An Enhanced Network-based Mobility Management Protocol for Fast Mobility Support

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Abstract

In this paper, we propose the enhanced network-based mobility management protocol, called enhanced proxy mobile ipv6 (E-PMIPv6), which can provide mobile nodes (MNs) with a fast and efficient mobility service in PMIPv6 domain. The proposed scheme can provide a fast and efficient mobility service to MNs and also the strength of network scalability and stability to an access network by proposing the dynamic virtual hierarchical network architecture. In addition, the pre-authentication procedure for an MN, based on the information of neighbor mobile access gateway (MAG) list in the enhanced-policy server (E-PS), is proposed to support seamless handover by reducing MN's handover latency. Through performance evaluations of numerical analyses and simulations, we have confirmed and verified the superiority of the proposed scheme compared to the conventional proxy mobile ipv6 (PMIPv6).

Keywords: Mobile IPv6, proxy MIPv6, handover, mobility, hierarchical network

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1. Introduction

Interest in the next-generation mobile wireless networks for providing a fast, efficient and seamless mobility support to MNs is ever-increasing. Therefore, much research has been carried out to develop mobility management protocols and it is still a challenging issue on how to support a fast and efficient mobility service to MNs [1][2].

There are many researches around Internet Engineering Task Force (IETF) on IP mobility management scheme which have developed IP-based mobility protocols. These researches can be divided into two approaches, which are host-based and network-based mobility management scheme. Mobile IPv6 (MIPv6), which is a representative protocol of the host-based mobility management schemes [3][4][5][6][7][8], provides a global mobility service in IPv6 Internet for an MN [3]. That is, MIPv6 allows an MN to move freely within the Internet while maintaining reach-ability and ongoing sessions, using a permanent MN's home address. In this approach, the MN is mainly involved in mobility-related signaling with the home agent (HA) for a global mobility support whenever it moves to other networks. However, although MIPv6 is a mature technology through many researchers' development for the last decades, it is still not widely adapted and deployed in commercial networks. This is because 1) there is no cohesive mobility architecture for the real operator networks, 2) MIPv6 stack is quite a burden on the MN, 3) it may cause bottleneck at the HA, and 4) layer 3 (L3) signaling operation via radio link is recognized as to be inefficient and expensive, etc. To overcome MIPv6's disadvantages, the IETF NetLMM WG [2] has standardized network-based mobility protocol, which is based on PMIPv6 [9][10][11][12][13][14].

PMIPv6 [14] describes a mobility management solution without a mobile node's participation in mobility management for the support of mobility service of an MN. In this approach, mobility support nodes located in the network side recognize an MN's movement and perform mobility-related signaling on behalf of an MN. Therefore, compared to MIPv6 approach, this approach produces some good features, such as fast handover support, low mobility-related signaling in a wireless link, little changes of an MN's protocol stack, etc. However, PMIPv6 has still some limitations to be discussed. Firstly, the localized mobility anchor (LMA) has to treat all the packets which are transmitted from outside and inside domains, so that it causes bottleneck problems, which leads a network scalability and reliability. Secondly, all the packets heading for the MN are always transmitted through the LMA, so that it is not efficient and optimized for transporting data traffic between MNs. This situation is worsening when two MNs are located in the same PMIPv6 domain [9][10]. Lastly, the authentication procedure for the MN in PMIPv6 causes the long handover latency. The latency from the MN's authentication procedure should be minimized for the fast mobility support of the MN.

In this paper, we propose the enhanced network-based mobility management protocol, called enhanced proxy mobile ipv6 (E-PMIPv6), which can provide MNs with a fast and efficient mobility service in PMIPv6 domain. The proposed scheme can provide a fast and efficient mobility service to MNs and also the strength of network scalability and stability to an access network by proposing the dynamic virtual hierarchical network architecture. In addition, the pre-authentication procedure for an MN, based on the information of neighbor MAG list (NML) in the E-PS, is proposed to support seamless handover by reducing MN's handover latency.

The rest of this paper is organized as follows: in Section 2 we briefly review PMIPv6 by IETF NetLMM WG. Section 3 describes the overview of the proposed network-based mobility protocol, which includes the network architecture and signaling procedure of the proposed scheme. Section 4 presents performance evaluations and discussions of the proposed scheme through numerical analyses and simulations. Finally, some concluding remarks are presented in Section 5.

2. Related Works

2.1 Host-based Mobility Management Scheme

MIPv6 [3] is the host-based global mobility management scheme for IPv6 networks. When an MN remains in its home network, it communicates like other IPv6 nodes with its correspondent node (CN). When an MN moves to a new point of attachment (PoA) in another subnet, its home-of-address (HoA) is not valid anymore. Packets sent by its CN continue to reach its home network. Therefore, the MN needs to acquire a new valid IP address in a visiting subnet, which is the care-of-address (CoA), and to register the CoA at its HA and CN. The association made between the HoA and the current CoA of an MN is known as a binding.

Research efforts have been carried out to improve the handoff protocols of MIPv6, such as the fast handoff for mobile IPv6(FMIPv6) [4], hierarchical mobile IPv6(HMIPv6) [5][6], etc.

FMIPv6 [4] was proposed to improve MIPv6 movement detection and the new CoA (nCoA) configuration procedure. FMIPv6 reduces the handover delay by exploiting various layer 2 triggers to prepare a nCoA at the new access router (nAR) while being connected to the link of the old AR (oAR). It relies on the oAR to resolve the network prefix of the nAR based on the layer 2 identifier reported by the link layer triggers in the MN. FMIPv6 has two modes of handoff scenario depending on the handoff situations; predictive mode and reactive mode. When it performs handoff in a predictive mode, FMIPv6 can reduce the handoff delay through the nCoA confirmation procedure with nAR.

