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July 11, 2011

Rapid acquisition of the MN multicast subscription after handover
<draft-contreras-multimob-rams-01.txt>

Abstract

A new proposal is presented for speeding up the acquisition by the MAG of the MN's active multicast subscription information, in order to accelerate the multicast delivery to the MN during handover. To do that, an extension of the current PMIPv6 protocol is required. The solution described in this memo is not only applicable to the base multicast solution, but also it can be applied to other solutions envisioned as possible architectural evolutions of it. Furthermore, it is also independent of the role played by the MAG within the multicast metwork (either acting as MLD proxy or multicast router).

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1 Introduction

Recently, a base solution has been adopted for continuous multicast service delivery in PMIPv6 domains [4]. That solution specifies the basic functionality needed in the PMIPv6 entities to provide a multicast service, and supports the continuous delivery of multicast obtaining the on-going multicast subscription information directly from the MN after handover. Thus, once the MN attaches to a new MAG, the MN is interrogated by the MAG through an MLD General Query, which is sent just after any new link sets up, to get knowledge of any existing subscription, as specified in [2].

However, as highlighted by [5], the base solution must be improved to cover some performance requirements, especially those referred to the user perceived service quality, seriously affected by the disruption of multicast content forwarding to the MN during handovers.

The method used in the base solution to get knowledge of an existing multicast subscription relies on the intrinsics of the IGMP/MLD protocols. Both protocols send multicast membership interrogation messages when a new link is up. The answer to that request will report any existing multicast subscription by the MN.

Due to this behaviour, despite of being a straightforward method, the MAG can incur in a huge delay in receiving the corresponding MLD Report message caused by either the MLD query processing time or the radio transfer delays associated with this procedure.

The new approach proposed here consists of the extension of the current PMIPv6 signaling protocol defined in [1] by including a new multicast information option to update PMIPv6 entities during registration and de-registration processes, as well as new messages to trigger the transfer of such multicast information. No extension is considered for any of the multicast-related protocols (IGMP/MLD nor PIM protocols).

This proposal intends to provide a signaling method internal to the network to speed up the subscription information acquisition by the MAG, in order to accelerate the multicast delivery to the MN. By doing so, the knowledge by the MAG of the currently active multicast subscription becomes independent of the underlying radio technology dynamics and relaxes the requirement of a rapid response from the MN in processing MLD control messages. Issues like radio framing, radio access contention, channel reliability, IGMP/MLD timers optimisation for wireless environments, etc, are not relevant any more to determine multicast performance after handoff.

The solution described in this memo is not only applicable to the base solution defined in [4], but also it can be applied to other solutions envisioned as possible architectural evolutions of it, as those stated in [6] or [7]. Furthermore, it is also independent of the role played by the MAG within the multicast network (either acting as MLD proxy or multicast router).

1.1 Conventions and Terminology

This document uses the terminology referring to PMIPv6 components as defined in [1]. Additionally, the following terms are defined.

pMAG
: The previous MAG or pMAG is the MAG where the MN is initially registered in a handover event.

nMAG
: The new MAG or nMAG is the MAG where the MN is finally registered in a handover event.

Reactive Handover
: A reactive handover is a handover event where the LMA receives the MN registration from the nMAG without having previously received the MN de-registration from the pMAG.

Predictive handover
: A predictive handover is a handover event where the LMA firstly receives the MN de-registration from the pMAG previously to receive the MN registration from the nMAG.

2 Overview

The LMA is a key element within the PMIPv6 infrastructure. It traces the MN reachability along the PMIPv6 domain, therefore the LMA is the best element to store and forward the multicast subscription information to the rest of entities within the PMIPv6, that is, to the MAGs, as the MN moves.

The LMA only requires to know the detailed subscription information (in terms of the IP addresses of both the multicast group subscribed, G, and the source delivering it, S) during the handover event. Apart from the handover event, it is not worthy to continuously inform the LMA about it. Such procedure would significantly increase the signaling load within the PMIPv6 domain without a clear benefit. The subscription information (S,G) is only critical during handover, neither after nor before. Indicating the active subscription while the handover is ongoing guarantees that such information will be up-to-date, ready to be transferred to the new MAG where the MN has just attached.

To do that, it will be necessary to extend the PMIPv6 protocol in several ways. First of all, a new mobility option is needed to pack the IP addresses of the current multicast subscription. Furthermore, additional messages are required to manage the interchange of the multicast information among PMIPv6 entities. Finally, some flags are defined to govern the process.

Next sections provide the details.

3 PMIPv6 extensions

This section outlines the extensions proposed to the PMIPv6 protocol specified in [1].

3.1 New "Active Multicast Subscription" mobility option

3.1.1 Option application rules

A new TLV-encoded mobility option, "Active Multicast Subscription" option is defined for use with the PBU and PBA messages exchanged between an LMA and a MAG to transfer the multicast subscription information. This option is used for exchanging the IP addresses of both the group subscribed by the MN, and the source delivering it as well. There can be multiple "Active Multicast Subscription" options present in the message, one for each active subscription maintained by the MN when the handover is taken place.

