIPv6 under the influence of a small wireless interval and wired interval.

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