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Enhancing QoS of Mobile Devices by a New Handover Process in PMIPv6 Networks

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Abstract The handover processes in present IP mobility management protocols incur significant latency, thus aggravating QoS of consumer devices. In this paper, we introduce an enhanced handover process for the Proxy Mobile IPv6 (PMIPv6) protocol, which is a recently developed IP mobility management protocol aiming at providing network-based mobility support. The proposed handover process further improves handover performance of PMIPv6 by allowing a new access network obtains handover context before a consumer's mobile node (MN) moves to the new access network. Data packets destined for the MN are buffered to prevent packet loss and immediately delivered to the MN as the MN moves to the new access network. We evaluate the handover latency and data packet loss of the proposed handover process compared to the basic one of PMIPv6. The conducted analysis results confirm that the proposed handover process yields the reduced handover latency compared to that of the basic PMIPv6 and also prevents data packet loss. We moreover evaluate the buffering cost of the proposed handover process.

Keywords Handover · Buffering · Packet loss · PMIPv6

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1 Introduction

The advance and wide deployment of wireless technologies lay the foundation stone of mobile communications allowing consumers have fun with multimedia/business applications during movements. However, an MN (consumer's smartphone or laptop) experiences the service interruption time during its handover, i.e., the MN changes its point of attachment while maintaining ongoing sessions, due to perceptible handover latency and data packet loss.

The recently developed PMIPv6 protocol [1] allows an unaltered and mobility-unaware MN to change its point of attachment while maintaining its network connectivity. Compared to previously developed host-based mobility management protocols such as Mobile IPv6 [2], Fast Mobile IPv6 [3], and Hierarchical Mobile IPv6 [4], PMIPv6 is a glamorous mobility management protocol designed for telecommunication service providers as well as manufacturers. As PMIPv6 is deployed in mobile access networks, manufacturers do not need to implement a mobility stack at MNs they produce. From the aspect of telecommunication service providers, they can easily manage and control mobility services for consumers [5–7]. Moreover, from the viewpoint of performance, PMIPv6 generally outperforms the previously developed host-based mobility management protocols [8].

The basic specification of PMIPv6 mainly focuses on defining essential service entities and operational procedures for network-based mobility management. However, the basic handover process defined in [1] is arguable if it would satisfy the QoS requirements for delay sensitive applications, especially, in high mobility environments where an MN frequently performs its handover. The limitations of the basic handover process of PMIPv6 are (1) inefficient handover steps from the aspect of handover latency; and (2) lacking of a buffering mechanism for preventing data packet loss.

The forthcoming consumer mobile networks will be in charge of delivering QoS sensitive application traffic to individual consumers. Accordingly, the investigation and analysis on the handover process of PMIPv6, which is expected to be a base mobility management protocol for the forthcoming consumer mobile networks, is required. In addition, a proposal for improving the handover performance is a desirable work. Nevertheless, in recently published literatures [5–10], improvements for the handover process of PMIPv6 have not considered. In this paper, we develop an enhanced handover process in which a home network prefix (HNP) assigned to a moving MN is actively provided from a local mobility anchor (LMA) to a mobile access gateway (MAG) located at a new access network. In addition, data packets destined for the MN are also smoothly forwarded to the MAG. By doing so, as soon as the MN attaches with the MAG located at the new access network, the MN can receive the data packets buffered and a router advertisement (RA) message including the HNP from the MAG. In order to demonstrate its handover performance, we develop analytical models for estimating the handover latency and data packet loss based on devised handover timing diagrams. Moreover, we evaluate the buffering cost of the proposed handover process.

The rest of the paper is organized as follows: Sect. 2 discusses the current handover process of PMIPv6. In Sect. 3, we introduce the proposed handover process designed for enhancing QoS of consumer mobile devices by reducing handover latency and preventing data packet loss. In Sect. 4, we develop analytical models for performance evaluation. Then, in Sect. 5, we present conducted analysis results. Finally, Sect. 6 concludes this paper.