This new option will be used, with the same aim, also by the new message Subscription Response described later in this document.

3.1.2 Option format

The format of this new option is as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
                                +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                |      Type     |     Length    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                   Multicast Source IP address                 +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                   Multicast Group IP address                  +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type
   To be defined

Length
   8-bit unsigned integer indicating the length of the option in octects, excluding the type and length fields. This field must be set to the value 8 for IPv4, and 32 for IPv6.

Multicast Source IP address

Unicast IP address of the node which injects the multicast content in the network.

Multicast Group IP address
Multicast IP address identifying the content which the MN subscribes to.

3.2 New "multicast Signaling" flag on PBU/PBA message headers

3.2.1 Flag application rules

A new flag S is added in both PBU and PBA message headers to advise about the MAG and the LMA capabilities of processing multicast-related signaling for the MN subject of the message.

This flag will govern the multicast-related signaling between the LMA and the MAG. As a general rule, the value of the flag in the PBA message should be a copy of the value received in the PBU message. Specific rules are described in next sub-sections.

3.2.1.1 Registration process

These rules apply for the Initial Binding registration process.

o PBU message

* S=0, it indicates that the MAG sending the PBU message does not accept multicast-related signaling for the MN being attached. This can be used to discriminate PMIPv6 nodes which are not multicast enabled, for backward compatibility reasons.

* S=1, it indicates that the MAG sending the PBU message accepts multicast-related signaling for the MN being attached. Depending on the type of handover (reactive or predictive) the LMA will take some actions, described later in this document.

o PBA message

* If S=0 in the corresponding PBU message, the value of the flag in the PBA message should be a copy of the value received in the PBU message, without any further meaning.

* If S=1 in the corresponding PBU message, two sub-cases can happen

o S=1 in the PBA message if the multicast subscription information is provided in this message for the MN. When S=1, if the MN maintains an active multicast session, the PBA message will include the "Active Multicast Subscription" mobility option with the IP addresses of the subscribed group and the source providing it.

o S=0 in the PBA message if the multicast subscription information is not provided in this message for the MN. The PBA message will include the "Active Multicast Subscription" mobility option with the IP addresses of the group and the source set to 0. This case is useful to decouple unicast and multicast signaling for a MN being registered at nMAG. A way for obtaining later active multicast-subscription information is described later in this document.

3.2.1.2 De-registration process

These rules apply for the Binding De-registration process

o PBU message

* S=0, it indicates that the MN has no active multicast session.

* S=1, it indicates that the MN has an active multicast session, and the IP addresses of the subscribed group and the source providing it are transported in the "Active Multicast Subscription" mobility option.

o PBA message

The value of the flag in the PBA message should be a copy of the value received in the PBU message, without any further meaning.

3.2.2 New format of conventional PBU/PBA messages

3.2.2.1 Proxy Binding Update Message

As result of the new defined flag, the PBU message results as follows:

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
                                   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                   |            Sequence #         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |A|H|L|K|M|R|P|S|   Reserved    |            Lifetime           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

3.2.2.2 Proxy Binding Acknowledgement Message

As result of the new defined flag, the PBA message results as follows:

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
                                   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                   |    Status     |K|R|P|S| Rsrvd |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |           Sequence #          |           Lifetime            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

3.3 New "multicast Active" flag on LMA Binding Cache (and optionally on the MN’s policy store)

3.3.1 Flag application rules

A new flag A is added in the LMA Binding Cache to retain the knowledge that the registered MN maintains or not an active multicast subscription. The basic use of this flag is to restrict the interrogation of the pMAG only to the cases in which the MN certainly is maintaining an active subscription.

The algorithm which is followed by the LMA to interrogate or not the pMAG (after receiving a PBU message from the nMAG) is as follows:

- Flag S=0 & flag A=0: this situation represents the case where the nMAG does not support multicast-related signaling for the MN being registered, and, additionally, the LMA is not aware of any active multicast subscription on-going. Then, the LMA does not interrogate the pMAG, and registers the MN as attached to the nMAG as usual.

- Flag S=0 & flag A=1: this situation represents the case where the nMAG does not support multicast-related signaling for the MN being registered, but the LMA is aware of one or more on-going MN’s active multicast subscriptions. Due that multicast signaling is not supported by the nMAG for that MN, the LMA does not interrogate the pMAG, and registers the MN as attached to the nMAG as usual.

- Flag S=1 & flag A=0: this situation represents the case where the nMAG supports multicast-related signaling for the MN being registered, but the LMA is not aware of any active multicast subscription. Then, the LMA does not interrogate the pMAG, and registers the MN as attached to the nMAG as usual.

