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Improved PMIPv6 handover procedure for consumer multicast traffic

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Abstract: As Internet Protocol (IP) multicast allows the efficient use of network bandwidth for multipoint communication, it is expected to be an essential communication type for delivering multimedia services to mobile nodes (MNs). In this study, the authors address an issue of consumer multicast traffic support in a Proxy Mobile IPv6 (PMIPv6) environment wherein network-based mobility management is deployed for MNs. The recently standardised PMIPv6 multicast listener support provides options for deploying multicast listener functions in a PMIPv6 domain, whereas it does not address specific optimisations and efficiency improvements of multicast routing. The authors first review the PMIPv6 multicast listener support and point out the limitations of the current approach. Then, propose an improved multicast handover procedure that optimises multicastgroup management by utilising the context of consumer's MN running multicast applications. The authors develop analytical models to evaluate the proposed multicast handover procedure compared with the base one. From the conducted analysis, it is demonstrated that the proposed multicast handover procedure minimises the service interruption time and prevents the multicast packet loss during handovers. Furthermore, in terms of signalling cost consumption, the proposed multicast handover procedure operates on an equal basis with the base one.

1 Introduction

Internet Protocol (IP) multicast is a dominant communication type for delivering multimedia services, for example, video on demand and IP television services, from content distribution servers located at the Internet to consumers. In recent years, network service providers around the world are facing the challenge of building efficient mobility-management systems for delivering multimedia services to mobile consumers. As the number of mobile consumers using their mobile devices to pay for multimedia services continues to grow rapidly, consumer multicast traffic support in wireless-mobile networks is the pressing need.

Previous IP mobile multicast approaches introduced in [1–4] are based on host-based mobility-management protocols such as Mobile IPv6 [5] and Fast Mobile IPv6 [6]. Those host-based mobility-management protocols rely on mobility signalling of a mobile node (MN) to support IP mobility for the MN. That is, a mobility stack at the MN is required. The IPv6 network stack is intended to include the mobility stack by default, but that has not happened. This is one of biggest negative aspects of host-based mobility-management protocols that require modifications or upgrades of existing IPv6 network stack. Accordingly, the previously developed IP mobile-multicast mechanisms [1–4] are also limited to be used only with mobility-aware MNs.

A new approach to enabling IP mobility is network-based mobility management that has been recently standardised by the Internet Engineering Task Force (IETF) as a Proxy Mobile IPv6 (PMIPv6) protocol [7]. By introducing new proxy mobility agents such as mobility-access gateway (MAG) and local-mobility anchor (LMA), PMIPv6 provides IP mobility to mobility-unaware MNs. The MAG implemented in an access router (AR) registers an MN's movement to the LMA, which is a home agent for all registered MNs in a given PMIPv6 domain, by sending a proxy binding update (PBU) message. In response, the LMA sends a proxy binding acknowledgment (PBA) message including the home network prefix (HNP) for the MN back to the MAG. The MN at the access network of the MAG configures its address, proxy home address (pHoA), based on the HNP included in the router advertisement (RA) message sent from the MAG. When the MN changes its point of attachment, for example, the MN performs its handover to a new access network, it again obtains the same HNP, which was obtained in the previous access network, from the new MAG at the new access network so that the MN cannot recognise its network movement during its handovers in the given PMIPv6 domain. This is because the LMA assigns the same HNP to the MN and the MAG emulates the MN's home link by advertising the same HNP to the MN. Thereby mobility-unaware MNs at the networking layer are able to perform handovers without requiring their participation in any mobility signalling. In addition, recently published works concerning PMIPv6 performance demonstrate that PMIPv6 generally outperforms existing host-based mobility-management protocols [8–10].

However, as PMIPv6 transparently supports IP mobility to MNs, previously developed IP mobile multicast mechanisms, that is, enabling multicast handover for mobility-stack enabled MNs, cannot be directly deployed in a PMIPv6 domain. The specification of PMIPv6 [7] does not also define the multicast handover procedure. Since multicast traffic is mostly real time and delay sensitive traffic, multicast handover performance is critical than unicast-handover performance. Accordingly, in this paper, we propose a fast multicast handover procedure that optimises multicast group management by utilising the context of MN running multicast applications. We first review the recently developed PMIPv6 multicast listener support in the IETF and point out the limitations of PMIPv6 multicast listener support. Then, we introduce the proposed fast multicast handover procedure that supports quick and packet-loss free handovers in the context of PMIPv6 protocol. The simplicity of the concept is an advantage as well as the fact that a packet-loss free handover is guaranteed. We use the developed analytical models to analyse the performance of proposed multicast handover procedure compared with the base one.