2 Handover Process of PMIPv6

PMIPv6 provides network-based mobility support for mobility-unaware MNs. It means that an MN does not need to participate in any mobility signaling while it changes its point of attachment in a given PMIPv6 domain consisting of at least one LMA and MAGs. Fig. 1 shows the conceptual PMIPv6 domain. As shown in Fig. 1, an MN performs its handover from MAG_1 to MAG_2, but its address called a home address (HoA) is maintained. Since the LMA assigns the unique and same HNP to the moving MN, the MN can already receive RA messages including the same HNP so that the MN cannot recognize its movements at the IP layer. This is a distinguishing point of PMIPv6 from existing host-based mobility management protocols such as Mobile IPv6 and Fast Mobile IPv6.

Figure 2 illustrates the currently specified handover process of PMIPv6 [1].

As MAG_1 located at the previous access network detects the MN's detachment from its access network, it sends a de-registration message, i.e., de-registration proxy binding update (De-Reg. PBU) message, to an LMA. The De-Reg. PBU message involves the identifier of

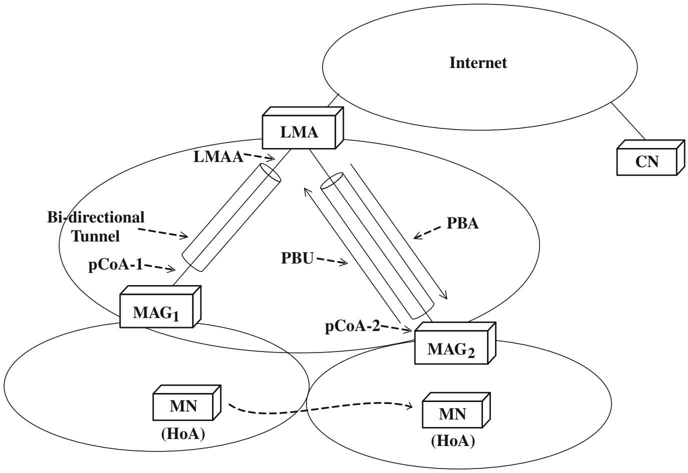

Fig. 1 Conceptual PMIPv6 domain: An MN changes its point of attachment while maintaining the same address configured its interface

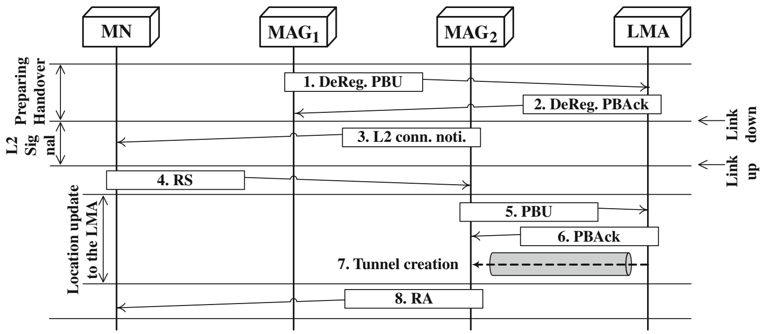

Fig. 2 Handover process of PMIPv6: An MN detaches from MAG_1 located at a previous access network and attaches to MAG_2 located at a new access network

the MN, assigned HNP, etc. As soon as receiving the De-Reg. PBU, the LMA recognizes the movement of the MN. Then, it waits a new registration message, i.e., proxy binding update (PBU) message, from another MAG. In this example, the MN attaches to MAG_2 that receives a router solicitation (RS) message. MAG_2 informs the attachment event of the MN to the LMA by sending a PBU message. The LMA updates its binding cache entry for the MN and responds by sending a proxy binding acknowledgement (PBAck) message including the HNP for the MN. Then, a bi-directional tunnel for data packets destined for the MN is also established between them. Note that the PBAck message and the data packets for the MN are simultaneously sent from the LMA. MAG_2 sends an RA message including the HNP to the MN. Because the HNP is the same HNP the MN has received from the previous access network, from the viewpoint of the MN, the whole PMIPv6 domain can be viewed as a single network. That is, the MN does not need to configure new addresses for every movements in the PMIPv6 domain managed by at least the LMA and MAGs. This is a difference with the previously developed IP-layer mobility management protocols such as Mobile IPv6 [2] and Fast Mobile IPv6 [3]. In addition, thanks to the network-based mobility service provided by mobility service provisioning entities such as the LMA and MAG, any mobility signaling from the MN is not required so that an ordinary MN can be supported [5–7].

