            PMIPv6 Multicast Routing Optimization with PIM-SM
               draft-asaeda-multimob-pmip6-ropt-with-pim-00

Abstract

   This document describes IP multicast routing optimization with PIM-SM
   in Proxy Mobile IPv6 (PMIPv6) environment. The Mobile Access Gateway
   (MAG) and the Local Mobility Anchor (LMA) are the mobility entities
   defined in the PMIPv6 protocol and act as PIM-SM routers. The
   proposed protocol optimization addresses the tunnel convergence
   problem and cooperates with seamless handover mechanisms.

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1. Introduction

    Proxy Mobile IPv6 (PMIPv6) [1] enables network-based mobility for
    IPv6 mobile nodes (MNs) that do not implement any mobility protocols.
    The Local Mobility Anchor (LMA) is the topological anchor point to
    manages the mobile node's binding state. The Mobile Access Gateway
    (MAG) is an access router or gateway that manages the mobility-
    related signaling for an MN. An MN is attached to the Proxy Mobile
    IPv6 Domain (PMIPv6-Domain) that includes LMA and MAG(s), and is able
    to receive data coming from outside of the PMIPv6-Domain through LMA
    and MAG.

    Network-based mobility support for unicast is addressed in [1], while
    multicast support in PMIPv6 is not discussed in it. Since LMA and
    MAG set up a bi-directional IPv6-in-IPv6 tunnel for each mobile node
    and forwards all mobile node's traffic according to [1], it highly
    wastes network resources when a large number of mobile nodes join/
    subscribe the same multicast sessions/channels, because independent
    data copies of the same multicast packet are delivered to the
    subscriber nodes in a unicast manner through MAG.

    The base solution described in [12] provides options for deploying
    multicast listener functions in PMIPv6-Domains without modifying
    mobility and multicast protocol standards. However, in this
    specification, MAG MUST act as an MLD proxy [2] and hence MUST
    dedicate a tunnel link between LMA and MAG to an upstream interface
    for all multicast traffic. This limitation does not allow to use
    Protocol-Independent Multicast - Sparse Mode (PIM-SM) [3] native
    routing on MAG, and hence does not solve the tunnel convergence
    problem; MAG receives the same data from multiple LMAs when MAG
    attaches to them for mobile nodes and has subscribed the same
    multicast channel to them. It does not enable direct routing and
    does not optimize source mobility.

    This document describes IP multicast routing optimization using
    PIM-SM in Proxy Mobile IPv6 (PMIPv6) environment. The Mobile Access
    Gateway (MAG) and the Local Mobility Anchor (LMA) are the mobility
    entities defined in the PMIPv6 protocol and act as PIM-SM routers.
    The proposed protocol optimization assumes that both LMA and MAG
    enable the Protocol-Independent Multicast - Sparse Mode (PIM-SM)
    multicast routing protocol [3]. The proposed optimization uses a
    dedicated GRE [4] tunnel for multicast, called M-Tunnel between MAG
    and PIM-SM router such as LMA. The proposed protocol optimization
    addresses the tunnel convergence problem and provides seamless
    handover. It can cooperate with localized routing and direct routing
    to deliver IP multicast packets for mobile nodes and source mobility.
    In this document, because multicast listener mobility is mainly
    focused on, the detail specification of source mobility is not

described.

This document does not require to change unicast communication
methods or protocols defined in [1], and therefore both unicast and
multicast communications for mobile nodes in PMIPv6-Domain are
enabled if this extension is implemented.

2. Conventions and Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL
NOT","SHOULD", "SHOULD NOT", "RECOMMENDED","MAY", and "OPTIONAL" in
this document are to be interpreted as described in RFC 2119 [5].

The following terms used in this document are to be interpreted as
defined in the Proxy Mobile IPv6 specification [1]; Mobile Access
Gateway (MAG), Local Mobility Anchor (LMA), Mobile Node (MN), Proxy
Mobile IPv6 Domain (PMIPv6-Domain), LMA Address (LMAA), Proxy Care-of
Address (Proxy-CoA), Mobile Node's Home Network Prefix (MN-HNP),
Mobile Node Identifier (MN-Identifier), Proxy Binding Update (PBU),
and Proxy Binding Acknowledgement (PBA).

