Shall We Apply Paging Technologies to Proxy Mobile IPv6?[*]

Jong-Hyouk Lee[*] , Tai-Myoung Chung
Sungkyunkwan University, Korea
{jhlee, tmchung}@imtl.skku.ac.kr

Sangheon Pack
Korea University, Korea
shpack@korea.ac.kr

Sri Gundavelli
Cisco, USA
sgundave@cisco.com

ABSTRACT

Proxy Mobile IPv6 has been proposed to overcome limitations of host-based mobility protocols in IPv6 networks. In Proxy Mobile IPv6, mobility entities such as Mobile Access Gateway and Local Mobility Anchor have been newly introduced. These entities eliminate the burden of requiring host-based mobility stack and the signaling cost concentrated to a mobile host. However, there has been no attempt to apply paging technologies, which can also reduce the signaling cost focusing to Local Mobility Anchor, into Proxy Mobile IPv6. In this paper, we propose a paging extension scheme for Proxy Mobile IPv6 to enable an efficient mobility management that reduces the location update signaling cost for the mobile host in the idle mode. Performance analysis results demonstrate that our paging extension scheme improves the scalability by supporting large numbers of mobile hosts with decreased signaling cost under various system parameters.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Network communications, network topology, wireless communication; C.2.2 [**Network Protocols**]: Protocol architecture

General Terms

Design, Performance

Keywords

Internet Mobility, Paging, Proxy Mobile IPv6

1. INTRODUCTION

As the number of mobile devices grows, a numerous kind of mobility protocols has been proposed. In particular, the host-based mobility (HBM) protocols such as Mobile IPv6 and Hierarchical Mobile IPv6 have been considered as a mainstream for enabling IPv6 mobility. The HBM protocol achieves its mobility support depending on the mobility stack installed in a mobile host (MH). The main operation of HBM protocol is registration; sending binding update (BU) message and maintaining binding information. This mechanism is simple but requires installing mobility stack into the MH. Moreover, the MH typically operates in a limited capacity so that sending BU message and maintaining binding information have a strong influence on the limited resource.

Recently, the IETF has formed NETLMM Working Group in order to develop a new mobility protocol, Proxy Mobile IPv6 (PMIPv6), which overcomes the shortcomings of the current HBM protocols [4]. PMIPv6 has been developing from a different view. PMIPv6 supports network-based mobility for the MH. Thus implying that the MH does not need to install the mobility stack into its protocol stack. The two new mobility entities control all signaling related mobility support. Thus, an ordinary host can hand off across different networks without its own mobility signaling cost.

The distinguishing mark of PMIPv6 would solve a number of challenges of HBM protocols. However, several drawbacks exists in PMIPv6. The most important one identified is that all mobility signaling is controlled through the mobility entities. Also, data traffic of MH must be managed by the mobility entities. This network-based mobility architecture not only lacks the network resource, but also limits the scalability in support of very large numbers of MHs [7]. To overcome these drawbacks, we propose a paging extension scheme in order to minimize the signaling overhead and optimize mobility management cost in PMIPv6.

The major contributions of this paper are: we first argue that extending PMIPv6 to support the paging mechanism would improve the scalability issues. Our newly proposed paging extension scheme allows simultaneous connection of a very large number of MHs. The scheme also reduces the signaling cost associated with the registration process performed by the mobility entities. Our numerical results point out the better performance of our scheme thereby achieving greater scalability with lower signaling cost.

The rest of the paper is organized as follows: Section 2 discusses the current PMIPv6 specification and the paging mechanism. In Section 3, we present an overview of our paging extension scheme for PMIPv6 and its detailed oper-

---

[*] This study was supported by a grant of the Korea Health 21 R&D Project, Ministry of Health & Welfare, Republic of Korea

[*] Correspondence to: Jong-Hyouk Lee, jhlee@imtl.skku.ac.kr , Internet Management Technology Laboratory, Electrical and Computer Engineering, Sungkyunkwan University, 300 Cheoncheon-dong, Jangan-gu, Suwon-si, Gyeonggi-do, 440-746, Korea, Tel: +82-31-290-7222.