- Flag S=1 & flag A=1: this situation represents the case where the nMAG supports multicast-related signaling for the MN being registered, and, additionally, the LMA is aware of one or more on-going MN’s active multicast subscriptions. Then, the LMA interrogates the pMAG to obtain the multicast subscription details in the form of (S,G) previously to complete the registration of the MN attached to the nMAG.

The flag A should be initialized to the value 0.

Optionally, this flag can be also added to the MN’s policy store, and dynamically updated by the LMA to signal that the MN has (or not) an active multicast subscription. By introducing this flag in the MN’s policy profile, the nMAG can know in advance the existence of an active multicast session by the incoming MN.

3.4 New messages for active multicast subscription interrogation

A new pair of messages is defined for interrogating entities about the active multicast subscription of the MN when the handover is of reactive type.

These messages are sent using the Mobility Header as defined in [3].

3.4.1 Subscription Query message

3.4.1.1 Message application rules

The Subscription Query message is sent by the LMA towards the pMAG to interrogate it about any existing multicast subscription of the MN which is being registered by the nMAG. This message is generated in case of the handover is of reactive type.

Additionally, this message is sent by the nMAG towards the LMA to interrogate it about the existing multicast subscription of the MN when the LMA acknowledges the PBU sent by the nMAG but the multicast information is not provided (in detail, when the PBU messages has set the flag S to 1, and the PBA message has set the flag S to 0).

3.4.1.2 Message format

The Subscription Query message has the following format.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
                                +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                |  Sequence #   |   Reserved    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Sequence Number

The Sequence Number field establishes the order of the messages sent in the Subscription Query / Subscription Response dialogue between the LMA and the MAG for a certain MN. The initial Sequence Number will be determined by the entity which creates the message (either LMA or MAG, depending on the scenario), which will be responsible of managing this counter.

Reserved

This field is unused for now. The value must be initialized to 0.

Mobility options

This message will carry one or more TLV-encoded mobility options. The valid mobility options for this message are the following:

- Mobile Node Identifier option (mandatory)

- Home Network Prefix option (optional)

There can be one or more instances of the Home Network Prefix option, but only one instance of the Mobile Node Identifier option.

3.4.2 Subscription Response message

3.4.2.1 Message application rules

The Subscription Response message is sent by the pMAG towards the LMA, or by the LMA towards the nMAG, to answer a previously received Subscription Query message, as described above.

3.4.2.2 Message format

The Subscription Response message has the following format.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
                                +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                |  Sequence #   |I|  Reserved   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Sequence Number

The value of the Sequence Number field in the Subscriber Response message must be a copy of the Sequence Number received in the Subscription Query message.

Multicast Information (I)

The multicast Information flag I specifies if there is multicast subscription information available for the MN or not. The meaning is the following:

I=0: there is no multicast subscription information available for the MN identified by the Mobile Node Identifier option in this message.

I=1: there is multicast subscription information available for the MN identified by the Mobile Node Identifier option in this message. The multicast subscription information is carried on one or more instances of the Active Multicast Subscription option in this message (one instance for each active subscription).

Reserved

This field is unused for now. The value must be initialized to 0.

Mobility options

This message will carry one or more TLV-encoded mobility options. The valid mobility options for this message are the following:

- Mobile Node Identifier option (mandatory)

- Active Multicast Subscription option (mandatory) only when flag I=1, not present in any other case

- Home Network Prefix option (optional)

There can be one or more instances of the Home Network Prefix option (in all cases) and the Active Multicast Subscription option (only when I=1), but only one instance of the Mobile Node Identifier option.

3.5 New messages for active multicast subscription indication

A new pair of messages is defined for setting up and down the optional A flag defined above.

These messages are sent using the Mobility Header as defined in [3].

3.5.1 Multicast Activity Indication message

3.5.1.1 Message application rules

The Multicast Activity Indication message is sent by a MAG towards the LMA to set to 1 or 0 the A flag either to indicate the start or the complete cease of any multicast subscription by the MN. Through the use of this message, the LMA becomes aware that one or more multicast flows are being forwarded to a MN. This information is useful for the LMA during a handover to discriminate if the pMAG should be asked or not about multicast information corresponding to the MN being registered at the nMAG, in case of the handover is of reactive type.