The remainder of this paper starts with an outline of the current status and limitations of PMIPv6 multicast listener support. Then, in Section 3, the proposed multicast handover procedure is introduced which overcomes the revealed limitations. The analytical models for performance evaluation are presented in Section 4. Performance analysis results are given in Section 5. Finally, the conclusions are given in Section 6.

2 Multicast listener support in PMIPv6

In this section, we outline the PMIPv6 multicast listener support recently developed by the IETF Multicast Mobility (MultiMob) working group [11] and point out its limitations.

2.1 *Deployment requirements*

When the specification of PMIPv6 [7] was developed, the basic handover support, that is, only the unicast-handover support was developed. Subsequently the MultiMob working group was established to develop Internet standards for enabling IP mobile multicast listener support in a PMIPv6 environment. As the first work of the MultiMob working group, the PMIPv6 multicast listener support was standardised. The following are the deployment requirements for each entity [12]:

- MN: any specific function related to IP mobile multicast listener support is not required. This requirement reflects the concept of network-based mobility management.
- MAG: the multicast listener discovery (MLD) proxy functionality is required to assist an MLD membership report sent from an MN and to forward multicast traffic to the MN.
- LMA: the designated multicast router functionality is required to maintain multicast forwarding states for the MN and to forward multicast traffic to the MN. In some cases, the MLD proxy functionality is also required to relay the MLD membership report further.

Conceptually, the LMA is connected to the multicast routing infrastructure via its egress interface, whereas its ingress interface is connected to its MAGs. The MNs attached to the MAG will receive multicast traffic via the tunnel established between the MAG and the LMA.

2.2 *Base multicast handover procedure*

The base multicast handover procedure is shown in Fig. 1.

The operation steps from the de-registration PBU (DeReg. PBU) message to the RA message are for the basic PMIPv6 handover for unicast communication. Note that we here assume that the new MAG (nMAG) explicitly recognises the attachment of MN by receiving the RS message sent from the MN and begins the location update on behalf of the MN. Further PMIPv6 operation details can be found in [7, 8] and PMIPv6 authentication issues can be also found in [13, 14].

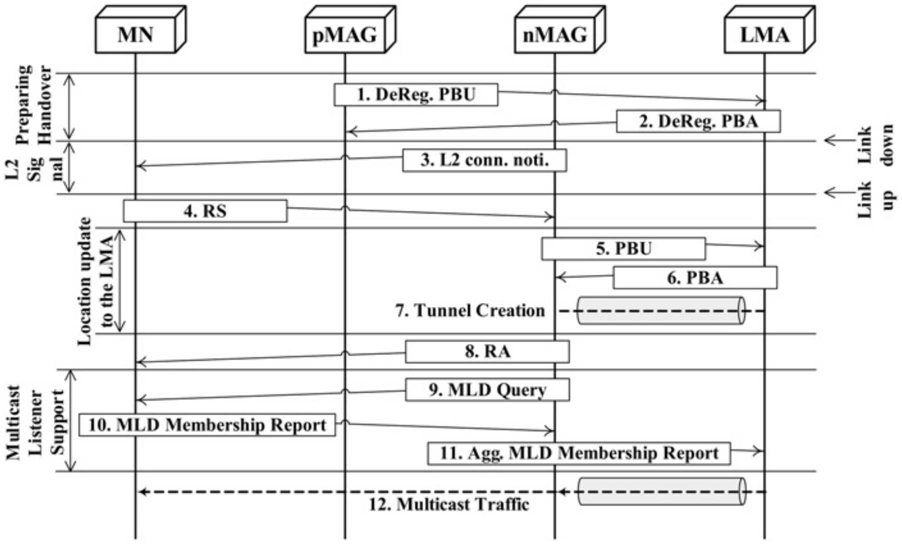

Fig. 1 *Base multicast handover: the MN performs its handover from the pMAG to the nMAG, but multicast traffic for the MN will be lost during the handover*

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The operation steps such as the MLD Query, MLD Membership Report and aggregated MLD Membership Report messages are for PMIPv6 multicast listener support [12]. After the location update, the nMAG currently serving the MN sends the MLD Query message to the MN as part of its standard multicast router operations. In response, the MN sends the MLD Membership Report message indicating specific interested multicast services. It is worth nothing that an unsolicited MLD Membership Report message triggered by the MN's handover cannot be guaranteed in PMIPv6 because the MN cannot recognise its network movement owing to the nMAG's home-link emulation. As the nMAG receives the MLD Membership Report message, it updates its multicast forwarding state as well as its MLD proxy-membership database if required. Then, the nMAG sends the aggregated MLD Membership Report message to the LMA if the MLD proxy-membership database is changed. The LMA updates its multicast forwarding state as it receives the aggregated MLD Membership Report message.

Thereby the proxy mobility agents transparently support IP mobile multicast listener support to mobility-unaware MNs in the given PMIPv6 environment. PMIPv6 transparently supports IP mobility to mobility-unaware MNs at the networking layer. It does not mean that the MNs are completely not unaware of their handovers; the MNs may detect their handovers by means of link-layer information.