HMIPv6 [6] proposed by the IETF is designed to mitigate the high handoff delay and the signaling overhead that occurs in MIPv6 when an MN should perform frequent handoffs. In HMIPv6, the mobility anchor point (MAP) has been introduced in order to handle binding update (BU) procedures resulting from handoffs within a mobility anchor point domain in a localized manner. Since the mobility anchor point acts as a local HA, it receives all of the packets on behalf of MNs and tunnels the received packets to the MN’s current address. If an MN changes its current address within a local mobility anchor point domain, it only needs to register the new local address with the mobility anchor point. The regional address of an MN does not change as long as the MN moves within the same mobility anchor point domain. This makes an MN’s mobility transparent to the HA and CNs.

2.2 Network-based Mobility Management Scheme

Network-based mobility management scheme by Network-based Localized Mobility Management (NetLMM in [9]) Working Group in IETF enables IP mobility for an MN without requiring its participation in any mobility-related procedures [9][10][11][12][13][14]. The core functional entities in the NetLMM are the localized mobility anchor (LMA) and mobile access gateway (MAG). The LMA is an entry point in the localized mobility domain, which manages the location of MNs. The MAG is an access gateway with mobility support based on MIPv6. The NetLMM defines two interfaces; between the MAG and the MN, between the MAG and the LMA. The MAG detects an MN’s movement and performs a location binding update to the LMA. The LMA manages the location binding entry for the MN in PMIPv6 domain according to the MAG’s location reporting.

PMIPv4/v6 defines a localized mobility management domain and specifies the network architecture and protocol to handle mobility within a localized mobility management domain with a network-based manner [9][10][11][12][13][14].

The initial registration procedure of PMIPv6 is shown in **Fig. 1**. When an MN firstly establishes a wireless link with a target PoA through the L2 association, the MAG acquires the MN's identification (ID) and requests the profile information of the MN to the policy server (PS). The profile information includes ID, the LMA address, the IP address configuration mechanism, and IPv6 home network address of the MN. The MAG sends a proxy binding update (PBU) message to the MN's LMA to update the MN's binding information. On receiving this message, the LMA sends a proxy binding acknowledgement (PBA) message, which includes the information of the MN's home network prefix (HNP). In case of the MN's initial registration, the LMA allocates a new HNP for the MN. The LMA also creates a binding cache entry (BCE) and establishes an IP tunnel to the MAG for the MN. When the MAG receives a PBA message, it establishes an IP tunnel to the LMA for the MN. The MN configures its IP address with the information of the home network prefix and IP address configuration mechanism from the route advertisement message. After the completion of these procedures, all the packets heading for the MN firstly arrive at the LMA and it forwards them to the MAG through the IP tunnel established for the MN. The MAG forwards them to the MN. On the other hand, all the packets coming from the MN firstly arrive at the MAG and it forwards them to the MN's LMA through the IP tunnel.

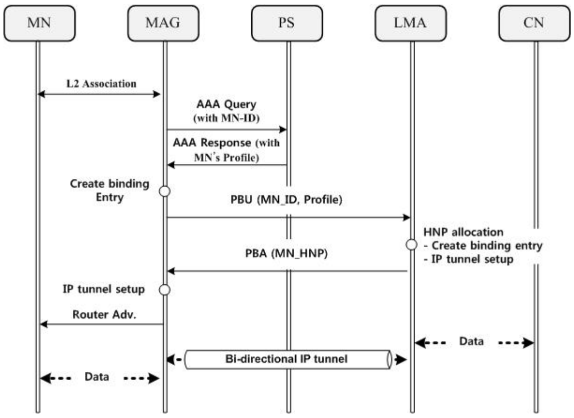

Fig. 1.Initial registration procedure of the PMIPv6

The handover procedure for the MN in the PMIPv6 domain is quite similar to the initial registration procedure. When an MN moves into a new access network, the MAG detects an MN's movement and performs the handover procedure for the MN on behalf of the MN. The MAG sends the PBU message to the MN's LMA to update the MN's binding information. The MAG registers its own IP address with the LMA as the MN's CoA. By updating the binding information of the MN's CoA, the LMA establishes the new IP tunnel for the MN with the new MAG and properly forwards packets heading for the MN to the MN. The HoA of an MN allocated in the initial registration procedure does not change during the handover as long as it stays in the same PMIPv6 domain. Therefore, the handover procedure for the MN does not include the process of the home network prefix allocation for the MN.

3. Proposed Network Architecture and Scheme

In this chapter, we describe the overview of the proposed network-based mobility protocol, which includes the network architecture and signaling procedures of the proposed scheme.

3.1 Overview of the Proposed Scheme

This paper proposes the enhanced network-based mobility management protocol, called enhanced PMIPv6 (E-PMIPv6), which can provide MNs with a fast and efficient mobility service in the PMIPv6 domain. The main features of the proposed scheme are as follows: Firstly, we propose the dynamic virtual hierarchical network architecture among enhanced MAGs (E-MAGs). The conventional PMIPv6 approach is based on the hierarchical network architecture between the LMA and the MAG. As a result from the network architecture, PMIPv6 has a single bottleneck point (i.e., LMA), at which all the data and signaling packets get together, so that it causes a scalability and stability problem. Therefore, we remove the centralized node (i.e., LMA) in PMIPv6 and devolve its functions on other mobility support nodes (i.e., E-MAG and enhanced PS (E-PS)). Secondly, we propose the fast and efficient procedure of the pre-authentication for an MN to save handover latency. When an MN performs handover, the proposed scheme anticipates a target network, which the MN moves into, and performs the fast authentication procedure with the information of neighbor MAG list in the E-PS, so that it can reduce the MN's handover latency.