3.5.1.2 Message format

The Multicast Activity Indication message has the following format.

```
 0                   1                   2                   3
```

```
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
                                 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                 |  Sequence #   |A|  Reserved   |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                                                               |
 |                                                               |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Sequence Number

The Sequence Number field establishes the order of the messages sent in the Activity Indication / Activity Indication Ack dialogue between the MAG and the LMA for a certain MN. The initial Sequence Number will be determined by the MAG, which will be responsible of managing this counter.

Activity indicator (A)

The Activity indicator flag A specifies if the MN multicast activity is on, that is, if the MN maintains one or more active multicast subscriptions at the MAG. The meaning is the following:

A=0: the multicast activity of the MN (identified by the Mobile Node Identifier option in this message) is off.

A=1: the multicast activity of the MN (identified by the Mobile Node Identifier option in this message) is on.

Reserved

This field is unused for now. The value must be initialized to 0.

Mobility options

This message will carry one or more TLV-encoded mobility options. The valid mobility options for this message are the following:

- Mobile Node Identifier option (mandatory)

- Home Network Prefix option (optional)

There can be one or more instances of the Home Network Prefix option, but only one instance of the Mobile Node Identifier option.

3.5.2 Multicast Activity Indication Acknowledge message

3.5.2.1 Message application rules

The Multicast Activity Indication Acknowledge message is sent by the LMA towards a MAG to confirm the reception of a previously sent Multicast Activity Indication message.

3.5.2.2 Message format

The Multicast Activity Indication message has the following format.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
                                +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                |  Sequence #   |   Reserved    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Sequence Number

The value of the Sequence Number field in the Activity Indication Ack message must be a copy of the Sequence Number received in the Activity Indication message.

Reserved

This field is unused for now. The value must be initialized to 0.

Mobility options

This message will carry one or more TLV-encoded mobility options. The valid mobility options for this message are the following:

- Mobile Node Identifier option (mandatory)

- Home Network Prefix option (optional)

There can be one or more instances of the Home Network Prefix option, but only one instance of the Mobile Node Identifier option.

3.6 New "PBA timer" in the LMA

A new timer named "PBA timer" is used in the LMA to define the maximum waiting time before the PBA message is sent to the nMAG in case the multicast subscription information relative to the MN is not yet available. The aim of this timer is to prevent potential large delays in the forwarding of unicast traffic towards the MN being registered at the nMAG. This timer allows to decouple the unicast signaling from the multicast one.

This timer should be upper bounded by the constant defined in [3] INIT_BINDACK_TIMEOUT, which value is 1 s. This constant sets the time when the nMAG will retry the MN registration by sending again the PBU message. The "PBA timer" has to ensure that the nMAG does not enter the retry mode.

4 Signaling process description

As the MN moves from one access gateway (named previous-MAG, pMAG) to another (named new-MAG, nMAG), the mobility-related signaling due to the handover event is carried out independently by the pMAG and the nMAG. That signaling process is not synchronized and, thus, two scenarios should be considered depending on the order in which the LMA receives notification of the MN registration and de-registration in the nMAG and the pMAG respectively.

4.1 Handover of predictive type

4.1.1 Rationale

In the predictive case, the LMA firstly receives the MN de-registration from the pMAG previously to receive the MN registration from the nMAG.

Only for those MNs which maintain an active multicast subscription, the pMAG will include as part of the PBU message (with flag S set to 1) the new TLV-encoded mobility option "Active Multicast Subscription" carrying the IP addresses of the multicast subscription(s) active in the MN at that moment.

The LMA will store that information in the corresponding binding cache. If, later on, the MN attaches to a nMAG, this information will be sent (using the same TLV option) to the nMAG as part of the PBA confirmation of the registration process (the PBU message sent by the nMAG should set the flag S to 1). On the other hand, if no further registration happens, the multicast information will be removed together with the rest of binding database for that MN.

After receiving the multicast addresses of the group(s) subscribed by the MN, and the source(s) delivering it(them), the nMAG can subscribe the multicast flow on behalf of the MN, if there is no other MN receiving it already at the nMAG. The multicast status can be also set in advance for the point-to-point link towards the MN.

4.1.2 Message flow description

The figure 1 summarizes this process.