2.3 Limitations

PMIPv6 multicast listener support being standardised in the IETF MultiMob working group does not focus on specific performance improvements or optimisations. That focuses on developing the base deployment specification for mobility-unaware MNs. The recently published works [15, 16], which are also based on the fast-handover approach, show the interests for performance improvements or optimisations. The following limitations are imperative and enforced to the base multicast handover procedure:

- Service interruption: any specific optimisation for improving multicast handover performance has been not considered. Accordingly, during an MN's handover, multicast traffic destined for the MN is lost, thus making it impossible to support seamless handover with delay-sensitive multicast traffic.
- Superfluous multicast traffic transmission: unnecessary multicast traffic is continuously transmitted to a previous access network of an MN, whereas the MN, which is the last subscriber to the multicast service, performs its handover to a new access network. Such superfluous multicast traffic transmission is continued until the designated multicast router, that is, LMA, updates its multicast forwarding state for the MN.

In the following section, we present the proposed multicast handover procedure that solves the limitations imposed by the base multicast handover procedure for PMIPv6.

3 Proposed multicast handover procedure for mobility-unaware MNs in PMIPv6

As an extension to PMIPv6, Fast Handovers for PMIPv6 (FPMIPv6) [17] has been recently published to enhance handover performance of PMIPv6, but it is only designed to optimise unicast traffic, not multicast traffic. In other words, owing to lack of dedicated multicast group management, benefits of FPMIPv6 cannot take effect to multicast traffic.

The proposed multicast handover procedure optimises multicast group management by utilising the context of roaming MN. The context, which is transferred from a previous MAG (pMAG) to an nMAG before the MN attaches to the nMAG, includes the MN's identification, the MN's LMA address, the MN's multicast subscription information, etc. As the nMAG obtains the context of the MN, it proactively updates its multicast forwarding state as well as its MLD proxy-membership database if required. Indeed, as a similar way to FPMIPv6, multicast traffic is forwarded from the pMAG to the nMAG. Thereby the MN can receive multicast traffic directly from the nMAG as soon as it arrives at the new access network. Fig. 2 shows the conceptual multicast support PMIPv6 domain wherein the MN performs its handover from the pMAG to the nMAG and multicast traffic is simultaneously forwarded from the pMAG to the nMAG.

3.1 Required functionalities

The proposed multicast handover procedure does not require any additional or new entity in a given PMIPv6 domain. Like in the base multicast handover procedure, no modification on MNs is needed, whereas some additional functionalities are required to the MAG and LMA.

In the proposed multicast handover procedure, the context transfer functionality at each MAG is required. This enables sending and receiving the context of the MN between neighbour MAGs. For this, each MAG maintains the neighbour MAGs' information such as network identification and address. The context transfer is executed by the L2 trigger so that it is reasonably assumed that the transmission of the context is completed from the pMAG to the nMAG before the MN actually attaches to the nMAG. The MN's multicast subscription information transmitted as part of the context is indeed used by the nMAG to update its multicast forwarding state and to perform an early MLD Membership Report if required. The multicast traffic forwarding and buffering functionalities are also required to prevent multicast traffic loss during the MN's handover.

As the MN's multicast subscription information transmitted from MAGs is used to update the multicast forwarding state of MN at the LMA, the LMA is required

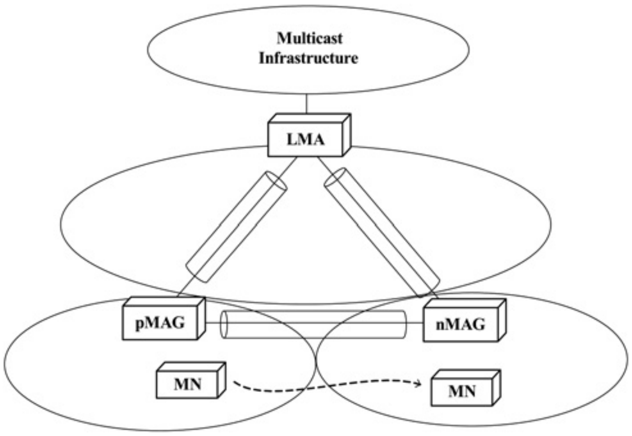

Fig. 2 *Conceptual multicast support PMIPv6 domain: the tunnel established between two neighbour MAGs is used for multicast traffic forwarding service*