MobiArch'08, August 22, 2008, Seattle, Washington, USA.

ations. In Section 4, we analyze the proposed paging extension scheme and show its improved performance compared to the basic PMIPv6 specification. Finally, Section 5 concludes the paper with pointers to future work.

2. PRELIMINARIES

In this section, we discuss the current PMIPv6 specifications and the related paging mechanisms.

2.1 Proxy Mobile IPv6

PMIPv6 introduces the network-based mobility management concept [4]. An MH in PMIPv6 is managed by the mobility entities such as Mobile Access Gateway (MAG) and Local Mobility Anchor (LMA). The LMA acts as the home agent, which manages the MH's binding state. From the perspective of the MH, the LMA is the topological anchor point because the MH's home network prefix is provisioned by the LMA. MAG is a function that can reside in an access router. The main task of MAG is to send a proxy binding update (PBU) message on behalf of an MH whenever the MH hands off within a localized mobility domain (LMD) managed by the LMA.

In PMIPv6, An MH is assumed to be an ordinary host. When the MH boots up in the LMD, the MAG detects an attachment event of the MH. Then, the MAG acquires the respective MH-Identifier and profile for the MH. If the MH is authorized for the PMIPv6 service, the MAG sends the PBU message on behalf of the MH to its LMA. The LMA on receiving PBU message sends the proxy binding acknowledgement message including the MH's home network prefix as a respond of the PBU message to the MAG. At this time, a binding information for the MH is recorded in the binding cache entry in the LMA and a bi-directional tunnel between the LMA and the MAG for the MH is established. Note that the tunnel end points of LMA and MAG are the LMA address and the proxy care-of address, respectively [4]. Now, the MAG sends the router advertisement (RA) messages to the MH. The MH on receiving these RA messages can configure its address allocation through the home network prefix included in the RA messages.

Each MH obtains its own proxy home address (pHoA) that can be used as a permanent address in the LMD. An MH can send and receive data traffic with its pHoA even if the MH hands off across different networks in the LMD. For instance, the MH sends packets to the correspondent node (CN); those packets have the pHoA in the source address field. The MAG forwards the packets to the LMA through the established tunnel for MH. After receiving the packets, the LMA on the other end of the tunnel, removes the outer tunnel header and forwards the packets to the CN.

In PMIPv6, all registration messages generated by MAGs, data traffic generated by MHs, and data traffic destined for MHs are concentrated into the LMA. This could lead to network traffic bottleneck at the LMA while it tries to support a large number of MHs [7]. Hence, PMIPv6 is regarded as a centralized mobility management protocol.

2.2 Paging mechanism

Originally, the paging mechanism was proposed to minimize the signaling overhead and optimize mobility management cost in cellular networks [1]. In the paging mechanism, an MH operates in two apparent states — *active mode* in which the mobility entity, i.e., home agent or LMA recognizes the exact location of the MH and *idle mode* in which the MH hands off across different networks in a paging area without the registration procedure resulting in need for paging [3]. What is important in here is that most MHs in the network update its location information by sending BU message frequently even though they are in the idle mode.

The paging mechanism operates on a set of neighboring networks which constitutes a paging area. An MH in the paging mechanism only informs its new location information to the mobility entity when it enters a new paging area, not a new network. Then, the mobility entity finds the current location of the MH by paging. Hence, the paging mechanism can achieve a reduction in signaling loads occurred by MHs in the idle mode. In addition, a battery consumption at the MH is reduced significantly because of the reduced signaling.

Since there are various advantages of the paging mechanism, attempts have been made to apply these paging mechanism into IP-based mobility protocols [5, 2, 6, 3]. Particularly, R. Ramjee et al. have presented various paging architectures, protocols, and algorithms for Mobile IPv4 networks in [3]. They reveal a domain paging architecture that outperforms other architectures such as home agent paging and foreign agent paging in terms of paging latency, location update rate, and reliability. The reason for a better performance of the domain paging architecture over others is: the use of distributed paging which helps in reducing the paging cost and failure rate in the paging networks. In addition, in [6], J. Kempf et al. have performed a paging performance study based on Mobile IPv6 indicating that the paging size is the most important unit for acquiring the effect of IP paging. They noticed that IP paging shows its ability only when the number of cells per network is small. However, we argue that this interpretation of paging in IP-based mobility protocols has to be examined under various performance parameters, not only by the cell size.