```
       +-----+          +-----+          +-----+          +-----+
       | MN  |          |p-MAG|          | LMA |          |n-MAG|
       +-----+          +-----+          +-----+          +-----+
          |                |                |                |
          |                |==Bi-Dir Tunnel=|                |
          | Multicast Data |                |                |
          |<---------------|                |                |
          |                |                |                |
   1) MN Detached          |                |                |
          |         MN Detached Event       |                |
          |                |                |                |
          |                |Ext’d DeReg PBU |                |
   2)     |                |--------------->|                |
          |                |                |                |
   3)     |                |            Accept PBU           |
          |                |(Multicast Subscription info stored)
          |                |                |                |
          |                |      PBA       |                |
   4)     |                |<---------------|                |
          |                |                |                |
   5) MN Attached          |                |                |
          |                |                |   MN Attached Event
          |                |                |                |
          |                |                |       PBU      |
   6)     |                |                |<---------------|
          |                |                |                |
          |                |                |   Ext’d PBA    |
   7)     |                |                |--------------->|
          |                |                |                |
   8)     |                |                |          Accept PBA,
          |                |                |   Multicast Group join
          |                |                | and P-t-P status setup
          |                |                |                |
          |                |                |==Bi-Dir Tunnel=|
          |                |                |                |
          |                |                | Multicast Data |
          |<-------------------------------------------------|
          |                |                |                |
          |                |                |                |
```

Figure 1. Predictive handover

The sequence of messages is the following:

1) A registered MN is receiving a multicast content which has been previously subscribed by sending an standard MLD report from the MN to the currently serving MAG, pMAG. The pMAG keeps the multicast status state of the point-to-point link with the MN.

2) The MN perceives a better radio link and decides to initiate a handover process over a radio access controlled by a new MAG, nMAG. As consequence, pMAG determines a detach event corresponding to this MN, and updates the attachment status of this MN to the LMA by sending an extended Proxy Binding Update message, including a new TLV-encoded option, named "Active Multicast Subscription", which contains the IP addresses of the (S,G) pairs of the active multicast subscriptions in the moment of handover.

3) The LMA processes the PBU message. Additionally, the LMA stores in the Binding Cache the information regarding the on-going multicast subscription when the handover has been initiated. This information will be kept until a new registration of the MN is completed by another MAG, or till the Binding Cache expiration, according to [1].

4) The LMA acknowledges to the pMAG the previous PBU message.

5) As a result of the handover process, the MN attaches to another MAG, called nMAG.

6) The nMAG triggers a registration process by sending a PBU message (with flag S set to 1) to the LMA.

7) After the analysis of the PBU message, the LMA sends an extended PBA including the new "Active Multicast Subscription" option, which contains the IP addresses of the (S,G) pairs of the active multicast subscriptions in the moment of handover.

8) The nMAG processes the PBA message, following all the standard procedures described in [1]. Additionally, with the new information relative to multicast subscription, the nMAG will set up the multicast status of the point-to-point link between the nMAG and the MN, and will join the content identified by (S,G) on behalf of the MN in case the nMAG is not receiving already such content due to a previous subscription ordered by another present MN attached to it. From that instant, the multicast content is served to the MN.

4.2 Handover of reactive type

4.2.1 Rationale

In the reactive case, the LMA receives the MN registration from the nMAG without having previously received the MN de-registration from the pMAG.

As the nMAG is not aware of any active multicast subscription of the MN, the nMAG will start a conventional registration process, by sending a normal PBU message (with flag S set to 1) towards the LMA.

After receiving the PBU message from the nMAG, the LMA will take the decision of interrogating or not the pMAG regarding any existing multicast subscription for that MN.

Once the multicast subscription information is retrieved from the pMAG, the LMA encapsulates it in the PBA message by using the TLV option "Active Multicast Subscription", and forwards the PBA message to the nMAG. Then, the nMAG can subscribe the multicast flow on behalf of the MN, if there is no other MN receiving it already at the nMAG. The multicast status can be also set in advance for the point-to-point link towards the MN.

4.2.2 Message flow description

The set of figures 2a to 2d summarize this process.

```
       +-----+ +-----+  +-----+          +------+          +------+
       | MN1 | | MN2 |  |p-MAG|          | LMA  |          |n-MAG |
       +-----+ +-----+  +-----+          +------+          +------+
          |       |        |                |                |
   1)     |       |        |==Bi-Dir Tunnel=|                |
          |       |        |                |                |
          |  unicast data  |                |                |
          |<-v-v-v-v-v-v-v-|                |                |
          |       |        |                |                |
          |      unicast data               |                |
          |       |<-v-v-v-|                |                |
          |       |        |                |                |
          |  MLD Rep(S,G)  |                |                |
          |--------------->| Act Ind(start) |                |
   2)     |       |        |--------------->|                |
          |   (S,G) Data   |           (flag A = 1)          |
          |<---------------|   Act Ind Ack  |                |
          |       |        |<---------------|                |
          |       |        |                |                |
          ~       ~        ~                ~                ~
          ~       ~        ~                ~                ~
```

Figure 2a. Reactive handover (steps 1 to 2)

The sequence of messages is the following:

1) A pair of MNs, named MN1 and MN2, are attached to the pMAG. Both MNs are multicast-enabled nodes, and both MNs are only receiving unicast traffic as usual in PMIPv6 domains, with no multicast subscription yet. At some point of time, the MN1 request to the pMAG

to be subscribed to the content identified by the IP addresses (S,G), by sending an standard MLD report from the MN to the pMAG. The pMAG will keep the multicast status state of the point-to-point link with the MN. The multicast flow (S,G) is then forwarded by the pMAG to the MN1.

2) Due to this initial multicast subscription for the MN1, the pMAG triggers the multicast Activity Indication message towards the LMA, to indicate that the MN1 multicast activity is on. The LMA will set the flag A to 1. Afterwards, the LMA sends an Activity Indication Ack message to the pMAG to acknowledge the previous indication.