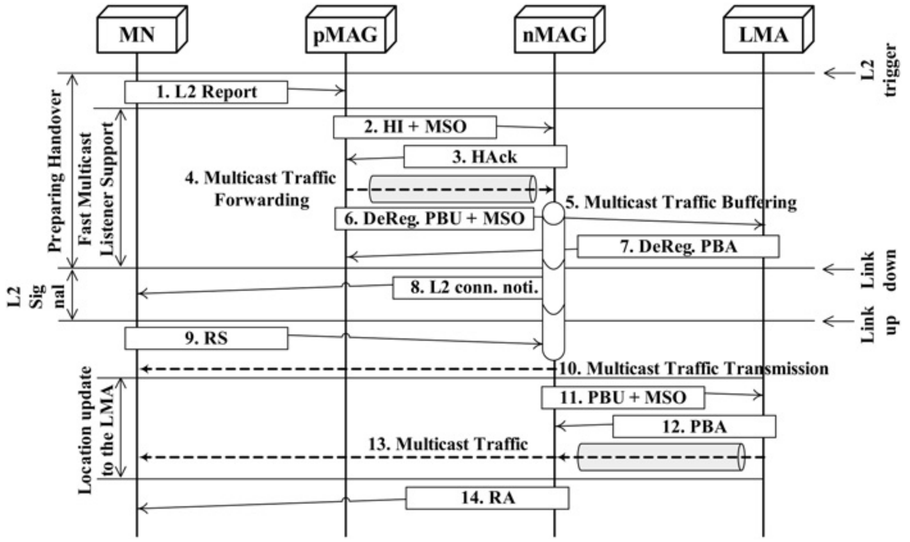

Fig. 3 *Proposed multicast handover: the MN performs its handover from the pMAG to the nMAG with the fast multicast listener support that accelerates the multicast handover performance by reducing multicast handover latency and preventing multicast traffic loss*

to have an ability of receiving and parsing such information. Note that the MN's multicast subscription information is included in the multicast support option (MSO) that will be described later. In some cases, the LMA is also required to buffer multicast traffic for the MN.

3.2 Procedure

Fig. 3 illustrates the signalling call flow of the proposed multicast handover procedure. In Fig. 3, the MN prepares its handover from the pMAG to the nMAG as its L2 trigger is up. Utilising its L2 trigger, the MN obtains the access network information of the nMAG, that is, the network identification. Then, the MN provides the network identification with its own identification to the pMAG, which is currently serving the MN, by sending the L2 report message.

As shown in Fig. 3, the fast multicast listener support of the proposed multicast handover procedure is started with the handover initiate (HI) message including the MN's identification, MN's HNP, MN's LMA address and MSO. The MN's multicast subscription information included in the MSO is transferred from the pMAG to the nMAG and is used as a parameter of the fast multicast listener support. As the nMAG obtains the HI message, it checks whether its status is able to serve the fast multicast listener support for the MN. The nMAG sends the handover acknowledge (HAck) message including the acceptance or refusal value back to the pMAG. In the case of acceptance, the nMAG updates its multicast forwarding state for the roaming MN. Note that the nMAG's decision for the request of the fast multicast listener support is determined based on the requested multicast service, available buffer size, capable of the number of MNs, etc. The pMAG forwards multicast traffic destined to the MN to the nMAG if only it receives the HAck message with the acceptance value. Note that the multicast traffic forwarding is performed until the pMAG receives multicast traffic for the MN from the LMA.

In Fig. 3, the pMAG informs the acceptance result of the fast multicast listener support to the LMA as it sends the DeReg. PBU message including the MN's identification, MN's HNP and MSO. As the LMA receives that DeReg. PBU message sent from the pMAG, it prepares to update its multicast forwarding state for the MN. However, at this point the LMA does not change the multicast traffic tunnel for the MN from the tunnel established with the pMAG to the tunnel established with the nMAG. Depending on a configured policy on the LMA: (i) the LMA continuously forwards multicast traffic for the MN via the pMAG or (ii) the LMA stops to forward multicast traffic for the MN via the pMAG and buffers them until it receives a PBU message from the nMAG. In response, the LMA sends the DeReg. PBU message back to the pMAG.

As the MN's link is down from the access network of the pMAG, it undergoes the link switching process, that is, L2 handover, from the pMAG to the nMAG. Then, as the nMAG is informed about the attachment of the MN at its access network, it immediately sends multicast traffic buffered to the MN. Therefore the service interruption incurred by the packet loss during the MN's handover is significantly reduced. As a result of the location update by the nMAG, the LMA updates its multicast forwarding state for the MN.