With such previous results in mind, we design and evaluate our paging extension scheme for PMIPv6.

3. PAGING EXTENSION FOR PMIPV6

3.1 Design considerations

The paging extension scheme operates based on PMIPv6 so that the following requirements have to be satisfied.

- Support for unmodified mobile hosts: PMIPv6 is not in accordance with HBM protocols. An MH in PMIPv6 has an unmodified IPv6 stack that cannot send any paging related signaling. Note that the previous paging mechanisms proposed for HBM protocols use the paging indication messages of the MH and they require paging response messages sent from the MH [6, 3, 11].

- Reduction in mobility signaling cost: All mobility signaling sent from MAGs is converged to an LMA. Such signaling converging to the LMA increases the network unavailability probability and also decreases the scalability in support of very large numbers of MHs.

- Avoidance of paging processing at a single point: The LMA can be a single point to track the precise location of the MH. However, to reduce the scalability and reliability concerns, we consider that the paging processing would be distributed among the MAGs [1, 3].

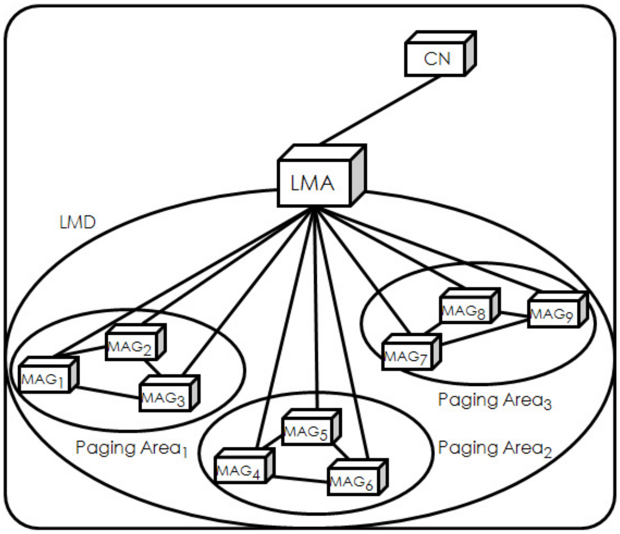


Figure 1: PMIPv6 architecture with paging areas

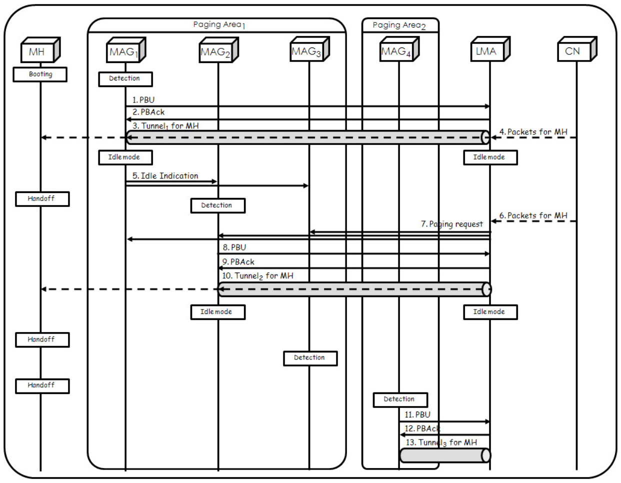


Figure 2: Messages sequences on the paging extension scheme enabled PMIPv6 architecture

The identified considerations are inevitable requirements to develop a paging mechanism for PMIPv6. In order to ensure such requirements, we devise the paging architecture, algorithm, and message sequences.

3.2 Paging architecture

Fig. 1 illustrates the paging extension scheme enabled PMIPv6 architecture where the LMD is formed by several paging areas and each paging area consists of a set of MAGs. The proposed paging extension scheme uses a router based paging architecture where the paging state is distributed among the access routers, which involve the functionality of MAG, in a paging area. In addition, the MAGs in the same paging area are involved in the same multicast group.