```
       +-----+ +-----+  +-----+          +-----+          +-----+
       | MN1 | | MN2 |  |p-MAG|          | LMA |          |n-MAG|
       +-----+ +-----+  +-----+          +-----+          +-----+
          |       |        |                |                |
          ~       ~        ~                ~                ~
          ~       ~        ~                ~                ~
          |       |        |                |                |
          |       |        |                |        MN1 Attached Event
          |       |        |                |                |
          |       |        |                |       PBU      |
   3)     |       |        |                |<---------------|
          |       |        |          LMA decision           |
          |       |        |                |                |
          |       |        |  Subscr Query  |                |
   4)     |       |        |<---------------|                |
          |       |        |                |                |
          |       |        |  Subscr Resp   |                |
   5)     |       |        |--------------->|                |
          |       |        |                |                |
          |       |        |    (Multicast Subscription      |
          |       |        |        info forwarding)         |
          |       |        |                |                |
          |       |        |                |   Ext’d PBA    |
   6)     |       |        |                |--------------->|
          |       |        |                |                |
   7)     |       |        |                |           Accept PBA,
          |       |        |                |      Multicast Group join
          |       |        |                |     and P-t-P status setup
          |       |        |                |                |
          |       |        |                |==Bi-Dir Tunnel=|
          |       |        |                |                |
          |       |        |                |  Unicast Data  |
          |<-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-|
          |       |        |                |                |
          |       |        |                |   (S,G) Data   |
          |<-------------------------------------------------|
          |       |        |                |                |
          ~       ~        ~                ~                ~
          ~       ~        ~                ~                ~
```

              Figure 2b. Reactive handover (steps 3 to 7)

3) Some time later, the MN1 perceives a better radio link and decides to attach at a new MAG, nMAG, in a handover process (as a reactive case, the pMAG is not aware of the detachment process). Then, the nMAG triggers a registration process by sending a PBU message (with flag S set to 1) to the LMA.

4) Prior to acknowledge the received PBU message, the LMA checks the status of the A flag for this MN. Due that the flag A=1, the LMA interrogates the pMAG about if there is any active multicast subscription for the MN1, by sending a Subscription Query message.

5) The pMAG answers the LMA with a Subscription Response message including the IP addresses of the existing subscriptions (the pair (S,G) in this case).

6) After processing the pMAG answer, the LMA acknowledges the PBU message, including the multicast subscription information within the new TLV-encoded option "Active Multicast Subscription". The nMAG then process the extended PBA message.

7) The nMAG processes the PBA message, and it proceeds to set up the multicast status of the point-to-point link between the nMAG and the MN1, and to join the content identified by (S,G) on behalf of the MN1 in case the nMAG is not receiving already such content. (The bidirectional tunnel is also set up between the nMAG and the LMA if it has not been established before by another MN connection). At this moment, the multicast content can be served to the MN1. The unicast traffic for the MN1 can be forwarded as well.

```
       +-----+ +-----+  +-----+          +-----+          +------+
       | MN1 | | MN2 |  |p-MAG|          | LMA |          |n-MAG|
       +-----+ +-----+  +-----+          +-----+          +------+
          |       |        |                |                |
          ~       ~        ~                ~                ~
          ~                ~                ~                ~
          |  MLD Done(S,G) |                |                | nMAG
   8)     |--------------------------------------------------->X stops
          |       |        |                |  Act Ind(stop) | fwrding
   9)     |       |        |                |<---------------|
          |       |        |          (flag A = 0)           |
          |       |        |                |  Act Ind Ack   |
          |       |        |                |--------------->|
          |       |        |                |                |
          ~       ~        ~                ~                ~
          ~       ~        ~                ~                ~
```

Figure 2c. Reactive handover (steps 8 to 9)

8) Some time later, the MN1 decides to totally stop all the active multicast subscriptions that it maintains. The MN1 will send an MLD Done message to nMAG to request the cease of the multicast traffic delivery. As consequence, the nMAG will stop all the multicast

traffic forwarding to the MN1.

9) After removing the active subscriptions for the MN1, the nMAG sends a multicast Activity Indication message to the LMA indicating that the MN1 multicast activity is off. The LMA will set the flag A to 0, its default value. Afterwards, the LMA sends an Activity Indication Ack message to the nMAG to acknowledge the previous indication.