As shown in Fig. 3, the MN's multicast subscription information is transmitted by the MSO:

- MSO in the HI message transmitted from the pMAG to the nMAG: it is transmitted during the MN's handover, that is, before attachment to the nMAG. This accelerates multicast handover performance as it allows the nMAG to update multicast forwarding state in advance and perform an early MLD membership report to the LMA, if required.
- MSO in the DeReg. PBU message transmitted from the pMAG to the LMA: it is transmitted during the MN's handover, that is, before attachment to the nMAG. This helps to explicitly notify the MN's multicast subscription information to the LMA. As mentioned previously, the LMA can take at least two options: (i) continuously forward multicast traffic via the pMAG until the MN attaches to the nMAG or (ii) stop to forward multicast traffic and buffer until the MN attaches to the nMAG.
- MSO in the PBU message optionally transmitted from the nMAG to the LMA: it is transmitted after the MN's handover, that is, after attachment to the nMAG. It is optionally required because the MN identification can be used to distinguish the MN. Depending on the option taken with the MSO in

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the DeReg. PBU message transmitted from the pMAG, the LMA either (i) changes a multicast traffic forwarding interface to the nMAG or (ii) starts to send buffered multicast traffic to the nMAG.

4 Analytical models

In this section, we develop analytical models to evaluate the proposed multicast handover procedure compared with the base one.

4.1 Assumption

In the considered network model, the MN performs its handover within the PMIPv6 consisting of one LMA and MAGs. The communication path between the LMA and the MAG is a wired link, whereas the communication path between the MAG and the MN is a wireless link. We assume that the processing and queuing delays at each entity are negligible and messages over wired/wireless links are transmitted without errors. Then, the message transmission delay over the wired link is calculated as [18]

$$d_{\text{wd}}(M_S, h_{X-Y}) = \frac{M_S \times h_{X-Y}}{\text{BW}_{\text{wd}}} + L_{\text{wd}} \tag{1}$$

where M_S is the message (option) size, h_{X-Y} is the number of hops between X and Y, BW_{wd} is the bandwidth of wired link and L_{wd} is the latency of wired link consisting of the propagation delay and the link-layer delay. Similarly, the message transmission delay over the wireless link is calculated as

$$d_{\text{wl}}(M_S) = \frac{M_S}{\text{BW}_{\text{wl}}} + L_{\text{wl}} \tag{2}$$

where BW_{wl} is the bandwidth of wireless link and L_{wl} is the latency of wireless link consisting of the propagation delay and the link-layer delay. M_S is determined based on the actual message being sent, whereas h_{X-Y} depends on the PMIPv6 domain topology. For instance, the number of hops between the LMA and the MAG normally becomes larger as the size of the PMIPv6 domain increases. Table 1 shows the used message sizes and number of hops [10, 19]. Note that M_{MLD} listed in Table 1 is as per subscribed multicast address and M_{MSO} is assumed to be 24 bytes if one multicast subscription is considered.

Table 1 Message (option) size and number of Hops

Notation	Description	Value
M_{RS}	RS message size	52 bytes
M_{PBU}	PBU message size	76 bytes
M_{PBA}	PBA message size	76 bytes
M_{HI}	HI message size	52 bytes
M_{Hack}	HAck message size	52 bytes
M_{MLD}	MLD message size	72 bytes
M_{HD}	IPv6 header size	40 bytes
M_{MSO}	MSO size	24 bytes
M_{DATA}	multicast message size	120 bytes
$h_{\text{LMA-MAG}}$	number of hops between LMA and MAG	[3, 9]
$h_{\text{pMAG-nMAG}}$	number of hops between pMAG and nMAG	$\sqrt{h_{\text{LMA-MAG}}}$
$h_{\text{MAG-MN}}$	number of hops between MAG and MN	1

We adopt the modelling result presented in [20] that analyses the average number of access networks passed by the MN N. Let $1/\alpha$ be the average residence time of the MN in an access network. Suppose $f^*(s)$ and $f_\alpha^*(s)$ are the Laplace transform of the probability density function (PDF) of the residence time of the MN and the Laplace transform of the PDF of the session holding time of the MN, respectively. With given session holding time and network residence time with gamma distribution, N is obtained as

$$N = -\alpha \sum_{p \in \phi_\alpha} \text{Res}_{s=p} \frac{1 - f^*(s)}{1 - (1 - p_f) f^*(s)} f_\alpha^*(-s) \tag{3}$$

where p_f is the handover blocking probability, ϕ_α is the singular points of $f_\alpha^*(-s)$ and $\text{Res}_{s=p}$ is the residue at a singular point $s = p$. If we further assume that a session duration time T_S has an exponential distribution with its mean value $1/\eta$ and $p_f = 0$, the average number of handovers ϖ_{H} is obtained as

$$\varpi_{\text{H}} = \left\lceil \frac{\mu}{\eta} \right\rceil - 1 \tag{4}$$

where $1/\mu$ is the average residence time of the MN within the given access network.

4.2 Handover latency

We define the handover latency $L_{\text{HO}}^{(\cdot)}$ as the time interval during which an MN cannot receive any multicast packet while it performs its handover.