The distributed paging state provides the scalability since the processing load of paging MHs will be split on the MAGs in the LMD. The paging area information is only updated in the LMA when the MH hands off to the new paging area. Thus, when the LMA needs the precise location of the MH, the LMA uses a specific multicast address of paging area to send paging request message. The MAG on receiving the paging request message responses only if the MAG is currently serving to the MH.

Our paging extension derives the *time-based state* which is an extension of binding timer managed in the MAG and the LMA for each MH. In the time-based state, a lifetime of a currently active binding for an MH turns into the idle mode when the lifetime is expired. Then, the serving MAG for the MH informs other MAGs located in the same paging area that the MH is now in the idle mode. If the MH hands off from the current MAG, e.g., MAG_1, to another one, e.g., MAG_2, in the same paging area, the MAG_2, which detects the movement of the MH, does not send the PBU message to the LMA. Since the MAG_2 already recognized that the MH is now in the idle mode.

In the idle mode, there is no incoming or outgoing data session. When an MH has any data session, the state is changed from the idle mode to the active mode. In the active mode, the lifetime for the MH is updated by the paging request message sent from the LMA to find the exact location of the MH. In the case of the lifetime is expired, the state is changed to the idle mode. In other words, the MH stays in the active mode until its lifetime expires. In addition, when the MH hands off to another paging area, the lifetime is reset.

3.3 Paging algorithm

There are four well-known paging algorithms used in the previous paging approaches — the fixed algorithm, the hierarchical algorithm, the last-location algorithm, and the dynamic algorithm. We choose the simple one, the fixed paging algorithm, because our goal is to present that PMIPv6 can be extended to support the paging mechanism in order to minimize its limitation. However, we believe that other paging algorithms can be easily applied into PMIPv6. Moreover, there are already many investigations regarding the impact of various paging algorithms.

3.4 Paging message sequences

In Fig. 2, the MH boots up in the paging area_1 and then it communicates with its CN. First, the MAG_1 detects the booting of the MH and then the MAG_1 performs the registration process with the LMA. As a result, the Tunnel_1 is created and then the data packets destined to the MH are transferred to the MH. As becoming to expire the lifetime, the MH falls into the idle mode. As the MAG_1 recognizes the status of the MH, it informs other MAGs in the same paging area via multicast. The MH in the idle mode hands off from the MAG_1 to the MAG_2. At this point, the MAG_2 does not send a PBU message to the LMA because the MAG_2 knows that the MH is now in the idle mode. If the LMA receives data packets destined to the MH, the LMA sends paging request messages to the MAGs located in the paging area_1 via multicast. On the receiving the paging request message, the serving MAG, i.e., MAG_2, responds to the LMA by sending the PBU message. Subsequently, the Tunnel_2 is created and then the buffered data packets in the LMA are forwarded to the MH via the tunnel. Note that all MAGs on receiving the paging request message turn the MH's status to the active mode. In Fig. 2, the MH in the idle mode performs the second handoff from the MAG_2 to the MAG_3. At time, there is no registration process for the MH. In the case where the MH hands off to another paging area, i.e., the paging area$_2$, the MH's registration process is occurred. Thus, in Fig. 2, the MAG$_4$ sends a PBU message to the LMA as it detects the movement of the MH.

In our paging extension scheme, the paging request messages sent from the LMA are distributed to all MAGs in a paging area. To send the paging request messages, the paging area information including the location and address of MAGs and paging size is allocated in the LMA.

4. PERFORMANCE EVALUATION

4.1 Network model

A layered hexagonal network model, as shown in Fig. 3, is used as our network model [8]. We assume that each paging area is consisted of the same number of cells and an MAG is located in each cell. Thus, a cell is considered as a subnet.