```
       +-----+ +-----+  +-----+          +-----+          +-----+
       | MN1 | | MN2 |  |p-MAG|          | LMA |          |n-MAG|
       +-----+ +-----+  +-----+          +-----+          +-----+
          |       |        |                |                |
          ~       ~        ~                ~                ~
          ~       ~        ~                ~                ~
          |       |        |                |                |
          |       |        |                |        MN2 Attached Event
          |       |        |                |                |
          |       |        |                |       PBU      |
   10)    |       |        |                |<---------------|
          |       |        |          LMA decision           |
          |       |        |                |      PBA       |
   11)    |       |        |                |--------------->|
          |       |        |                |                |
   12)    |       |        |                |            Accept PBA
          |       |        |                |                |
          |       |        |                |  Unicast Data  |
          |<-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-|
          |       |        |                |                |
```

Figure 2d. Reactive handover(steps 10 to 12)

10) In parallel, the MN2 perceives a better radio link and decides to attach also to the nMAG, in a reactive handover process as well (the pMAG is neither aware of the detachment process). Then, the nMAG triggers a registration process by sending a PBU message (with flag S set to 1) to the LMA.

11) Prior to acknowledge the received PBU message, the LMA checks the status of the A flag for this MN. Due that the flag A=0, the LMA does not interrogate the pMAG, and acknowledges the PBU message. The nMAG then process the extended PBA message.

12) The nMAG is now ready to forward the unicast traffic to the MN2.

4.2.3 Further considerations for the reactive handover signaling

A handover event is managed independently by the pMAG and nMAG. It is not a synchronized process. In a reactive handover, the LMA will receive a registration PBU from nMAG before a de-registration PBU from pMAG, if any.

In the message flows detailed above, it could be the case that the LMA receives a de-registration PBU from pMAG just after sending the Subscription Query message, but before receiving the Subscription Response message. That de-registration PBU message from pMAG will carry the multicast subscription information required to assist the MN in the handover, so such valuable information should be kept by the LMA. Furthermore, it is possible that once the Subscription Query message arrives to pMAG, the pMAG could have already removed the multicast related information for the MN.

In order to not loose the multicast subscription information sent in the de-registration PBU message, the LMA should store it, and include it in the PBA message towards the nMAG in case the Subscription Response message from the pMAG does not contain multicast subscription information for the MN.

4.2.4 Prevention of large delays of the binding acknowledgement for unicast traffic

Attending to the message sequences detailed above for reactive handovers, in case the LMA has to request the multicast subscription information to the pMAG, the binding request sent by the nMAG is maintained on-hold till the LMA receives, processes and includes the multicast subscription information into the extended PBA message. As consequence, the unicast traffic may then suffer an extra delay motivated by the multicast-related signaling. During that time, the unicast traffic with destination the MN being registered by the nMAG must be buffered or discarded by the LMA.

In order to avoid any potential large delay in the forwarding of unicast traffic arriving to the LMA towards the MN, a mechanism should be implemented to decouple multicast from unicast traffic reception by the MN.

The figures 3a and 3b show this mechanism:

```
       +-----+          +-----+          +-----+          +-----+
       | MN  |          |p-MAG|          | LMA |          |n-MAG|
       +-----+          +-----+          +-----+          +-----+
          |                |                |                |
   1)     |                |==Bi-Dir Tunnel=|                |
          |                |                |                |
          |  unicast data  |                |                |
          |<-v-v-v-v-v-v-v-|                |                |
          |                |                |                |
          | Multicast Data |                |                |
          |<---------------|                |                |
          |                |                |                |
          ~                ~                ~                ~
          ~                ~                ~                ~
```

Figure 3a. Decoupling of unicast and multicast signaling (step 1)

The sequence of messages is the following:

1) An MN, named MN1, is attached to the pMAG. The MN is a multicast-enabled node, and it is receiving both unicast and multicast traffic simultaneously.