3.2 Network Architecture and Entities

Fig. 2 shows the network architecture of the proposed scheme. The main feature of the proposed network architecture is that the LMA in the conventional PMIPv6 is removed and the proposed PMIPv6 network consists of E-MAGs and the E-PS. In this architecture, several gateways are located at edges of the network, which provide an access network with multiple paths to outside domains.

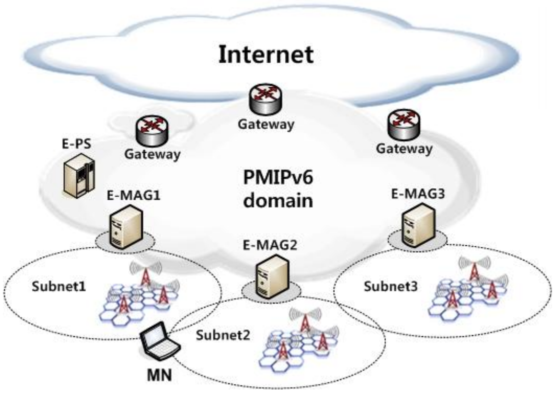

Fig. 2. Network architectures of the proposed scheme

The E-MAG is the mobility support node, which is on an access router of a sub-network and performs functions of the conventional MAG in PMIPv6. In addition, the E-MAG has some additional functions from the conventional LMA, which are the function of mobility anchor for an MN and the function of neighbor MAG list allocation during its initial registration. When an MN performs an initial network access, the E-MAG performing the procedure of the initial registration on behalf of an MN, is named as the home E-MAG for the MN. Therefore, all the MNs in the proposed PMIPv6 domain have their own home E-MAG, which has the same functions as the LMA in the conventional PMIPv6. It is responsible for the E-MAG to provide MNs with a mobility service by creating and configuring bi-directional tunnels with other neighbor E-MAGs when an MN moves around freely and performs handover between sub-networks.

The E-PS is the policy server with some additional functions from the LMA in the conventional PMIPv6. The E-PS especially stores two additional pieces of information for the support of mobility and location information for the MN, which are the information of the home E-MAG and present E-MAG of the MN. To support a fast and efficient handover for the MN, the E-PS also performs the pre-authentication procedure in advance of an MN's handover by configuring and managing the neighbor MAG list in the PMIPv6 domain. In the proposed approach, the E-PS is the appropriate node which configures and manages the neighbor MAG list in PMIPv6. This is because it is the E-PS that can configure the neighbor MAG list efficiently and economically by inferring the NML from the information of MNs' movement patterns among E-MAGs without any additional signaling for it.

3.3 Initial Registration Procedure

The procedure of the initial registration of an MN in the proposed scheme is shown in **Fig. 3**. When an MN firstly establishes a wireless link with a target PoA through the L2 association process, the E-MAG detects an MN's attachment in its network and gets the identification of the MN (MN_ID). With this information of the MN_ID, the E-MAG performs the authentication procedure with E-PS. The E-MAG also acquires the profile information of the MN including the information of the policy, mobility support, etc as well as general information of the MN. Especially, the E-MAG obtains the information of home E-MAG, present E-MAG, IP address configuration mechanism and so on. When the E-MAG receives the authentication response message from the E-PS, it checks whether the information of the home E-MAG of the MN exists or not. If it exists, it means that the MN has just moved from another network, indicating the MN's L3 handover. Otherwise, the E-MAG perceives that the MN has just attached the network, indicating the MN's initial registration.

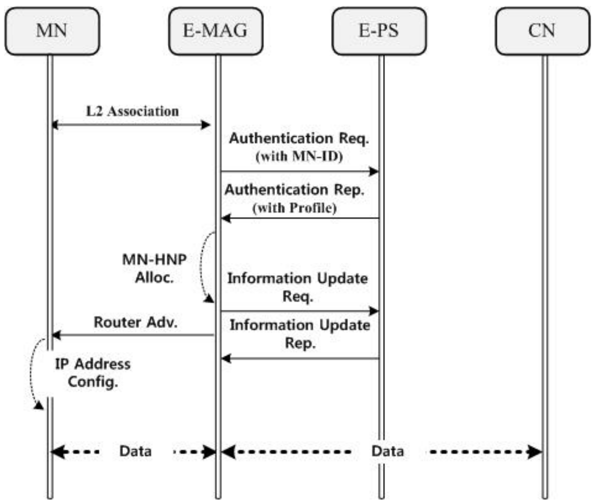

Fig. 3. Initial registration procedure of the proposed scheme

In case of the MN's initial registration, the E-MAG allocates the unique home network prefix to the MN by sending the route advertisement message. Then, it becomes the home E-MAG for the MN in the PMIPv6 domain. In addition, it sends an information update message to the E-PS to update MN's information such as home E-MAG, present E-MAG, home network prefix, etc. Based on this message, the E-PS updates the binding information for the MN and responds with the information update response message. On receiving the route advertisement message, the MN configures a new IP address with the information of the network prefix from the route advertisement message.