3. Overview

3.1. Multicast Communication in PMIPv6

Required components to enable IP multicast are multicast routing
protocols and host-and-router communication protocols. This document
assumes PIM-SM [3] as the multicast routing protocol and Multicast
Listener Discovery (MLD) as the host-and-router communication
protocol. This document allows mobile nodes to participate in Any-
Source Multicast (ASM) and Source-Specific Multicast (SSM) [6].
However, in order to explicitly participate in SSM, mobile nodes MUST
support either MLDv2 [7] or Lightweight-MLDv2 (LW-MLDv2) [8].

The architecture of a Proxy Mobile IPv6 domain is shown in Figure 1.
LMA and MAG are the core functional entities in PMIPv6-Domain. The
entire PMIPv6-Domain appears as a single link from the perspective of
each mobile node.

```
                       +---------+
                       | Content |
                       | Source  |
                       +---------+
                            |
              ***   ***   ***   ***   ***
            *    **    **    **    **     *
           *                              *
            *       Fixed Internet     *
           *                              *
            *    **    **    **    **     *
              ***   ***   ***   ***   ***
                 /               \
             +----+          +----+
             |LMA1|          |LMA2|
             +----+          +----+
        LMAA1 -> |               |  <-- LMAA2
                 |               |
                 \\            //\\
                  \\          //  \\
                   \\        //    \\
                    \\      //      \\
                     \\    //        \\
                      \\  //          \\
           Proxy-CoA1--> |             | <-- Proxy-CoA2
                      +----+        +----+
                      |MAG1|---{MN2} |MAG2|
                      +----+  |      +----+
                        |     |        |
        MN-HNP1 -->    |  MN-HNP2     |  <-- MN-HNP3, MN-HNP4
                    {MN1}          {MN3}
```
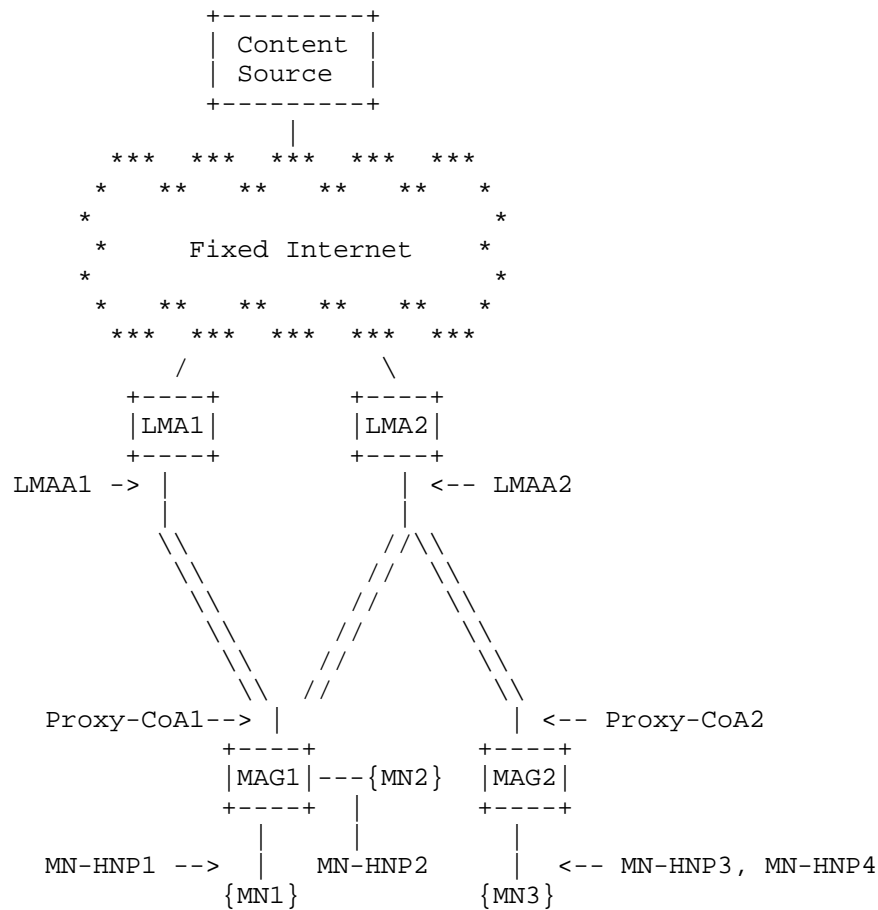
                 Figure 1: Proxy Mobile IPv6 Domain