```
       +-----+          +-----+          +-----+          +-----+
       | MN  |          |p-MAG|          | LMA |          |n-MAG|
       +-----+          +-----+          +-----+          +-----+
          |                |                |                |
          ~                ~                ~                ~
          ~                ~                ~                ~
          |                |                |                |
          |                |                |        MN1 Attached Event
          |                |                |                |
          |                |                |       PBU      |
   2)     |                |                |<---------------|
          |                |  Subscr Query  |                |
   3)     |                |<---------------|                |
          |                |                |                |
   4)     |                |       <PBA timer starts>        |
          |                |               ///               |
          |                |               ///               |
   5)     |                |       <PBA timer expires>       |
          |                |                |                |
          |                |                |   Ext'd PBA    |
          |                |                |--------------->|
          |                |                |                |
          |                |                |          Accept PBA
          |                |                |                |
          |                |                |==Bi-Dir Tunnel=|
          |                |                |                |
          |                |                |  Unicast Data  |
          |<-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-v-|
          |                |                |                |
          |                |                |  Subscr Query  |
   6)     |                |                |<---------------|
          |                |  Subscr Resp   |                |
   7)     |                |--------------->|                |
          |                |                |                |
          |                |   (Multicast Subscription       |
          |                |       info forwarding)          |
          |                |                |                |
          |                |                |  Subscr Resp   |
   8)     |                |                |--------------->|
          |                |                |                |
          |                |                |   Multicast Group join
          |                |                | and P-t-P status setup
          |                |                |                |
          |                |                | Multicast Data |
          |<-------------------------------------------------|
          |                |                |                |
```

Figure 3b. Decoupling of unicast and multicast signaling (steps 2 to 8)

2) Some time later, the MN1 perceives a better radio link and decides to attach at a new MAG, nMAG, in a handover process (as a reactive case, the pMAG is not aware of the detachment process). Then, the nMAG triggers a registration process by sending a PBU message (with flag S set to 1) to the LMA.

3) Prior to acknowledge the received PBU message, the LMA decides to interrogate the pMAG about if there is any active multicast subscription for the MN1, by sending a Subscription Query message. The LMA decision is based on the checking of flag A when the reactive handover manages the multicast activity indication.

4) Immediately after sending the Subscription Query message, the LMA starts the timer "PBA timer", which duration determines the maximum waiting time before the PBA is sent to avoid any potential large delay in the forwarding of unicast traffic towards the MN.

5) In case the "PBA timer" expires, the LMA acknowledges the PBU message, by sending the PBA message with flag S=0. The nMAG then processes the extended PBA message. Such acknowledgement will allow the MN to receive the unicast traffic from that time on. (The bidirectional tunnel is also set up between the nMAG and the LMA if it has not been established before by another MN connection).

6) In parallel, the nMAG sends a Subscription Query message to the LMA requesting the multicast-subscription details yet unknown for the MN.

7) The pMAG answers the Subscription Query message originally sent by the LMA, including the IP addresses of the existing subscriptions (the pair (S,G) in this case).

8) After processing the pMAG answer, the LMA sends a Subscription Response message to the nMAG, including the multicast subscription information within the new TLV-encoded option "Active Multicast Subscription". The nMAG processes the PBA message, and it proceeds to set up the multicast status of the point-to-point link between the nMAG and the MN1, and to join the content identified by (S,G) on behalf of the MN1 in case the nMAG is not receiving already such content. (The bidirectional tunnel is also set up between the nMAG and the LMA if it has not been established before by another MN connection). At this moment, the multicast content can also be served to the MN.

5 Co-existence with PMIPv6 multicast architectural evolutions

Along this document, it has been considered that the LMA entity is in charge of delivering both unicast and multicast traffic to a certain MN through the bi-directional tunnels connecting to the MAG where the MN is attached, as specified in the base solution defined in [4]. However, the solution described in this memo is not only applicable to the base solution, but also it can be applied to other solutions envisioned as possible architectural evolutions of it, as those stated in [6] or [7].

The architectural proposal in [6] make use of a separate entity to serve multicast traffic through distinct tunnels connected to the MAGs. The tunnels for multicast traffic could not be set up in advance if they are dynamical in nature.

In case of the "multicast activity" flag is also present in the MN's policy store, the nMAG knows in advance the multicast activity of the incoming MN. Consequently, the nMAG can trigger the multicast tunnel set up in parallel to the registration process, including the acquisition of the active multicast subscription details (the IP addresses of the source and the content), saving time on serving the multicast flow to the incoming MN. The concrete procedure for multicast tunnel establishment is out of the scope of this memo, and it is left to the distinct proposal specifications.

6 Security Considerations

TBD.

7 IANA Considerations

This document defines the new following elements which values should be allocated:

o Mobility Header types: the Subscription Query and Subscription Response, and the Multicast Activity Indication and Multicast Activity Indication Acknowledge mobility header types.

o Mobility options: the Active Multicast Subscription mobility option.

o Flags: the multicast Signaling (S), the multicast Information (I), and the multicast Active (A) flags.

8 References

8.1 Normative References

[1]   S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil, "Proxy Mobile IPv6", RFC 5213, Augurst 2008.

[2]   S. Deering, W. Fenner, B. Haberman, "Multicast Listener Discovery (MLD) for IPv6", RFC 2710, October 1999.

[3]   D. Johnson, C. Perkins, and J. Arkko, "Mobility Support in IPv6", RFC 3775, June 2004.

8.2 Informative References

[4]   T.C. Schmidt, M. Waehlisch, and S. Krishnan, "A Minimal Deployment Option for Multicast Listeners in PMIPv6 Domains", RFC6224, April 2011.

[5]   D. von Hugo, H. Asaeda, B. Sarikaya, and P. Seite, "Evaluation of further issues on Multicast Mobility: Potential future work for WG MultiMob", draft-von-hugo-multimob-future-work-02, (work in progress), June 2010.

[6]   J.C. Zuniga, A. Rahman, L.M. Contreras, C.J. Bernardos, and I. Soto, "Support Multicast Services Using Proxy Mobile IPv6", draft-zuniga-multimob-smspmip-06, (work in progress), July 2011.

[7]   S. Jeon and Y. Kim, "PMIPv6 Multicasting Support using Native Infrastructure", draft-sijeon-multimob-direct-routing-pmip6-00, (work in progress), March 2011.

9 Acknowledgments

The research of Carlos J. Bernardos leading to these results has received funding from the European Community's Seventh Framework Programme (FP7-ICT-2009-5) under grant agreement n. 258053 (MEDIEVAL project). The research of Luis M. Contreras and Ignacio Soto leading to these results has received funding from the Spanish MICINN through the I-MOVING project (TEC2010-18907).

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