However, the basic handover process is arguable if it would satisfy the requirements for delay sensitive applications, especially, in high mobility environments where an MN frequently performs its handover due to its high velocity. The limitations of the basic handover process are (1) inefficient handover steps from the aspect of handover latency; and (2) lacking of a buffering mechanism for preventing data packet loss. In the following section, the proposed handover process designed to solve the above limitations is presented.

3 Proposed Handover Process

As a proposal for improving the handover performance of PMIPv6, in this section, we introduce a new handover process aiming at reducing handover latency while preventing data packet loss. Fig. 3 shows the proposed handover process.

Each step of the proposed handover process is as follows:

– Messages 1–3: By utilizing the L2 trigger, an MN detects information of neighbor access networks. Then, it reports information of the next network the MN will attach to. This message is an access technology specific, but at least the identifiers of the MN and the next network must be provided to MAG_1, where the MN is currently attached. MAG_1 sends

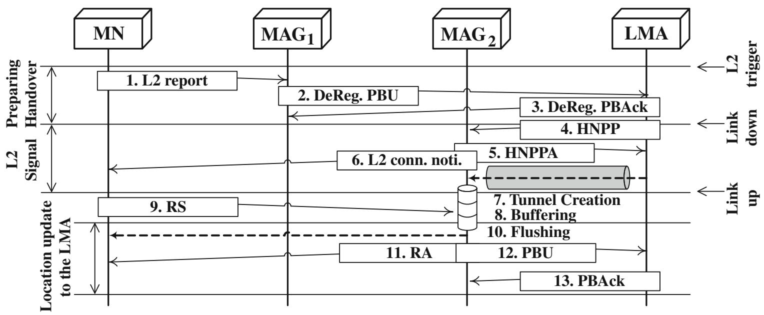

Fig. 3 Proposed handover process for PMIPv6: An LMA proactively provisions an HNP assigned to an MN by sending an HNPP message to MAG_2 located at a new access network where the MN attaches to. In addition, MAG_2 buffers data packets arrived from the LMA and sends to the MN as soon as the MN attaches

a De-Reg. PBU message to an LMA in order to inform the detachment of the MN from its access network. The De-Reg. PBU message involves the identifiers of the MN and the next network (MAG_2's access network). Upon receiving the De-Reg. PBU message indicating that the MN has been detached from MAG_1's access network, the LMA checks its corresponding mobility session for the MN and accepts the De-Reg. PBU message if it is valid. As a response, the LMA sends a De-Reg. PBAck message.
- Messages 4–7: The LMA proactively provides required information to MAG_2 by sending a home network prefix provisioning (HNPP). The HNPP message at least involves the following information of the MN: identifier, link-local address, and HNP. Note that a De-Reg. PBAck message and HNPP message are simultaneously sent from the LMA, but in Fig. 3, they are presented in stepwise. As a response, MAG_2 sends a HNPPA message with the status bit. For instance, if MAG_2 is available to serve the MN, the status bit is set as 1. As the LMA receives the HNPPA with the status bit 1, it establishes a bi-directional tunnel with MAGs and sends data packets destined for the MN. Then, the LMA waits for a pre-defined time to receive a PBU message from MAG_2 [1]. As the MN approaches an access network of MAG_2, it receives the L2 connection notification from the access network of MAG_2. Then, the MN's wireless link is attached to MAG_2.
- Messages 8–9: Data packets for the MN sent from the LMA are buffered at MAG_2. This buffering technique prevents data packet loss. As the MN attaches to MAG2, it sends an RS message in order to explicitly inform its attachment and to receive an RA message quickly from to MAG2. Note that an only authenticated MN is allowed to access to a PMIPv6 domain and here we simply omit an authentication process in Fig. 3 because it is immaterial to the analysis in this paper. More details for authentication in PMIPv6 can be found at [11].
- Messages 10–13: As MAG_2 receives the RS message sent from the MN, it recognizes the attachment event and immediately sends the data packets being buffered to the MN. This data packet flushing can be also triggered by the authentication process for the MN if MAG_2 explicitly knows the attachment of the MN via the authentication process, but this case is not considered in this letter. MAG_2 sends the RA message including the HNP obtained from the HNPP message. As the MN receives the RA message, it obtains the same HNP used in the previous access network, i.e., MAG_1's access network. Accordingly, the MN does not need to generate a new address for MAG_2's access network so that it also yields to avoid the duplicate address detection process, which is being used by the previously developed IP-layer mobility management protocols. As a default operation, MAG_2 registers the MN to the LMA by sending a PBU message. Note that the data packet flushing, sending RA message, and sending PBU message are simultaneously executed, but in Fig. 3, they are presented in stepwise. As a response, the LMA sends a PBAck message to MAG_2.