   When a mobile node wants to subscribe/unsubscribe a multicast
   channel, it sends MLD Report messages specifying sender and multicast
   addresses to the access link. The attached MAG detects this
   membership information and sends the PIM Join/Prune message to the
   corresponding LMA over a bi-directional GRE tunnel called M-Tunnel
   (described in Section 4) when the LMA is selected as the previous-hop
   router for the multicast channel, or sends the PIM Join/Prune message
   to the adjacent upstream multicast router for the multicast channel.
   When the LMA or the adjacent router receives the PIM Join/Prune
   message, it coordinates the corresponding multicast routing tree if
   necessary and starts forwarding the data.

   When the MAG detects mobile node's handover, it can proceed the
   seamless handover procedures. Since both PMIPv6 and multicast

   protocols (i.e., MLD and PIM-SM) do not have functions for multicast
   context transfer in their original protocol specifications, the
   external functions or protocols should be used for handover. One of
   the possibile ways is the use of "mobile node's Policy Profile", as
   it could include "multicast channel information", which expresses
   mobile node's subscribing multicast channel list, as well as the
   mandatory fields of the Policy Profile specified in [1]. Mobile
   node's Policy Profile is provided by "policy store" whose definition
   is the same as of [1].

3.2. Protocol Sequence for Multicast Channel Subscription

   A mobile node sends unsolicited MLD Report messages including source
   and multicast addresses when it subscribes a multicast channel. When
   the MAG operating as a PIM-SM router receives MLD Report messages
   from attached mobile nodes, it sends PIM Join messages to its
   neighboring routers (Figure 2) to join the multicast delivery tree
   (if not joined). When the upstream router for the requested channel
   is LMA (or a non-adjacent PIM router), the MAG sends the
   corresponding PIM Join messages to the LMA (or the non-adjacent PIM
   router) using M-Tunnel (see Section 4). When the upstream router for
   the requested channel is a directly attached adjacent router, the MAG
   sends the corresponding PIM Join messages to the adjacent upstream
   router natively. The LMA or such routers then join the multicast
   delivery tree and forward the packets to the downstream MAG.

```
MN1           MN2              MAG                LMA
 |             |                |                  |
 |------MLD Report--------->|                  |
 |       (S1,G1) join        |  PIM (S1,G1) Join |
 |             |             |===== M-Tunnel ===>|
 |             |             |                  |---> PIM (S1,G1) Join
 |             |             |                  |
 |             |--MLD Report-->|                  |
 |             | (S2,G2) join  |                  |
 |             |             |---> PIM (S2,G2) Join |
 |             |             |                  |
 |             |--MLD Report-->|                  |
 |             | (S1,G1) join  |                  |
 |             |                |                  |
```