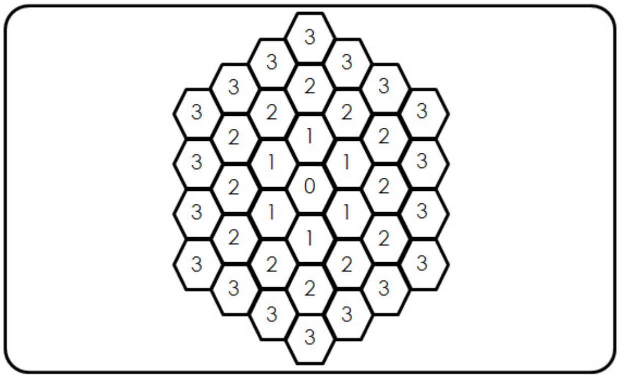


Figure 3: Layered hexagonal network model where an L-level paging area is consisted of 3L(L+1)+1 cells

In a paging area, the inmost cell is labeled as a zero. The first layered cells are located around the zero labeled cell and so on. The number of cells in the L-level paging area is calculated as follows [9]:

$$N_c = \begin{cases} 1, & \text{L} = 0, \\ \sum_{c=1}^{L} 6c + 1, & \text{else.} \end{cases} \qquad (1)$$

4.2 Mobility model

As our mobility model, we use the fluid-flow model which is suitable for MHs having a high mobility and static velocity. The direction of an MH is distributed uniformly in the range of $(0, 2\pi)$. Suppose R_c and R_p be the cell crossing rate and paging area crossing rate, respectively. Let ν is the average velocity of the MH. The cell crossing rate is calculated as follows [8, 11]:

$$R_c = \frac{\rho \cdot \nu \cdot L_c}{\pi}, \qquad (2)$$

where ρ is the MH's density and L_c is the cell perimeter. The paging area crossing rate is calculated as follows [8, 11]:

$$R_p = \frac{\rho \cdot \nu \cdot L_p}{\pi}, \qquad (3)$$

where L_p is the paging area perimeter.

4.3 Cost analysis

In the basic PMIPv6, the location update for an MH occurs whenever the MH hands off between MAGs. An MH in the paging extension scheme calls forth the location update only when the MH hands off between paging areas. However, the paging extension scheme requires the additional paging cost.

Let t_α and t_β be the signaling costs for between the MAGs and between the MAG and the LMA, respectively. Suppose p_α be the cost of the bi-directional tunnel created between the MAG and the LMA. Thus, the location update for the basic PMIPv6 can be represented as follows:

$$C_{ba} = (t_\alpha + t_\gamma + p_\alpha) \times \left(R_c \cdot N_c + \rho \left(\frac{L_c}{4} \right)^2 \cdot N_c \cdot r \right), \quad (4)$$

where r is the average location update refreshing rate which causes the reset of the lifetime. The size of N_c varied based on the paging level. For instance, according to Eq (1), the 3-level paging area has 37 MAGs ($N_c = 37$). The MH causes the location update whenever it hands off across different cells or its MAG sends the re-registration (refreshing) message for the MH. In fact, according to the characteristic of PMIP, the location update signaling occurs between the MAG and the LMA.

In the paging extension scheme, the MH in the idle mode does not induce the location update when the MH hands off between cells, whereas the MH performs the location update when the MH hands off from a paging area to another area that can be expressed as follows:

$$\begin{aligned} C_{ex} \;=\; & (t_\alpha + t_\gamma + p_\alpha) \times \Bigg(R_p + (R_c \cdot N_c - R_p) \cdot s \\ & + \rho \left(\frac{L_c}{4} \right)^2 \cdot N_c \cdot r \\ & + \rho \left(\frac{L_c}{4} \right)^2 \cdot N_c \cdot (1 - s) \cdot (\lambda_i + \lambda_o) \Bigg) \\ & + \Bigg((N_c - 1) \cdot (t_\alpha + t_\beta + t_\gamma) \\ & \cdot \rho \cdot \left(\frac{L_c}{4} \right)^2 \cdot N_c \cdot (1 - s) \cdot \lambda_i \Bigg), \end{aligned} \qquad (5)$$

where s is the ratio of the MHs in the active mode to the total number of MHs; λ_i and λ_o are the incoming data session rate for the MH and the outgoing data session rate for the MH, respectively.