Compared to the basic handover process of PMIPv6, the proposed one minimizes the handover latency and prevents data packet loss. In the following section, we develop analytical models for the proposed handover process and the basic one of PMIPv6.

4 Analytical Modeling

In this paper, the handover latency $L_H^{(\cdot)}$ is defined as the time interval during which an MN cannot receive any data packets while it performs its handover. The notations used for our analysis are as follows:

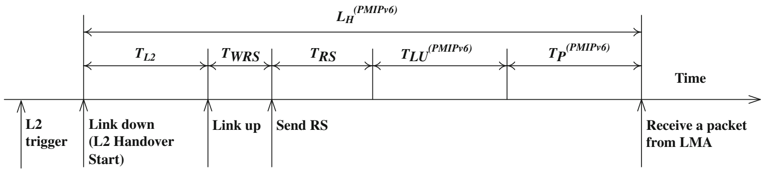

Fig. 4 Handover timing diagram of the basic handover process

- T_{L2} is the link-layer handover latency, which mainly depends on an implementation chipset for a wireless interface;
- T_{WRS} is the random amount of delay before sending an initial RS message;
- T_{RS} is the arrival delay of the RS message sent from the MN to the MAG at the new access network;
- $T_{LU}^{(PMIPv6)}$ is the delay of the location update (registration) for the MN;
- $T_P^{(PMIPv6)}$ is the arrival delay of the first packet sent from the LMA to the MN;
- $T_P^{(PRO)}$ is the arrival delay of the first packet sent from the MAG to the MN;
- T_{BS} is the buffering start time in the proposed handover process;
- T_{BE} is the buffering end time in the proposed handover process;
- $T_{L2-REP}^{(PRO)}$ is the arrival delay of the L2 report sent from the MN to the MAG;
- $T_{DREG}^{(PRO)}$ is the delay of the de-registration for the MN;
- $T_{HNPP}^{(PRO)}$ is the delay of the HNPP;
- $T_{HNPPA}^{(PRO)}$ is the delay of the HNPPA; and
- $M_S^{(X)}$ is the size of the message X, which is used in the handover, i.e., $X \in \{PBU, RS, HD, DATA\}$.

4.1 Handover Latency of the Basic Handover Process

Figure 4 depicts the handover timing diagram of the basic handover process. Let $L_H^{(PMIPv6)}$ be the handover latency of the basic handover process in PMIPv6. Then, it is expressed as:

$$L_H^{(PMIPv6)} = T_{L2} + T_{WRS} + T_{RS} + T_{LU}^{(PMIPv6)} + T_P^{(PMIPv6)}, \tag{1}$$

where T_{WRS} can be determined as a value between 0 and $MAX\_RTR\_SOLICITATION\_DELAY$ [12]. Here, we assume that T_{WRS} is uniformly distributed in the interval [0, $MAX\_RTR\_SOLICITATION\_DELAY$]. T_{RS} is calculated as:

$$T_{RS} = \left(\frac{M_S^{(RS)}}{b_{WL}} + t_{WL}\right) + \left(\frac{M_S^{(RS)}}{b_{WL}} + t_{WL}\right) \times \sum_{n_f}^{\infty} n_f \times Prob\{n_f \textit{ failures and 1 success}\}, \tag{2}$$

where $M_S^{(RS)}$ is the size of RS message. b_{WL} is the bandwidth of the wireless link between the MN and the MAG. t_{WL} is the propagation time for the wireless link. n_f is the number of message failures over the wireless link. Suppose p_f is the link failure probability. By applying p_f in Eq. (2), it is rewritten as [13]:

$$T_{RS} = \left(\frac{M_S^{(RS)}}{b_{WL}} + t_{WL}\right) + \left(\frac{M_S^{(RS)}}{b_{WL}} + t_{WL}\right) \times \frac{p_f}{1 - p_f}. \tag{3}$$