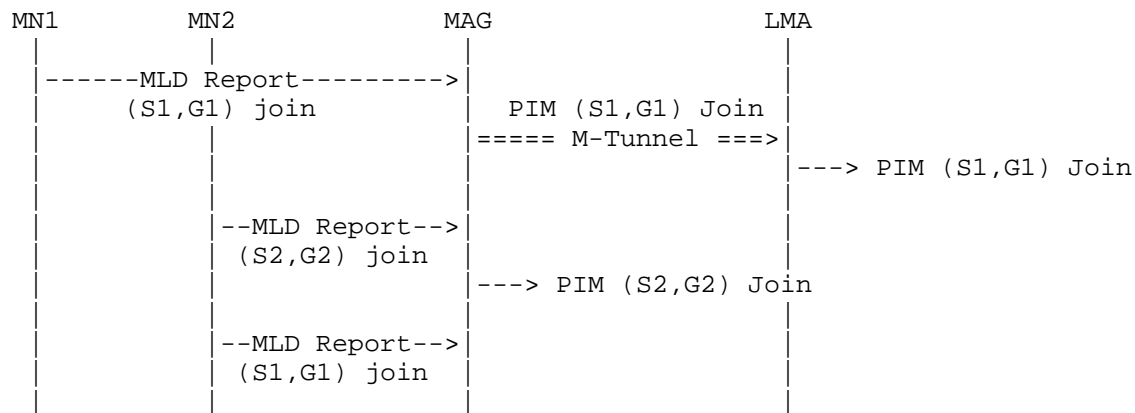   Figure 2: MLD Report and PIM Messages Transmission

   PIM-SM relies on Multicast Routing Information Base (MRIB) to select
   a single upstream interface for each multicast channel by the Reverse
   Path Forwarding (RPF) algorithm. After all potential upstream
   interfaces including M-Tunnel are recognized in MRIB (as described in
   Section 4), the MAG enabling PIM-SM can select either M-Tunnel

interface or physical interface for a multicast channel by the
Reverse Path Forwarding (RPF) algorithm. The proposed architecture
for PMIPv6 with PIM-SM therefore does not cause the tunnel
convergence problem, and hence duplicate packets are not forwarded to
the MAG.

4. Multicast Tunnel (M-Tunnel)

4.1. Packet Encapsulation

M-Tunnel is a bi-directional GRE tunnel [4] dedicated for PIM
messages and IP multicast data transmissions. The tunnel end-point
of M-Tunnel is a MAG that is a PIM-SM capable router. Another tunnel
end-point is also a PIM-SM capable router. The typical use case of
M-Tunnel is to establish a bi-directional tunnel link between LMA and
MAG; therefore LMA shall be another tunnel end-point. M-Tunnel can
be established in a bootstrap phase of MAG (without detecting a
multicast channel subscription request from a mobile node) and kept
while the MAG enables PIM routing functions to forward multicast
packets. An M-Tunnel is not set up per mobile node basis, but per
MAG basis; it can be shared with mobile nodes attached to the MAG as
seen in Figure 3.

```
           MC1
             \
              \-->
           MC2---->LMA===MC1,MC2 for MNs====>MAG

           MC: Multicast packets, ==>: M-Tunnel
```
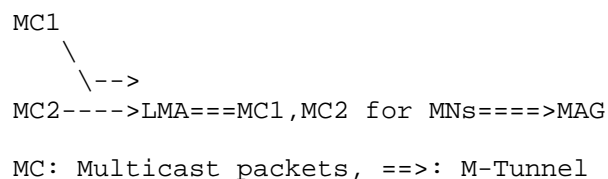
         Figure 3: Multicast packet forwarding through M-Tunnel

In order for the PIM routing protocol to use an M-Tunnel for
multicast forwarding, an M-Tunnel interface must be recognized by the
PIM routing protocol as the upstream multicast interface for MAG. It
is done by the configuration of static multicast routes, such as "ip
mroute 0.0.0.0 0.0.0.0 gre0" or "ip mroute 1.1.1.0 255.255.255.0
gre0". By such configuration, MAG inserts the multicast forwarding
paths using the M-Tunnel into its MRIB. MAG then selects the
M-Tunnel interface as the corresponding RPF interface, and forwards
the PIM Join/Prune messages over the M-Tunnel. If operators want to
select other interface, e.g. a physical interface, as the upstream
multicast interface for some specific source prefixes, e.g. sources
inside the PMIPv6-Domain, they can *additionally* configure the
specific multicast routes with longer prefixes. This configuration
will be used for direct routing. Then the MAG selects as the
appropriate upstream router according to the MRIB entry. Note that

the case having multiple M-Tunnels configured on MAG is described in
Section 4.2.