3.4 Handover Procedure

Fig. 4 illustrates the handover control procedure for an MN in the proposed scheme. In this figure, we assume that the MN has just moved into the E-MAG2's network from the E-MAG1's network. When the MN moves into another network, the E-MAG1, in which the MN resides before handover, can detect a network detachment of the MN. The E-MAG1 sends a handoff indication (HI) message to the E-PS to notify the E-PS of the MN's movement. This HI message triggers the E-PS to perform the pre-authentication process for the MN. On receiving this message, the E-PS performs pre-authentication procedure with possible target E-MAGs, which are indicated by the information of the neighbor MAG list. When the new E-MAG (E-MAG2) detects the MN's attachment, the E-MAG2 performs the handoff procedure for the MN, based on the information of home E-MAG, present E-MAG, home network prefix, etc from the E-PS through the pre-authentication procedure. The E-MAG2 firstly sends to the MN the RA message containing MN's home network prefix information. The E-MAG2 creates and updates a binding cache entry of the binding update list (BUL) for the MN, based on the MN's profile information. It sends the inter-MAG proxy binding update (IM-PBU) message to old E-MAG, which can be inferred by the present E-MAG information of the MN. On receiving the IM-PBU message, the E-MAG1 creates the binding information for the MN in its binding cache entry and it establishes a new IP tunnel for the MN heading for the new MN's E-MAG. Afterward, the E-MAG1 sends back the inter-MAG proxy binding acknowledge (IM-PBA) message to the E-MAG2. After the completion of this binding procedure, the bi-directional tunnel between E-MAG1 and E-MAG2 is created to transport the MN's packets. The E-MAG1 starts forwarding all the packets heading for the MN through the tunnel heading for the E-MAG2. The E-MAG2 updates the location information of the MN, which is the present E-MAG information of the MN in the E-PS, by sending location binding update message to the E-PS. This location binding process between E-MAGs for the MN makes the E-PS configure and manage the neighbor MAG list in the PMIPv6 domain efficiently and economically without any complicated procedures.

When an MN moves around freely and changes its network access several times, it can cause the long delivery path for the MN, which causes a routing inefficiency in the PMIPv6 domain. Therefore, the route optimization (RO) procedure is required for an efficient packet delivery for the MN. However, the mechanism of the route optimization procedure can be diversified depending on how to support the route optimization, and it is still one of our research topics. In this paper, we only consider that the new E-MAG performs the route optimization procedure with the HE-MAG of the MN whenever the MN performs a handover. That is, all the packets first arrive the home E-MAG of the MN and then, are forwarded to the present E-MAG through the IP tunnel. Therefore, we consider the E-MAG1 as the home E-MAG of the MN in **Fig. 4**.

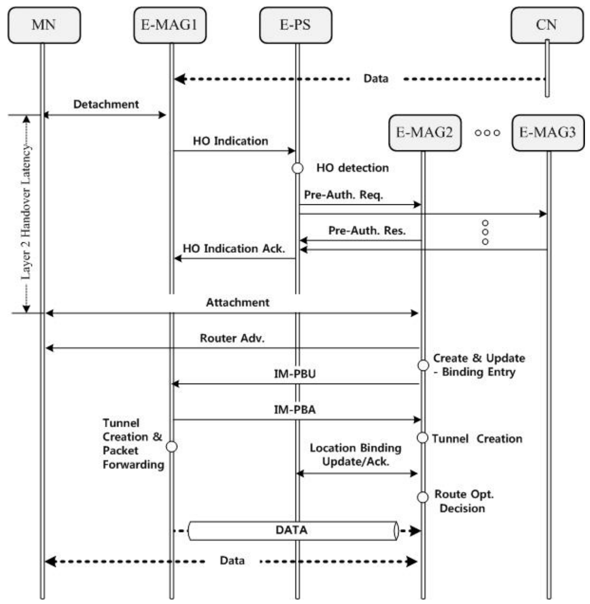

Fig. 4. Handover control procedure of the proposed scheme

3.5 Data Packet Transport Procedure

Data packet transport procedure between two MNs of the proposed scheme is illustrated in **Fig. 5**. In this procedure, we assume that the CN in the E-MAG2's network sends packet to the MN residing in the E-MAG1's network. When the CN transmits packets to the MN, these packets are firstly delivered to the E-MAG2, which is the MN's default access router. The E-MAG2 looks up the binding cache entry to check whether there exists a forwarding entry for packets' destination IP address. If the binding entry for the packet exists in the binding cache entry, the E-MAG2 immediately forwards packets according to the information of the binding entry. Otherwise, the E-MAG2 checks the destination IP address of packets to inspect whether these packets are heading for the destination inside or outside PMIPv6 domain. If the destination of packets is outside PMIPv6 domain, packets are forwarded through the conventional IP routing mechanism. On the other hand, if the destination of packets is inside PMIPv6 domain, the E-MAG2 performs the location query procedure for the MN with the E-PS in the PMIPv6 domain. That is, the E-MAG2 sends a location request message to the E-PS to get the information of the MN's present location. With response to this message, the E-PS provides the E-MAG2 with the MN's location information by sending a location response message. Afterward, the E-MAG2 creates a binding cache entry for the MN and sends inter-MAG proxy binding update message to the present E-MAG of the MN, which is the E-MAG1 in **Fig. 5**. On receiving this message, the E-MAG1 establishes a new IP tunnel for the CN and also creates the binding cache entry for the CN. It sends back the inter-MAG proxy binding acknowledge message to the E-MAG2. The E-MAG2 also establishes an IP tunnel for the MN and updates the binding cache entry for the CN. After the completion of location query and binding update procedure, all the packets heading for the MN from the CN are delivered through the IP tunnels between the E-MAG1 and the E-MAG2.

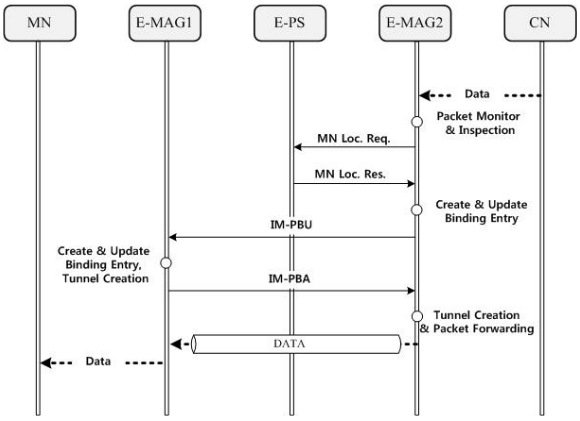

Fig. 5. Data Packet Transport Procedure of the proposed scheme

4. Performance Evaluation and Discussion

In this chapter, we show performance evaluations of the proposed scheme and compare it with the conventional PMIPv6 scheme in terms of handoff latency and total signaling cost.