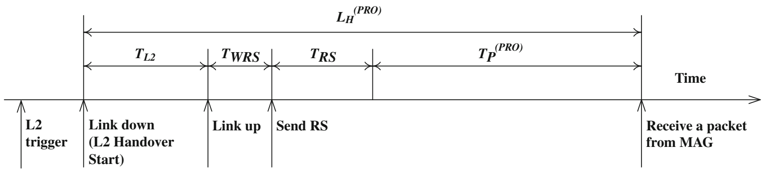

Fig. 5 Handover timing diagram of the proposed handover process

We assume the wired link between the MAG and the LMA is robust and no message failure is expected. Then, $T_{LU}^{(PMIPv6)}$ in Eq. (1) is obtained as:

$$T_{LU}^{(PMIPv6)} = n_h\left(\frac{M_S^{(PBU)}}{b_{WD}} + t_{WD}\right), \tag{4}$$

where $M_S^{(PBU)}$ is the size of PBU messages. n_h is the number of wired link hops between the MAG and the LMA. b_{WD} is the bandwidth of the wired link between the MAG and the LMA. t_{WD} is the propagation time for the wired link. And, $T_P^{(PMIPv6)}$ in Eq. (1) is obtained as:

$$T_P^{(PMIPv6)} = n_h\left(\frac{M_S^{(HD)} + M_S^{(DATA)}}{b_{WD}} + t_{WD}\right) + \left(\frac{M_S^{(DATA)}}{b_{WL}} + t_{WL}\right) + \left(\frac{M_S^{(DATA)}}{b_{WL}} + t_{WL}\right) \times \frac{p_f}{1-p_f}, \tag{5}$$

where $M_S^{(HD)}$ and $M_S^{(DATA)}$ are the sizes of IPv6 header and data message, respectively. Recall data packets for the MN are traversed via the bi-directional tunnel established between the LMA and the new MAG, i.e., MAG_2 in Fig. 3 when the MN attaches to the new MAG. Note that the LMA knows the attachment of the MN to the new MAG as it receives the PBU message from the new MAG. Note that the data packets are protected by a means of IPsec, but here we skip the overhead of IPsec in this analysis.

4.2 Handover Latency of the Proposed Handover Process

Figure 5 depicts the handover timing diagram of the proposed handover process. Let $L_H^{(PRO)}$ be the handover latency of the proposed handover process for PMIPv6. Then, it is expressed as:

$$L_H^{(PRO)} = T_{L2} + T_{WRS} + T_{RS} + T_P^{(PRO)}, \tag{6}$$

where $T_P^{(PRO)}$ is obtained as:

$$T_P^{(PRO)} = \left(\frac{M_S^{(DATA)}}{b_{WL}} + t_{WL}\right) + \left(\frac{M_S^{(DATA)}}{b_{WL}} + t_{WL}\right) \times \frac{p_f}{1-p_f}, \tag{7}$$

In Eq. (7), the data transmission delay over the wired link between the LMA and the new MAG is excluded, which has taken account in the basic handover process as shown in Eq. (5). This is because that the proposed handover process allows the LMA and the new MAG, i.e., MAG_2 in Fig. 3, to establish the bi-directional tunnel while the MN prepares its handover to the new MAG. Then, the LMA forwards the data packets destined for the MN to the new MAG. Accordingly, as soon as the MN attaches to the new MAG, it receives the data packets from the new MAG.

4.3 Data Packet Loss

If any buffering mechanism is not supported, data packets destined for an MN will be lost when the MN undergoes its handover. Suppose $\psi_p^{(\cdot)}$ is the amount of data packet loss during the handover process. Let λ_s denote the average session arrival rate per sec at the MN. $\psi_p^{(\cdot)}$ is obtained as follows:

$$\psi_p^{(\cdot)} = \lambda_s E(S) L_H^{(\cdot)}, \tag{8}$$

where $E(S)$ is the average session length in packets.

4.4 Buffering Cost

The proposed handover process prevents data packet loss by utilizing the buffering mechanism which motivates us to evaluate its buffering cost.