The format of the tunneled multicast packet forwarded from LMA to MAG
is shown below. "S" and "G" are the same notation used for (S,G)
multicast channel.

```
   IPv6 header (src= LMAA, dst= Proxy-CoA) /* Outer Header */
      GRE header                           /* Encapsulation Header */
         IPv6 header (src= S, dst= G)       /* Inner Header */
            Upper layer protocols           /* Packet Content */
```

        Figure 4: Multicast packet format tunneled from LMA to MAG

When a PIM message is sent from MAG to LMA, the src and dst addresses
of the outer tunnel header will be replaced to Proxy-CoA and LMAA,
respectively. To convey a PIM message, the src address of the inner
packet header is changed to either LMA's or MAG's link-local address.
The dst address of the packet header is assigned based on the PIM's
condition (see [3]).

In order to establish M-Tunnel, LMA and MAG need to negotiate GRE
encapsulation and GRE keys for M-Tunnel. The GRE Key option to be
used for the negotiation of GRE tunnel encapsulation mode and
exchange of the uplink and downlink GRE keys is defined in [9]. It
is also possible to use the static fixed GRE keys for M-Tunnel.

4.2. M-Tunnels Connecting to Multiple PIM-SM Routers and ECMP Routing

There can be multiple LMAs in a PMIPv6-Domain each serving a
different group of mobile nodes. In that case, a MAG will connect to
multiple LMAs with different M-Tunnels having different GRE keys.
For example, in Figure 5, MAG1 establishes two M-Tunnels with LMA1
and LMA2, and MAG2 establishes one M-Tunnel with LMA2.

A MAG that has multiple M-Tunnels, such as MAG1 in Figure 5, must
decide a single upstream M-Tunnel interface for an RP or a source
address or prefix. There are two ways to decide a single upstream
M-Tunnel for a MAG. One is only with static MRIB configuration by
operation. For example, operators can configure each M-Tunnel
interface as the RPF interface for specific source adddress(es) or
prefix(es) one by one. Each M-Tunnel interface is then inserted into
the MAG's MRIB and used for different source adddress(es) or
prefix(es).

The other way to select a single upstream M-Tunnel interface is with
PIM ECMP [13]. A MAG enabling PIM routing functions selects a path
by the ECMP algorithm as described in [13]. The PIM ECMP function

chooses the PIM neighbor with the highest IP address or the best hash
value over the destination and source addresses. The algorithm
choosing a single interface is based on an operator's decision. When
operators decide to use PIM ECMP to select a single upstream M-Tunnel
from multiple M-Tunnels, both the MAG and the tunnel end-point PIM-SM
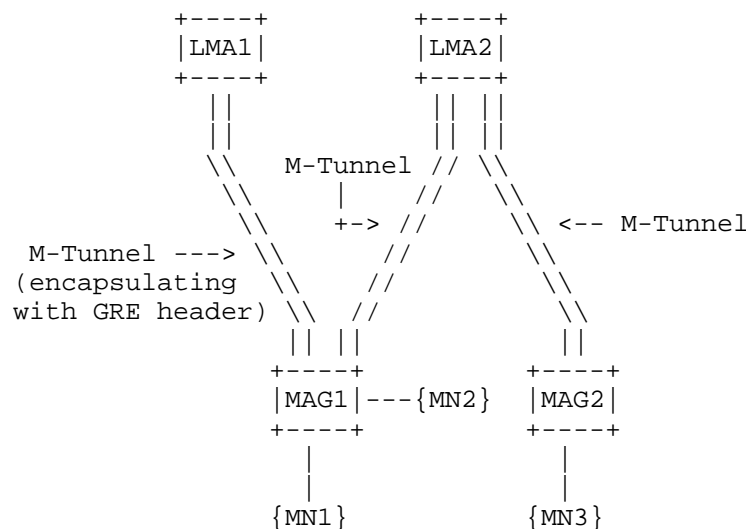routers (e.g., LMAs) MUST enable PIM ECMP.

```
              +----+           +----+
              |LMA1|           |LMA2|
              +----+           +----+
               ||               || ||
               ||               || ||
               \\    M-Tunnel  // \\
                \\      |     //    \\
                 \\    +-> //        \\ <-- M-Tunnel
     M-Tunnel ---> \\       //         \\
     (encapsulating \\     //           \\
     with GRE header) \\  //             \\
               || ||                     ||
               +----+           +----+
               |MAG1|---{MN2}    |MAG2|
               +----+           +----+
                 |                 |
                 |                 |
               {MN1}             {MN3}
```