4.4 Numerical results

To estimate the signaling costs in PMIPv6 networks without the paging extension scheme and with the proposed paging extension scheme, we set the system parameters listed in Table 1 as typical values for analyzing performance [11].

The average number of hops between the MAG and the LMA depends on the network topology as well as the average number of hops between the MAGs. However, it is typically assumed that the distance between the MAG and the LMA (t_γ) is larger than the distance between the MAGs (t_β). In addition, we set that the cost for creating and maintaining of bi-directional tunnel (p_α) is smaller than t_γ. For simplicity,

Table 1: System parameters

Notations	Descriptions	Values
L	The paging level	$2 \sim 10$
ρ	The density of MHs in a paging area	$0.005 \sim 0.02$
ν	The average velocity of MHs	$5 \sim 80$ (m/s)
L_c	The perimeters of a cell	100 (m)
t_α	The sig. cost between MH and MAG	1
t_β	The sig. cost between MAGs	$\sqrt{N_c}$
t_γ	The sig. cost between MAG and LMA	5
p_α	The proc. cost for tunnel	3
s	The active mode rate	$5 \sim 80$ (%)
r	The average refreshing rate	0.2
λ_i/λ_o	The incoming/outgoing session rate	$0.0008/s$

we assume that p_α includes CPU processing time, queuing delay, etc.

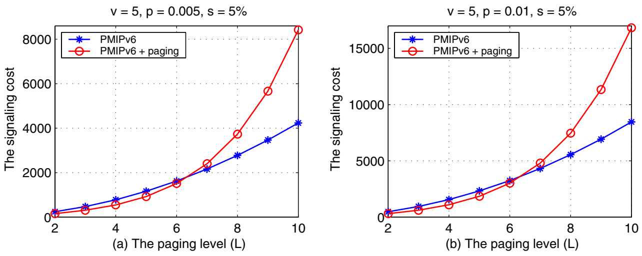


Figure 4: Effect of paging level on the signaling cost

First, we investigate the impact of paging level. Here, we set $\nu = 5$ and $\rho = 0.005$ or 0.01. Other parameters are set as default values shown in Table 4. Then, we vary L from 2 to 10. Fig. 4 shows the signaling cost for the proposed paging extension scheme is generally smaller than the basic PMIPv6. However, see Figs. 4 (a) and (b), the cost for the proposed scheme increases when there are low-velocity MHs in the above 7-level. Note that slow moving MHs stay in the same cell (subnet) for longer periods than the fast moving MHs. We can see that the paging signaling decreases the performance in the low-velocity MHs environments, where do not make frequent movements. Such a phenomenon was reported in [6]. Thus, it means that the size of paging areas is carefully designed and deployed in networks. In addition, such a problem can be absorbed by applying the dynamic paging algorithm [10] that the paging area is dynamically allocated based on several performance units.

Next, we vary ν from 5 to 80 to investigate the impact of velocity. In Fig. 5, the proposed paging extension scheme consumes low signaling compared to the basic PMIPv6. Especially, if an MH has a certain speed, i.e., 7 m/s, then the paging extension scheme starts to decrease the signaling load significantly. The reason why the basic PMIPv6 consumes a large amount of signaling cost in the high-velocity MHs environments is that the fast moving MHs frequently hand off across the cell boundary. However, contrary to the basic PMIPv6, the paging extension scheme reduces the number of location update under such conditions.