4.1 Analysis of Total Cost

We firstly evaluate the performance of the total cost of local data transmission for both the proposed scheme and conventional PMIPv6. In this analysis, we assume that the PMIPv6 domain consists of n number of MAGs, which are based on the hexagonal cells structure in [19]. The Fluid-flow mobility modeling is considered for the MN's velocity, direction and so on [17]-[19]. The network parameters for numerical analysis are summarized in **Table 1**, which is referred to [17]-[19]. The total cost of local data transmission is defined as a cost required for sending local data between MNs in PMIPv6, which consists of location update cost ($C_{location}$) and packet delivery cost ($C_{delivery}$) [18], [19].

$$C_{Total} = C_{location} + C_{delivery} \tag{1}$$

Table1. Network parameters for a numerical analysis

Network Parameter	Value	Description
τ	1	Unit transmission cost in wired link
κ	2	Unit transmission cost in wireless link
α	0.1	Weighting factor of binding list
β	0.2	Weighting factor of routing table lookup
$d_{(mag,ps)}$	1	Average distance between MAG and PS
$d_{(mag,lma)}$	2 (1~10)	Average distance between MAG and LMA
$d_{(mag,mag)}$	1	Average distance between MAG and MAG
$n_{(mag)}$	16	Number of MAGs
$n_{(total\_mn)}$	$N_{(mag)} * N_{(mn)}$	Total number of MNs in a domain
ρ	0.0002	Mobile density (mobiles/m^2)
v	28.9 m/s (1~40)	velocity
l	120 m	Cell perimeter

λ	1 (1~10)	Arrival rate
r_c		Cell crossing rate
ς	0.01	Bandwidth allocation cost

4.1.1 Location Update Cost

The location update cost is proportional to the number of hops of wired/wireless networks between two nodes. We define the number of hops from x to y as $d_{(x,y)}$. We denote the unit of the transmission cost for the wired link and wireless link by τ and κ, respectively [18]. According to these considerations, the transmission cost between an MAG and an MN, an MAG and the PS, an MAG and an MAG, an MAG and the LMA are expressed as shown in equation (2).

$$C_{t(mag,mn)} = d_{(mag,mn)}\kappa, \quad C_{t(mag,ps)} = d_{(mag,ps)}\tau$$
$$C_{t(mag,lma)} = d_{(mag,lma)}\tau, \quad C_{t(mag,mag)} = d_{(mag,mag)}\tau \tag{2}$$

In addition, the number of MNs in an MAG network and crossing rate (r_c) of fluid-flow model according to [17][18] is expressed as shown in equation (3).

$$n_{mn} = \rho \times S = \rho \frac{3\sqrt{3}}{2}(l)^2, \quad r_c = \frac{\rho v l}{\pi} \tag{3}$$

The location update cost ($C_{location}$) of PMIPv6 is as follows. In the conventional PMIPv6, the procedure of MN's movement, the procedure of MAG's authentication for the MN with the PS, and the procedure of location registration for the MN are performed consecutively. When we consider the processing cost of the PS and the LMA as the cost for looking up, creating and updating binding table, this cost is proportional to the size of the binding table. The size of the binding table is proportional to a number of MNs in the PMIPv6 domain, so that the processing cost in PMIPv6 can be expressed as shown in equation (4).

$$C_{p(ps)} = C_{p(lma)} = \alpha(n_{mn} \times n_{mag}) \tag{4}$$

Therefore, the location update cost of PMIPv6 can be calculated using Equation (2)-(4) and expressed as shown in equation (5).

$$C_{Location}^{PMIPv6} = \left[2\tau\left(C_{t(mag,ps)} + C_{t(mag,lma)}\right) + C_{p(ps)} + C_{p(lma)}\right] \times r_c \times n_{mag} \tag{5}$$

On the other hand, the proposed scheme is based on the dynamic virtual hierarchical network architecture, so that it requires the registration procedure between E-MAGs, not like registration procedure between the MAG and the LMA in PMIPv6. This feature of the proposed scheme distributes the processing cost of the LMA in PMIPv6 to several E-MAGs. Therefore, the processing costs of the PS and the MAG are expressed as shown in equation (6).

$$C_{p(ps)} = \alpha(n_{mn} \times n_{mag})$$
$$C_{p(mag)} = \alpha n_{mn} \quad (6)$$

According to above equations, the location updated cost of the proposed scheme is expressed as shown in Equation (7), in which t is the number of neighbor MAGs.

$$C_{Location}^{Proposed\_scheme} = \left[2\tau\left((t+1)C_{t(mag,ps)} + C_{t(mag,mag)}\right) + C_{p(ps)} + C_{p(mag)}\right] \times r_c \times n_{mag} \quad (7)$$

4.1.2 Packet delivery cost

In this analysis, we define the packet delivery cost ($C_{delivery}$) as the sum of a transmission cost and a processing cost for the packet delivery between two MNs. In the conventional PMIPv6, the packet delivery cost is the sum of the processing cost ($C_{p(lma)}$) of the LMA, and the transmission cost (C_t) between a CN and an MN, which is expressed in equation (8).

$$C_{delivery}^{PMIPv6} = C_{p(lma)} + C_t \quad (8)$$

The processing cost of the LMA consists of the lookup cost for the binding table and routing cost according to [18]. The lookup cost is proportional to the size of the binding table in the LMA and the routing cost is proportional to the number of MAGs in the domain on a logarithmic scale [18].

$$C_{p(lma)} = \lambda_s \varsigma n_{mag}\left(\alpha n_{mn} n_{mag} + \beta \log(n_{mag})\right) \quad (9)$$