Since the L2 trigger is used for handover anticipation in the proposed handover process, we here consider the L2 trigger time [14]. Suppose T_τ and p_s are the times taken from the occurrence of the L2 trigger and the probability of success handover after the L2 trigger, respectively. A small value of T_τ induces a high value of p_s that indicates a high probability of handover attaching to a new access network. The relationship between T_τ and p_s is expressed as:

$$p_s = \frac{1}{e^{\kappa T_\tau}}, \tag{9}$$

where κ is a scale factor.

In this paper, the buffering cost $C_B^{(PRO)}$ is represented as the maximum required buffer size at MAGs for preventing data packet loss during an MN's handover. Since the required buffer size is increased in proportion to λ_s and $E(S)$, we have

$$C_B^{(PRO)} = p_s\left[\lambda_s E(S)(T_{BE} - T_{BS})\right], \tag{10}$$

where T_{BE} and T_{BS} are obtained as:

$$T_{BE} = T_\tau + T_{L2} + T_{WRS} + T_{RS}, \tag{11}$$

$$T_{BS} = T_\tau + T_{L2-REP}^{(PRO)} + T_{DREG}^{(PRO)} + T_{HNPP}^{(PRO)} + T_{HNPPA}^{(PRO)}, \tag{12}$$

where $T_{L2-REP}^{(PRO)}$, $T_{DREG}^{(PRO)}$, $T_{HNPP}^{(PRO)}$ are assumed as the same values of T_{RS}, $T_{LU}^{(PMIPv6)}$, and $T_{LU}^{(PMIPv6)}$, respectively. In addition, we assume that $T_{HNPPA}^{(PRO)}$ is equal to $T_{HNPP}^{(PRO)}$.

5 Analysis Results

The following system parameters are used in our analysis [12,15]: $T_{L2} = 45.35$ ms, $b_{WD} = 100$ Mbps, $b_{WL} = 11$ Mbps, $t_{WD} = 0.5$ ms, $t_{WL} = 2$ ms, $p_f = [0.1, 0.4]$, $n_h = 5$, and $MAX\_RTR\_SOLICITATION\_DELAY = 1000$ ms. The sizes of messages used are as follows [16]: $M_S^{(RS)} = 52$ bytes, $M_S^{(PBU)} = 76$ bytes, $M_S^{(HD)} = 40$ bytes, $M_S^{(DATA)} = 120$ bytes, $\lambda_s = [0.3, 0.7]$, and $E(S) = 20$.

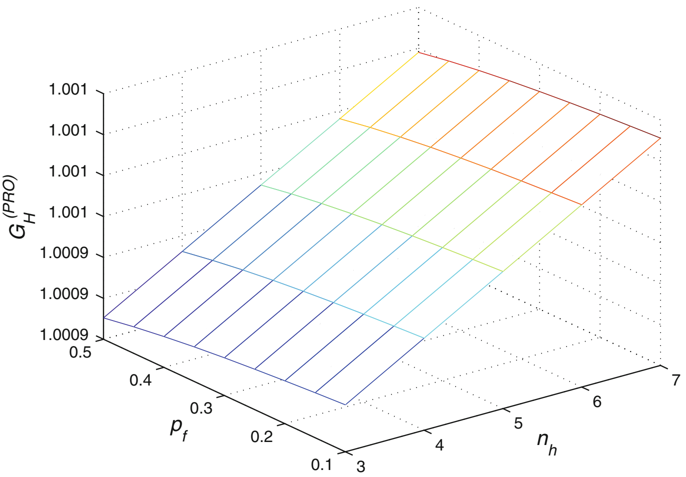

Fig. 6 Relative handover performance gain as functions of n_h and p_f

For the purpose of comparison, we define the relative gain of handover latency to the basic handover process as:

$$G_H^{(PRO)} = \frac{L_H^{(PMIPv6)}}{L_H^{(PRO)}}. \tag{13}$$

where $G_H^{(PRO)}$ is used for indicating a relative handover performance gain compared to the basic handover process. For instance, if $G_H^{(PRO)}$ is larger than 1.0, it means that the proposed handover process outperforms the basic one.

First, we observe the variation of $G_H^{(PRO)}$ with different values of n_h and p_f. As shown in Fig. 6, the proposed handover process always outperforms the basic one. As n_h is increased, $G_H^{(PRO)}$ is also increased, whereas $G_H^{(PRO)}$ is out of proportion to the increase of p_f. It is seen that n_h is sensitive to $G_H^{(PRO)}$, whereas p_f does not much affect. This phenomenons are caused by (1) the unstable wireless link between the MAG and the MN; and (2) fast data packet forwarding of the proposed handover process. In addition, an interesting observation is that as p_f decreases, the performance gap between the proposed handover process and the basic one is grown. This is because that the proposed handover process relies upon few messages over the unstable wireless link compared to the basic one.