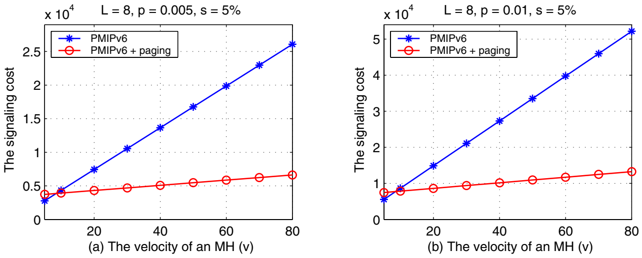


Figure 5: Effect of MH velocity on the signaling cost

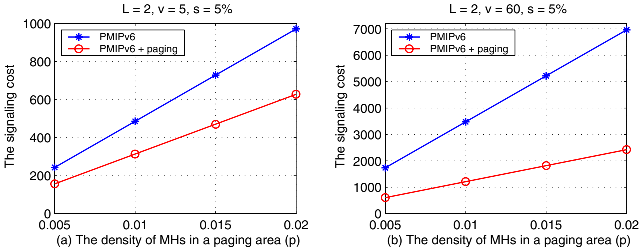


Figure 6: Effect of MH density on the signaling cost

Now, we observe the effect of MH density on the signaling cost in Fig 6. In this experiment, we set s as 5%. Thus, there is a small percentage of MHs operating in the active mode and others are all in the idle mode. The MH density only comes into effect to the small number of MHs that operates in the active mode. Nevertheless, the proposed paging extension scheme always outperforms the basic PMIPv6.

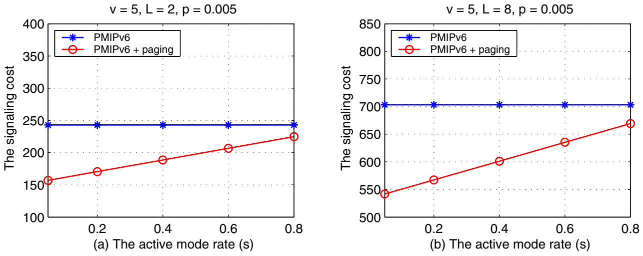
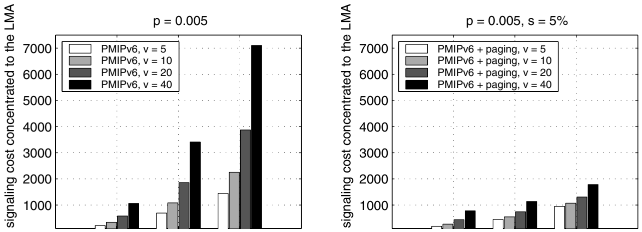


Figure 7: Effect of active mode on the signaling cost

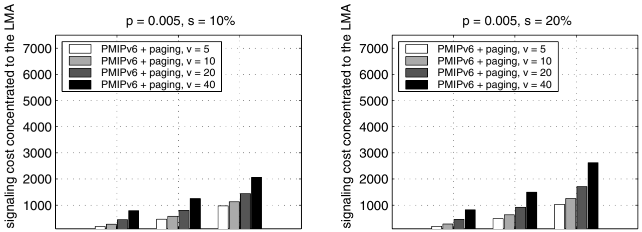
In Fig. 7, we vary s from 5% to 90% even though an estimate for the percentage of MHs operating in the active mode in cellular networks is known as 10% $\sim$ 20% [11]. Note that if there are all MHs operating in the active mode, the paging extension scheme cannot improve the network performance. As we can see in Fig. 7, the signaling cost for the paging extension scheme is increased as the active mode rate increase. Moreover, as the rate reaches the high, the both of basic PMIPv6 and paging extension scheme become equal in signaling cost. Note that the basic PMIPv6 does not effect on the active mode rate since there is no exact distinction for the operating modes — the active mode and the idle mode.

We finally investigate the signaling cost concentrated on the LMA. As already stated in Section 2, PMIPv6 has a centralized mobility management architecture due to which all the network traffic gets concentrated on the LMA posing heavy burden on it. Our paging extension scheme attempts to overcome these deficiencies of PMIPv6; by reducing the signaling load for the LMA and hence solving the scalability problem.



(a) The number of cells

(b) The paging level (the number of cells)



(c) The paging level (the number of cells)

(d) The paging level (the number of cells)

Figure 8: Effect of paging level and MH velocity on the signaling cost concentrated to the LMA

The measured signaling cost concentrated on the LMA is shown in Fig. 8. First, considering the case of basic PMIPv6, each cell size is set as 19, 61, and 127, respectively. Then, we vary ν from 5 to 40. The results are shown in Fig. 8 (a). As the velocity of MHs (ν) increases, the signaling cost focusing on the LMA also increases. The reason is that a fast moving MH in the basic PMIPv6 makes the frequent movements between different cells (subnets) so that there is a high rate of location update procedure.