Suppose $L_{\text{HO}}^{(\text{BASE})}$ is the handover latency for the base multicast handover procedure. Assuming that the nMAG immediately sends the MLD Query message to the MN as it establishes the tunnel between the LMA and itself for the MN, $L_{\text{HO}}^{(\text{BASE})}$ is expressed as

$$L_{\text{HO}}^{(\text{BASE})} = T_{\text{L2}} + T_{\text{RS}} + T_{\text{LU}} + T_{\text{MLD}} + T_{\text{FWD}}^{(\text{BASE})} \tag{5}$$

where T_{L2} is the link switching time, T_{RS} is the arrival delay of the RS message from the MN to the nMAG, which is obtained as $d_{\text{wl}}(M_{\text{RS}})$. T_{LU} is the update location delay that is obtained as $d_{\text{wd}}(M_{\text{PBU}}, h_{\text{LMA-MAG}}) + d_{\text{wd}}(M_{\text{PBA}}, h_{\text{LMA-MAG}})$ and T_{MLD} is the delay associated with the MLD operations. In the case that the MN's multicast service is not registered at the nMAG's MLD proxy-membership database, T_{MLD} is obtained as $2d_{\text{wl}}(M_{\text{MLD}}) + d_{\text{wd}}(M_{\text{MLD}}, h_{\text{LMA-MAG}})$, whereas in the case that the MN's multicast service is already registered at the nMAG's MLD proxy-membership database, T_{MLD} is obtained as $2d_{\text{wl}}(M_{\text{MLD}})$. Then, $T_{\text{FWD}}^{(\text{BASE})}$ is the arrival delay of the first packet of multicast traffic from the LMA to the MN, which is obtained as $d_{\text{wd}}(M_{\text{DATA}} + M_{\text{HD}}, h_{\text{LMA-MAG}}) + d_{\text{wl}}(M_{\text{DATA}})$.

Suppose $L_{\text{HO}}^{(\text{PRO})}$ is the handover latency for the proposed multicast handover procedure. Assuming that the fast multicast listener support is successfully completed before the MN attaches with the nMAG, $L_{\text{HO}}^{(\text{PRO})}$ is expressed as

$$L_{\text{HO}}^{(\text{PRO})} = T_{\text{L2}} + T_{\text{RS}} + T_{\text{FWD}}^{(\text{PRO})} \tag{6}$$

where $T_{\text{FWD}}^{(\text{PRO})}$ is the arrival delay of the first packet of multicast traffic buffered from the nMAG to the MN, which is obtained as $d_{\mathrm{wl}}(M_{\mathrm{DATA}})$.

4.3 Packet loss

As the base multicast handover procedure does not support any functionality to prevent the packet loss, multicast traffic is lost during the handover. Suppose $\psi_{\mathrm{p}}^{(\mathrm{BASE})}$ is the amount of multicast packet loss for the base multicast handover procedure. Let λ_s denote the average multicast session arrival rate per second at the MN. $\psi_{\mathrm{p}}^{(\mathrm{BASE})}$ is obtained as

$$\psi_{\mathrm{p}}^{(\mathrm{BASE})} = \lambda_s E(S) L_{\mathrm{HO}}^{(\mathrm{BASE})} \tag{7}$$

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

4.4 Signalling cost

We define the signalling cost $C_{\mathrm{SIG}}^{(\cdot)}$ as the signalling overhead for supporting the multicast handover. In contrast to the unicast handover case [10], MLD messages are also considered as signalling messages because those messages are requisitely required for multicast listener support. Suppose $C_{\mathrm{SIG}}^{(\mathrm{BASE})}$ is the signalling cost for the base multicast handover procedure per handover. Then, $C_{\mathrm{SIG}}^{(\mathrm{BASE})}$ is expressed as

$$\begin{aligned} C_{\mathrm{SIG}}^{(\mathrm{BASE})} = {} & 2M_{\mathrm{PBU}} h_{\mathrm{LMA-MAG}} + 2M_{\mathrm{PBA}} h_{\mathrm{LMA-MAG}} \\ & + \alpha 2 M_{\mathrm{MLD}} h_{\mathrm{MAG-MN}} + \kappa \end{aligned} \tag{8}$$

where α is a weighting factor for a wireless link that is used to emphasise the wireless link's unstability. In the case that the MN's multicast service is not registered at the nMAG's MLD proxy membership database, $\kappa = M_{\mathrm{MLD}} h_{\mathrm{LMA-MAG}}$, whereas in the case that the MN's multicast service is already registered at the nMAG's MLD proxy membership database, $\kappa = 0$.