Figure 5: M-Tunnels established between LMA and MAG

5. Local Mobility Anchor Operation

   The LMA is responsible for maintaining the mobile node's reachability
   state and is the topological anchor point for the mobile node's home
   network prefix(es). This document assumes that the LMA is capable of
   forwarding multicast packets to the MAG by enabling the PIM-SM
   multicast routing protocol [3]. The LMA acting as a PIM-SM multicast
   router may serve MAGs as downstream routers for some multicast
   channels when a mobile node is a multicast data receiver (or as
   upstream routers when a mobile node is a multicast data sender). The
   downstream (or upstream) MAG is connected to the LMA through the
   M-Tunnel for multicast communication.

   When the LMA sets up the multicast state and joins the group as the
   MAG's upstream router, the multicast packets are tunneled to the MAG
   that requested to receive the corresponding multicast session. The
   MAG then forwards the packets to the mobile node according to the
   multicast listener state maintained in the MAG. [1] supports only
   point-to-point access link types for MAG and mobile node connection;

hence a mobile node and the MAG are the only two nodes on an access
link, where the link is assumed to be multicast capable.

6. Mobile Access Gateway Operation

The MAG performs the mobility management on behalf of a mobile node.
This document assumes that the MAG is PIM-SM capable and forwards
multicast packets to the corresponding mobile nodes attached to MAG
by enabling the PIM-SM multicast routing protocol. In addition, the
MAG must maintain multicast membership status for the attached mobile
nodes at the edge and forwards the multicast data to the member
mobile nodes. This condition requires MAG to support MLDv2 [7] or
LW-MLDv2 [8], as well.

When mobile nodes subscribe multicast channel(s), they send MLD
Report messages with their link-local address to the MAG, and the MAG
sends the corresponding PIM Join messages to the upstream router if
the MAG has no multicast state for the requested channel(s). The
upstream router is selected by the Reverse Path Forwarding (RPF)
lookup algorithm, and that is either the LMA or an adjacent multicast
router attached to the same link. If the LMA is the upstream router
for the channel(s) for the MAG, the MAG encapsulates PIM Join
messages using the M-Tunnel.

The optimal multicast routing path may not include the LMA,
especially in localized routing as described in Section 6.10.3 of [1]
and [10]. The localized routing option is designed to support node-
to-node communication within PMIPv6-Domain where a local content
source exists. Details are described in Section 8.

7. Mobile Node Operation

Mobile nodes attached to the MAG can behave as regular receiver
hosts. A mobile node sends MLD report messages to the MAG when it
wants to subscribe and unsubscribe IP multicast channels.

In order to subscribe/unsubscribe multicast channel(s) by unsolicited
report messages and inform current membership state by solicited
report messages, mobile nodes MUST support either MLDv1 [7], MLDv2
[7], or LW-MLDv2 [8], and SHOULD support MLDv2 or LW-MLDv2.

8. Localized Multicast Routing

Localized routing defined in [10] allows mobile nodes attached to the
same or different MAGs to directly exchange unicast traffic by using

localized forwarding or a direct tunnel between the MAGs. Localized
routing must be initiated both MAG and LMA. Localized routing is not
persistent, and is initiated by two signaling messages, Localized
Routing Initiation (LRI) and Local Routing Acknowledgment (LRA), sent
by LMA or MAG.

To support localized multicast routing with PIM-SM capable LMA and
MAG, both LMA and MAG MUST include the routes organized by the
localized routing procedure specified in [10] into their MRIBs. The
exact mechanism to do this is not specified in this document and is
left open for implementations and specific deployments.