Next, we observe the case of our proposed paging extension scheme for PMIPv6. In Figs. 8 (b) $\sim$ 8 (d), we set each paging level as 2, 4, and 6, respectively. Then, we vary ν from 5 to 40 as we set in Fig. 8 (a). As we can see the results, the velocity cannot exert enormous influence in the proposed paging extension. In addition, even though the paging level (the number of cells) increases, the signaling cost also increases but its impact is smaller than that of the basic PMIPv6. However, as the percentage of active mode rate (s) increases, the signaling cost focused on the LMA also increases because the paging effect is damped in the high rate of active mode. In the extreme case, if all MHs are in the active mode, the signaling cost of the proposed paging scheme and basic PMIPv6 becomes to be equivalent.

The numerical results corroborate that our proposed paging extension scheme for PMIPv6 reduces the location update cost in terms of the paging level, MH velocity, MH density, and active mode rate. In addition, our scheme provides the scalability with reduced signaling cost concentrated on the LMA.

5. CONCLUSIONS AND FUTURE WORK

Proxy Mobile IPv6 (PMIPv6) is a novel mobility support protocol designed to overcome the shortcomings of host-based mobility protocols. PMIPv6 follows a centralized mobility management architecture. Such an architecture poses heavy burden on the LMA and causes network traffic bottleneck at the LMA. To overcome these problems, we propose a paging extension scheme for PMIPv6. Our proposed scheme has a decentralized paging architecture that distributes the paging state among the MAGs so that the processing load of paging MHs is decentralized. We have modeled the location update cost for our proposed paging extension scheme and the basic PMIPv6 using layered hexagonal network model and the fluid flow model. Our numerical results confirm that our proposed paging extension scheme provides significant reduction in the location update cost compared to the basic PMIPv6. Our scheme also outperforms the basic PMIPv6 in terms of the signaling cost concentrated at the LMA. In future, we would like to explore dynamic paging algorithms (which could be added to our proposal) to further reduce the signaling load.

6. REFERENCES

[1] R. Agrawal, A. S. Bedekar, and S. Kalyanasundaram. Analysis of Paging in Distributed Architectures for 4G Systems. In *Proc. of ACM IWCMC*, pages 31–36, August 2007.

[2] J. K. et al. Requirements and Functional Architecture for an IP Host Alerting Protocol. RFC 3154, August 2001.

[3] R. R. et al. IP Paging Service for Mobile Hosts. In *Proc. of ACM SIGMOBILE*, pages 332–345, July 2001.

[4] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil. Proxy Mobile IPv6. Internet-Draft (work in progress), February 2008.

[5] J. Kempf. Dormant Mode Host Alerting ("IP Paging") Problem Statement. RFC 3132, June 2001.

[6] J. Kempf and P. Mutaf. IP Paging Considered Unnecessary: Mobile IPv6 and IP Paging for Dormant Mode Location Update in Macrocellular and Hotspot Networks. In *Proc. of IEEE WCNC*, pages 1032–1036, March 2003.

[7] D. Le, J. Lei, and X. Fu. A New Decentralized Mobility Management Service Architecture for IPv6-based Networks. In *Proc. of ACM WMuNeP*, pages 54–61, October 2007.

[8] S. Pack and Y. Choi. A Study on Performance of Hierarchical Mobile IPv6 in IP-based Cellular Networks. *IEICE TRANSACTIONS on Communications*, E87-B(3):462–469, March 2004.

[9] G. Wan and E. Lin. Cost Reduction in Location Management Using Semi-Realtime Movement Information. *ACM-Baltzer Journal of Wireless Networks (WINET)*, 5(4):245–256, December 1999.

[10] Xie, H., Tabbane, S. and Goodman, D.J. Dynamic Location Area Management and Performance Analysis. In *Proc. of IEEE VTC*, pages 536–539, May 1993.

[11] X. Zhang, J. Castellanos, and A. Campbell. P-MIP: Paging Extensions for Mobile IP. *ACM Mobile Networks and Applications*, 7(2):127–141, March 2002.