Suppose $C_{\mathrm{SIG}}^{(\mathrm{PRO})}$ is the signalling cost for the proposed multicast handover procedure per handover. Then, $C_{\mathrm{SIG}}^{(\mathrm{PRO})}$ is expressed as

$$\begin{aligned} C_{\mathrm{SIG}}^{(\mathrm{PRO})} = {} & (M_{\mathrm{HI}} + M_{\mathrm{MSO}}) h_{\mathrm{pMAG-nMAG}} \\ & + M_{\mathrm{HAck}} h_{\mathrm{pMAG-nMAG}} \\ & + 2(M_{\mathrm{PBU}} + M_{\mathrm{MSO}}) h_{\mathrm{LMA-MAG}} \\ & + 2M_{\mathrm{PBA}} h_{\mathrm{LMA-MAG}} \end{aligned} \tag{9}$$

5 Evaluation results

In this section, we present our performance evaluation results based on the developed models in the previous section. For the numerical analysis, the following system parameters are used: $\eta = 0.2\ \mathrm{min}^{-1}$, $\mu = (1/1,\ 1/4)\ \mathrm{min}^{-1}$, $\alpha = 2$, $\lambda_s = (10,\ 20)$, $E(S) = 10$, $\mathrm{BW}_{\mathrm{wd}} = 10$ Mbps, $\mathrm{BW}_{\mathrm{wl}} = 3$ Mbps, $L_{\mathrm{wd}} = 0.5$ ms, $L_{\mathrm{wl}} = 2$ ms and $T_{\mathrm{L2}} = 45.35$ ms [21].

Depending on whether the MN's multicast service is already registered at the nMAG's MLD proxy-membership database or not, the handover latency of base multicast handover procedure incurs different values. For the sake of simplicity, let Base(a) be the case that the MN's multicast service is not registered at the nMAG's MLD proxy-membership database so the aggregated MLD Membership Report messages from the nMAG to the LMA is required, whereas Base(b) is the case that the MN's multicast service is already registered at the nMAG's MLD proxy-membership database.

We first investigate the handover latency on different values of $h_{\mathrm{LMA-MAG}}$, which varies depending on the topology configuration as well as the size of PMIPv6 domain. As shown in Fig. 4, the two cases of the base multicast handover procedure, that is, Base(a) and Base(b), are largely affected by $h_{\mathrm{LMA-MAG}}$ compared with the case of the proposed multicast handover procedure. The proposed one outperforms others because (i) the fast multicast listener support is started when the MN is still in the access network of the pMAG and (ii) when the MN attaches to the nMAG, multicast traffic for the MN is transmitted from the nMAG, not from the LMA.

We next examine the cumulative handover latency as a function of $1/\mu$. Fig. 5 shows the effect of $1/\mu$. The cumulative handover latencies for all cases, that is, Base(a), Base(b) and proposal, increase with the decrease in $1/\mu$ because of the increased handover frequency. Thanks to the reduced handover latency as shown in Fig. 4, the proposed multicast handover procedure shows stable performance even in high mobility environments. Here, we again confirm that $h_{\mathrm{LMA-MAG}}$ is one of performance factors that aggravate the performance of the base multicast handover

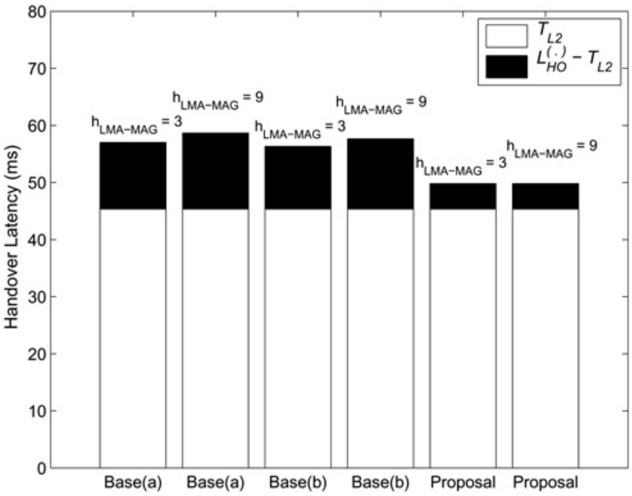

Fig. 4 *Variation of handover latency*

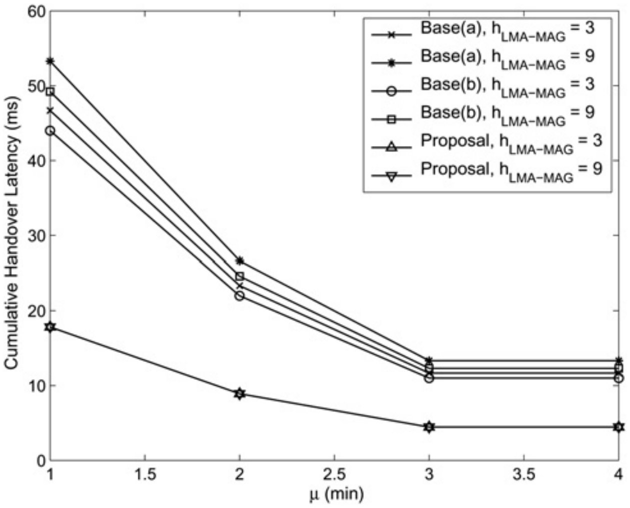

Fig. 5 *Cumulative handover latency as a function of* $1/\mu$

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procedure, whereas it is for nothing in the performance of the proposed one.