The transmission cost between a CN and an MN is expressed as shown in equation (10). This is because the packets are transmitted through the LMA in PMIPv6, which is the top level node in the domain. It is usually proportional to the distance between two nodes. It is assumed that the link cost of the wireless link is higher than that of the wired link.

$$C_t^{PMIPv6} = 2\lambda_s\left(C_{t(mag,lma)} + C_{t(mag,mn)}\right) \quad (10)$$

On the other hand, the proposed scheme performs a registration procedure between E-MAGs, which is based on the proposed dynamic virtual hierarchical network architecture. Therefore, the packet delivery cost ($C_{delivery}$) of the proposed scheme is the sum of the processing cost ($C_{p(mag)}$) in E-MAG and the transmission cost (C_t) between a CN and an MN, which yields

$$C_{delivery}^{Proposed\_scheme} = C_{p(mag)} + C_t \quad (11)$$

In this equation, the processing cost in the MAG is expressed in a similar way of equation (9), and the lookup cost for the binding table is proportional to the size of the binding table in the E-MAG and then, we have that

$$C_{p(mag)} = \lambda_s \varsigma n_{mag}\left(\alpha n_{mn} + \beta \log(n_{mag})\right) \quad (12)$$

The transmission cost (C_t) between a CN and an MN is expressed as shown in equation (13). This because E-MAGs in the proposed scheme sends packets through the direct IP tunnel each other.

$$C_t^{Proposed\_scheme} = 2\lambda_s \left(c_{t(mag,mag)} + c_{t(mag,mn)} \right) \tag{13}$$

4.2 Analysis of Handover Latency

We investigate the performance of the handoff latency of the proposed scheme and compared it with that of the conventional PMIPv6 scheme. In this paper, we define the handover latency as the time elapsed between the MN's reception of the last packet through the old network and the first packet reception through the new network.

The handoff latency of the PMIPv6 consists of the layer 2 (L2) handover latency(T_{L2HO}), the detection latency of MN's attachment(T_{LUE}), the authentication latency(T_{AAA}), the location registration latency($T_{PBU/PBA}$), and the packet delivery latency(T_D) for the first packet after the completion of handover and then, we have

$$\begin{aligned} T_{Handoff\_Delay}^{PMIPv6} &= T_{L2HO} + T_{LUE} + T_{AAA} + T_{PBU/PBA} + T_D \\ &= t_{L2HO} + 2t_{BtM} + 2t_{MtP} + 2t_{MtL} + t_{wireless} \end{aligned} \tag{14}$$

where t_{AtB} is the transmission time between A and B.

On the other hand, the E-MAG in the proposed scheme performs the pre-authentication procedure with the E-PS during MN's layer 2 handover. Therefore, the handoff latency of the proposed scheme is expressed as shown in equation (15), which includes the latency for the maximum value between L2 handoff and the authentication latency (max[T_{L2HO}, T_{LUE}+T_{AAA}]), the location registration latency ($T_{IM\text{-}PBU/PBA}$) and the packet delivery latency (T_D) for the first packet after handoff.

$$\begin{aligned} T_{Handoff\_Delay}^{Proposed\_scheme} &= max\left\{ T_{L2HO}, (T_{LUE} + T_{AAA}) \right\} + T_{IM-PBU/PBA} + T_D \\ &\approx t_{L2HO} + t_{BtM} + 2t_{MtM} + t_{wireless} \end{aligned} \tag{15}$$

Comparing the handoff latency for the PMIPv6 and the proposed scheme by subtracting Equation (14) from (15), gives the following:

$$T_{Handoff\_Delay}^{PMIPv6} - T_{Handoff\_Delay}^{Proposed\_scheme} \approx t_{BtM} + 2t_{MtP} + 2\left(t_{MtL} - t_{MtM} \right) \tag{16}$$

The proposed scheme can almost remove the latency of the authentication procedure in the conventional PMIPv6, because the authentication procedure is performed by the E-MAG during an MN's L2 handoff. This can reduce the handover latency of the proposed scheme. In addition, the proposed scheme can reduce handoff latency for the MN's location registration due to the dynamic virtual hierarchical network architecture, which causes a fast location registration through the short distance between E-MAGs, not like location registration between the MAG and the LMA.

Especially, when an MN and a CN stay in the same PMIPv6 domain, the proposed scheme shows better performance than that of PMIPv6 in terms of packet delivery latency and handover latency. In the PMIPv6, all the packets should be transmitted through the LMA even though it is not the shortest path or efficient path (MN↔MAG_{MN}↔LMA↔MAG_{CN}↔CN). On the other hand, the packets are transmitted between E-MAGs of an MN and a CN directly in the proposed scheme (MN↔$E\text{-}MAG_{MN}$↔$E\text{-}MAG_{CN}$↔CN). It improves the utilization of the network resources and reduces the packet delivery latency. Comparing packet delivery latency of the PMIPv6 and the proposed scheme gives the following:

$$T_{ETE\_Delay}^{PMIPv6} - T_{ETE\_Delay}^{Proposed\_scheme} = 2t_{MtL} - t_{MtM} \tag{17}$$

4.3 Numerical & Simulation Results

4.3.1 Numerical Results and Discussion

We firstly investigate the effect of the mobility on the total cost. **Fig. 6** shows the location update cost, packet delivery cost and total cost as a function of MN's velocity. As summarized in **Table 1**, we assume that the user density is about 0.0002 in this analysis. As the MN's velocity increases, the cross rate of the MN increases and the MN performs handover more frequently. Therefore, it causes the increase of location update cost so that the total cost of the MN increases accordingly. As shown in **Fig. 6**, the proposed scheme has the total cost gain about 25% higher than the conventional PMIPv6. This is due to the fast and efficient registration procedure between E-MAGs, based on the dynamic virtual hierarchical network architecture of the proposed scheme.