Without any buffering mechanism, data packets destined for the MN will be lost while the MN performs its handover. In order to consider mobility with $\psi_p^{(\cdot)}$, we adopt a simple mobility model presented in [5]. Suppose the MN moves with a mean velocity ν. Assuming that the movement of the MN is uniformly distributed over $(0, 2\pi)$ and all access networks in a given PMIPv6 have the same shape and area, we have the access network crossing rate of the MN as:

$$\lambda_c = \nu \frac{l}{\pi a}, \tag{14}$$

where l is the circumference of the access network, whereas a is the surface area of the access network. If we further assume that the access network has a circular form, Eq. (14) is rewritten as:

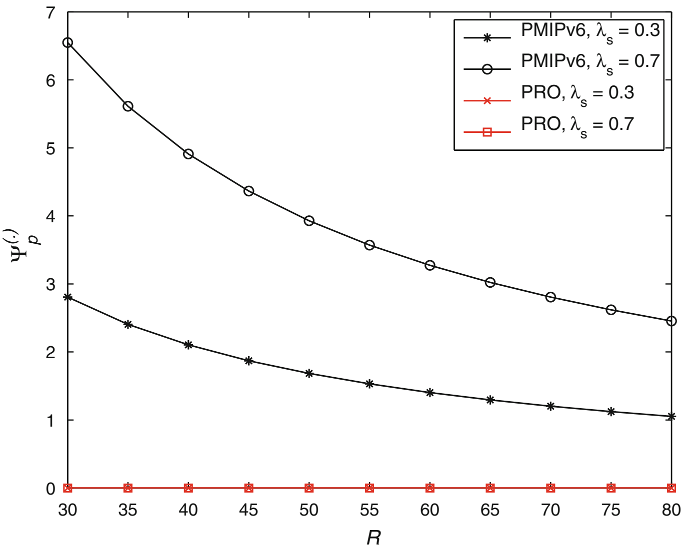

Fig. 7 Amount of data packet loss as a function of p_f

$$\lambda_c = \nu \frac{2}{\pi R}, \tag{15}$$

where R is the radius of the access network.

Here, we set n_h and p_f as 5 and 0.1, respectively. ν is fixed as 40 m/s, while R is changed from 30 to 80 m. The results for the amount of data packet loss is demonstrated in Fig. 7. Thanks to the employed buffering mechanism in the proposed handover process, no data packet loss is occurred. However, the basic handover process yields data packet loss due to the lack of any buffering mechanism. It is a similar case with Mobile IPv6; the basic handover process in Mobile IPv6 does not provide any buffering mechanism, but Fast Mobile IPv6 developed as an extension to Mobile IPv6 provides a means of data packet buffering and forwarding.

Figure 8 gives the analysis result for the buffering cost incurred in the proposed handover process. Here, λ_s is set as 0.7 and T_τ is varied from 0 to 15 ms. As presented, $C_B^{(PRO)}$ is decreased as T_τ is increased, because p_s is inversely proportional to $e^{\kappa T_\tau}$. In addition, in Fig. 8, we can find the optimal value of T_τ, i.e., 10 ms, in given environments.

6 Conclusion

We have introduced a new handover process for reducing handover latency and preventing data packet loss for the PMIPv6 protocol. The proposed handover process enables an LMA to provide a HNP assigned to an MN to a new MAG when the MN prepares its handover to the new access network. In addition, data packets destined for the MN are also actively sent to the MAG. By doing so, as soon as the MN attaches with the MAG located at the new access network, the MN can receive the data packets buffered and an RA message including the HNP from the MAG. From the conducted analysis results, we have confirmed that the