Thanks to in-built forwarding and buffering functionalities, in the proposed multicast handover procedure, multicast traffic is not lost during the handover. However, as shown in Fig. 6, the two cases of the base multicast handover procedure, that is, Base(a) and Base(b), suffer the packet loss. We also confirm that $\psi_{\mathrm{p}}^{(\mathrm{BASE})}$ is proportional to $h_{\mathrm{LMA-MAG}}$ and λ_s. Note that λ_s will affect the buffering functionality in the proposed one as well. In other words, as λ_s is increased, the required buffer size in the proposed one will be increased. However, the MN is still available to receive its multicast traffic without packet loss.

The results of signalling cost analysis are presented in Fig. 7. Since the fast multicast listener support of the proposed multicast handover procedure requires additional signalling, that is, HI and HAck messages, and transmission of the MN's multicast subscription information via the MSO during the MN's handover, it would be expected to consume more than the base multicast handover procedure. However, as shown in Fig. 7, the proposed one shows similar performance with others and at least outperforms Base(a). This phenomenon is explained because the base multicast handover procedure also requires additional signalling, that is, MLD messages, for the multicast listener support and those messages are even transmitted over the wireless link.

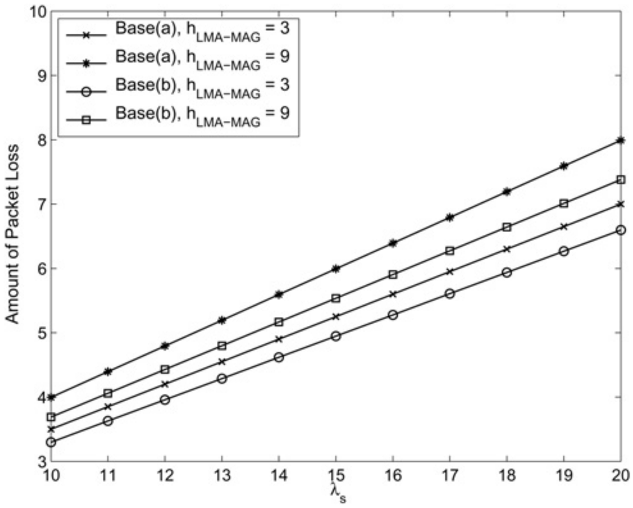

Fig. 6 *Amount of packet loss as a function of n*

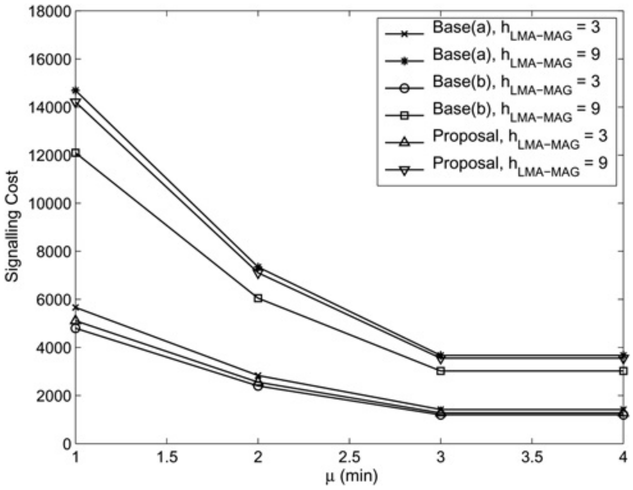

Fig. 7 *Cumulative signalling cost as a function of 1/μ*

6 Conclusions

In this paper, we have introduced a new PMIPv6 multicast handover procedure that supports quick and packet-loss free handovers. Compared with other previously developed IP mobile multicast approaches, the proposed multicast handover procedure has been designed for mobility-unaware MNs that cannot detect their network movements. As the base multicast handover procedure standardised by the IETF MultiMob working group does not have any performance improvement functionalities, its multicast handover latency is often not acceptable and thus suffers from serious packet losses during handovers. By comparison with the base multicast handover procedure, the proposed multicast handover procedure minimises the service interruption time and prevents the multicast packet loss during handovers by utilising the context of roaming MN. Based on the developed analytical models, we have corroborated that the proposed multicast handover procedure outperforms the base multicast handover procedure in terms of handover latency and packet loss. In addition, in terms of signalling cost consumption, the proposed multicast handover procedure operates on an equal basis with the base one.

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