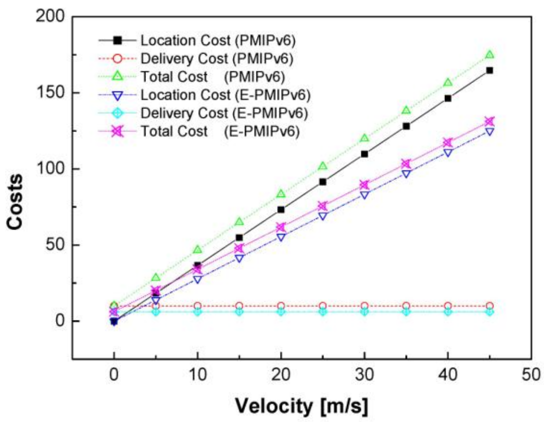

Fig. 6. Total cost as a function of MN's velocity

Fig. 7 shows the location update cost, packet delivery cost and total cost as a function of the average packet arrival rate. We can see that the total signaling cost increases with the average packet arrival rate. However, the proposed scheme has a lower increase rate of the packet delivery cost than that of PMIPv6 because the proposed scheme provides the direct packet delivery between E-MAGs due to the proposed dynamic virtual hierarchical network architecture. Therefore, the proposed scheme has the total signaling gain from 20% to 25% higher than PMIPv6.

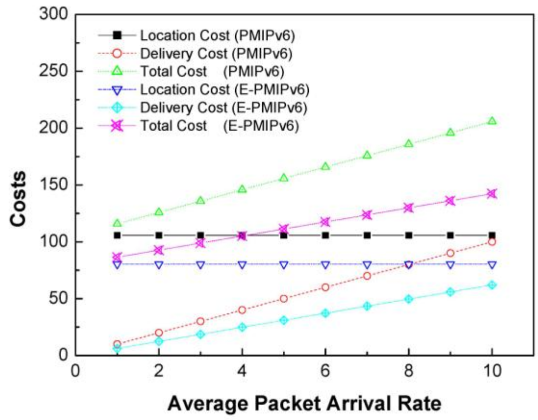

Fig. 7. Total cost as a function of the average packet arrival rate

When an MN and a CN stay in the same PMIPv6 domain, the signaling cost as a function of the distance between the MAG and the LMA is shown in **Fig. 8**. In this situation, the distance between the MAG and the LMA does not affect packet delivery cost in the proposed scheme because packets are delivered directly between E-MAGs. On the contrary, the packet delivery cost in PMIPv6 increase with the distance between the LMA and the MAG because all the packets are transmitted through the LMA. Therefore, the proposed scheme shows lower packet delivery cost according to the distance, so that we can see that total cost of the proposed scheme is lower than that of PMIPv6.

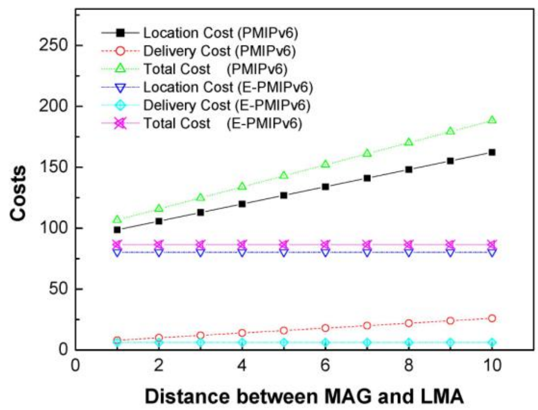

Fig. 8. Total cost as a function of the distance between the MAG and the LMA

Fig. 9 presents comparisons of signaling costs as a function of the number of MAGs in the PMIPv6 domain. As the number of MAGs increases in the domain, the cell size of an MAG decreases. Therefore, the crossing rate of the MN increases with the number of MAGs, so that the registration cost of the MN increases with the frequency of a handoff. In the proposed scheme, the MN's location registration is performed in a distributed manner on several E-MAGs, so that it has a lower increase rate of the registration cost than the conventional PMIPv6. This feature of the proposed scheme removes the bottleneck problem of the network, so that it provides the network with the strength of network scalability and stability.

Fig. 10 shows the location update cost, packet delivery cost and total cost as a function of the number of MNs. As the density of MN increases, the number of MNs increases in the domain. As explained in **Fig. 9**, the crossing rate of the MN increases with the number of MNs, so that the registration cost of the MN increases with the frequency of a handoff. The proposed scheme has a lower increase rate of the location registration cost than that of PMIPv6 by using distributed location management. It means that the proposed scheme can accommodate more MNs than PMIPv6 at the same cost, so that it provides network with the improvement of network scalability.