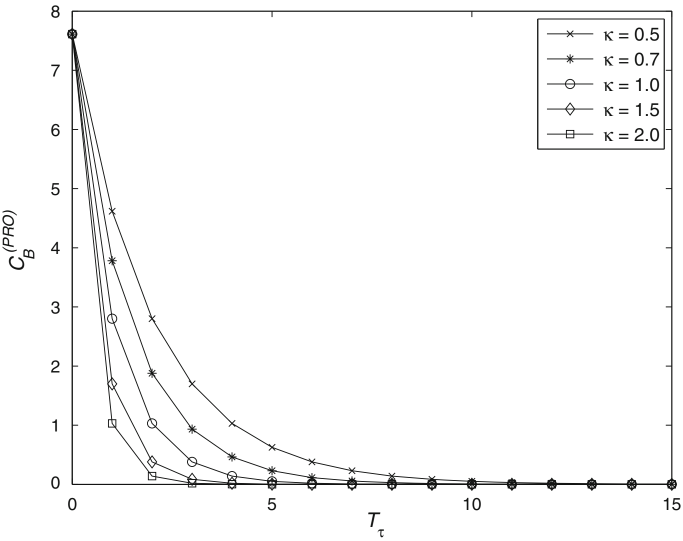

Fig. 8 Buffering cost as a function of T_τ

proposed handover process outperforms the basic handover process of PMIPv6 in terms of handover latency and data packet loss.

References

1. Gundavelli, S., Leung, K., Devarapalli, V., Chowdhury, K., & Patil, B. (2008, August). Proxy mobile IPv6. In *IETF RFC 5213*.
2. Johnson, D., Perkins, C., & Arkko, J. (2004, June). Mobility support in IPv6. In *IETF RFC 3775*.
3. Koodli, R. (2005, July). Fast handovers for mobile IPv6. In *IETF RFC 4068*.
4. Soliman, H., Castelluccia, C., ElMalki, K., & Bellier, L. (2005, August). Hierarchical mobile IPv6 mobility management (HMIPv6). In *IETF RFC 4140*.
5. Lee, J.-H., Pack, S., You, I., & Chung, T.-M. (2009). Enabling a paging mechanism in network-based localized mobility management networks. *Journal of Internet Technology, 10*(5), 463–472.
6. Lee, J.-H., Han, Y.-H., Gundavelli, S., & Chung, T.-M. (2009). A comparative performance analysis on hierarchical mobile IPv6 and proxy mobile IPv6. *Telecommunication Systems, 41*(4), 279–292.
7. Lee, J.-H., & Chung, T.-M. (2010). How much do we gain by introducing route optimization in proxy mobile IPv6 networks?. *Annals of Telecommunications, 65*(5–6), 233–246.
8. Lee, J.-H., Ernst, T., & Chung, T.-M. (2010). Cost analysis of IP mobility management protocols for consumer mobile devices. *Transactions on Consumer Electronics, 56*(2), 1010–1017.
9. Ali, I., Casati, A., Chowdhury, K., Nishida, K., Parsons, E., Schmid, S., & Vaidya, R. (2009). Network-based mobility management in the evolved 3GPP core network. *IEEE Communications Magazine, 47*(2), 58–66.
10. Yan, Z., Zhou, H., & You, I. (2010). N-NEMO: A comprehensive network mobility solution in proxy mobile IPv6 network. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 1*(2–3), 52–70.
11. Kim, H., & Lee, J.-H. (2010). Diffie-Hellman key based authentication in proxy mobile IPv6. *Mobile Information Systems, 6*(1), 107–121.
12. Narten, T., Nordmark, E., & Simpson W. (1998, December). Neighbor discovery for IP version 6 (IPv6). In *IETF RFC 2461*.
13. McNair, J., Akyildiz, I. F., & Bender, M. D. (2000, March). An inter-system handoff technique for the IMT-2000 System. In *Proceedings of IEEE Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM) 2000* (pp. 208–216).

14. Pack, S., & Choi, Y. (2003). Performance analysis of fast handover in mobile IPv6 networks. *Lecture Notes in Computer Science, 2775*, 679–691.
15. Pack, S., Choi, J., Kwon, T., & Choi, Y. (2007). Fast-handoff support in IEEE 802.11 wireless networks. *IEEE Communications Surveys & Tutorials, 9*(1), 2–12.
16. Fathi, S. S., Chakraborty, & R., Prasad (2007). Optimization of mobile IPv6-based handovers to support VoIP services in wireless heterogeneous networks. *IEEE Transactions on Vehicular Technology, 56*(1), 260–270.

Author Biographies

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