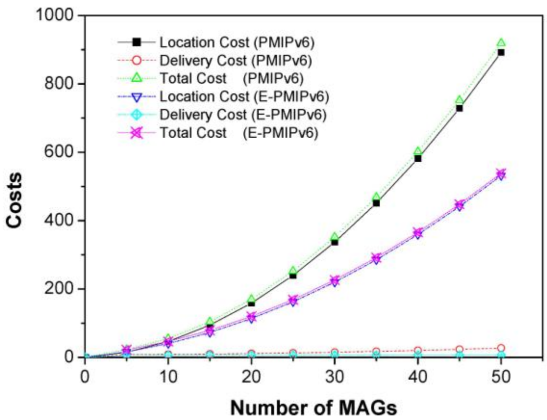

Fig. 9. Total cost as a function of the number of MAGs

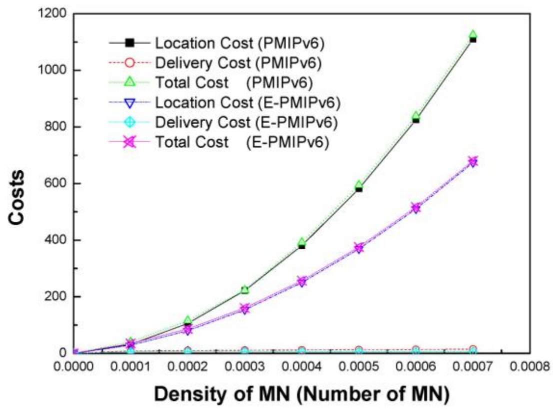

Fig. 10. Total cost as a function of the number of MNs

4.3.2 Simulation Results and Discussions

Simulations of the proposed scheme were carried out using OPNET™ where the performance metrics were handover latency and packet delivery latency. **Fig. 11** shows the simulation architecture topology, which consists of 3 sub-networks. The MN firstly stays in E-MAG1's subnet while the CN stays in E-MAG3's subnet. The MN is assumed to move following the path of the arrow, as shown in **Fig. 11**. We have considered WLAN environments for computer simulations. The CN generates constant bit rate traffic over a user datagram protocol with a 200 byte of packet length and 20~100 pps of packet arrival rate. In this analysis, network parameters for computer simulations are summarized in **Table 2**.

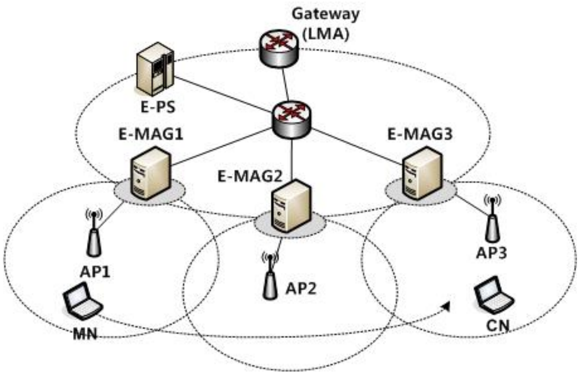

Fig. 11. Simulation architecture topology

Table 2. Simulation parameter

Parameter	Description	Value
t_{L2HO}	L2 handoff delay	150 ms
$t_{wireless}$	Delay between BS and MN	20 ms
t_{BtM}	Delay between BS and MAG	5 ms
t_{MtP}	Delay between MAG and PS	10~30 ms
t_{MtM}	Delay between MAG and MAG	10 ms
t_{MtL}	Delay between MAG and LMA	10~50 ms

Fig. 12 and **Fig. 13** show the handoff latency and packet delivery latency as a function of delays between MAG and LMA, respectively. As stated in the numerical analysis, the proposed scheme shows lower handoff latency irrespective of the latency between the MAG and the LMA, due to the dynamic virtual hierarchical network architecture. That is, this feature of the proposed scheme has an effect on distribution of the signaling and data traffic loads from the LMA to several E-MAGs, so that it can provide the network with the strength of network scalability and stability. In addition, the proposed scheme reduces the handoff latency by performing pre-authentication procedure for the MN between E-MAGs and the E-PS during the MN’s L2 handover. The result of simulations also represents that the packet delivery latency of the proposed scheme is lower than that of the conventional PMIPv6 due to the traffic delivery through the optimized route in the dynamic virtual hierarchical networks architecture of the proposed scheme.

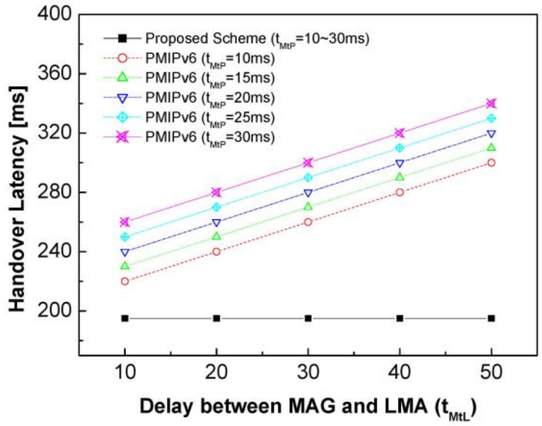

Fig. 12. Handoff latency as a function of Delay between the MAG and the LMA

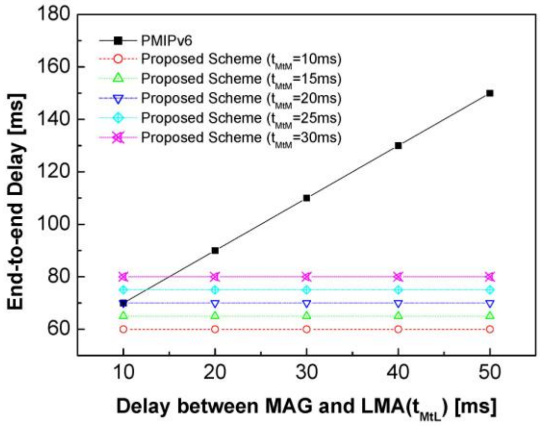

Fig. 13. Packet delivery latency as a function of the delay between the MAG and the LMA

5. Conclusions

This paper has proposed the enhanced network-based mobility management protocol, called enhanced PMIPv6, which can provide MNs with a fast and efficient mobility service in the PMIPv6 domain. The proposed scheme can provide a fast and efficient mobility service to MNs and also the strength of a scalability and stability to an access network by proposing the dynamic virtual hierarchical network architecture and pre-authentication procedure.

From performance evaluations of numerical analyses and computer simulations, we confirmed and verified that the proposed scheme has around 25% gains for improving signaling cost and low handoff latency compared to PMIPv6. This is due to the distribution of the traffic load from the LMA to several E-MAGs and the optimized route between neighboring E-MAGs, which improve not only the performance of mobility but also the network scalability and stability. As a further work, we will investigate various performance evaluations of the proposed scheme with various mobile node moving patterns. In addition, we will consider implementing test-bed of the proposed scheme for the performance evaluation.

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