To support localized routing for the case that a source node and a
receiver node are attached to different MAGs but the same LMA (as
seen in Section 6 of [10]), these MAGs must use the same tunneling
mechanism for the data traffic tunneled between them. M-Tunnel
defined in this document corresponds to the concept; these MAGs
establish M-Tunnel and enable localized multicast routing.

9. Smooth Handover

   The MAG is responsible for detecting the mobile node's movements to
   and from the access link and for initiating binding registrations to
   the mobile node's LMA. In PMIPv6, it does not require for mobile
   nodes to initiate to re-subscribe multicast channels, and the MAG
   keeps multicast channel subscription status for mobile nodes even if
   they move to a different MAG (i.e., n-MAG) in PMIPv6-Domain.

   The MAG needs to join the multicast delivery tree when an attached
   mobile node subscribes a multicast channel. When the mobile node
   changes the network, it seamlessly receives multicast data from the
   new MAG according to the multicast channel information stored in the
   "MN's Policy Profile" or by some handover mechanisms such as [14] and
   [15]. Whether the MN's Policy Profile or a handover mechanism mobile
   operators use depend on their policy or implementation.

   Here, a handover procedure using the MN's Policy Profile is described
   as an example. When the multicast channel information subscribed by
   mobile nodes is maintained in "MN's Policy Profile" stored in a
   policy store [1], the MAG can use the channel information to provide
   seamless handover. The procedures are described as follows and
   illustrated in Figure 6;

   1. Figure 6 shows the examples that a mobile node has received
       multicast data from an upstream multicast router via p-MAG (*1)
       and from LMA via p-MAG (*2).

2.   Whenever the mobile node moves a new network and attaches to
     n-MAG, the n-MAG obtains the MN-Identifier (MN-ID) and learns
     multicast channel information described in Mobile Node's Policy
     Profile associated to this MN-Identifier. Describing the method
     how the n-MAG identifies the p-MAG is out of scope of this
     document, while using the same mechanism described in [16] would
     be one of the possible methods.

3.   If there are multicast channels the mobile node has subscribed
     but the n-MAG has not yet subscribed, n-MAG joins the
     corresponding multicast channels by sending the PIM Join message
     to its upstream router. If the upstream router is the LMA, the
     PIM messages are encapsulated and transmitted over the M-Tunnel
     (*4); otherwise the PIM messages are sent natively to the
     adjacent upstream router (*3).

4.   The multicast data is forwarded from the LMA through the
     M-Tunnel between the LMA and n-MAG (*4) or from the adjacent
     upstream router (*3).

```
        MN              p-MAG                  LMA                n-MAG
         |                |                     |                  |
         |--MLD Report->  |                     |                  |
         |                |---> PIM Join (*1)    |                  |
         |                |    PIM Join (*2)     |                  |
         |                |==== M-Tunnel ====>   |                  |
         |                |                     |---> PIM Join (*2) |
         |                |                     |                  |
         |<--Multicast--  |                     |                  |
         |   data (*1)    |                     |                  |
         |                |Multicast data (*2)   |                  |
         |<------------   |<=== M-Tunnel =====   |                  |
         |                |                     |                  |
        Detach            |                     |                  |
         |                |                     |                  |
        Attach            |                     |                  |
         |                |                     |        MN attachment event
         |                |                     |      (Acquire MN-ID and Profile)
         |-----------------------------RS-------------------------->|
         |                |                     |                  |
         |                |                     |<-------PBU--------|
         |                |                     |                  |
         |                |                     |--------PBA------->|
         |                |                     |                  |---> PIM Join (*3)
         |                |                     |    PIM Join (*4)  |
         |                |                     |<==== M-Tunnel ====|
         |                |                     |                  |
         |<----------------------------RA---------------------------|
         |                |                     |                  |
         |                |    Multicast data (*3)                  |
         |<--------------------------------------------------------|
         |                |                     |Multicast data (*4)|
         |                |                     |==== M-Tunnel ====>|
         |<--------------------------------------------------------|
         |                |                     |                  |
```
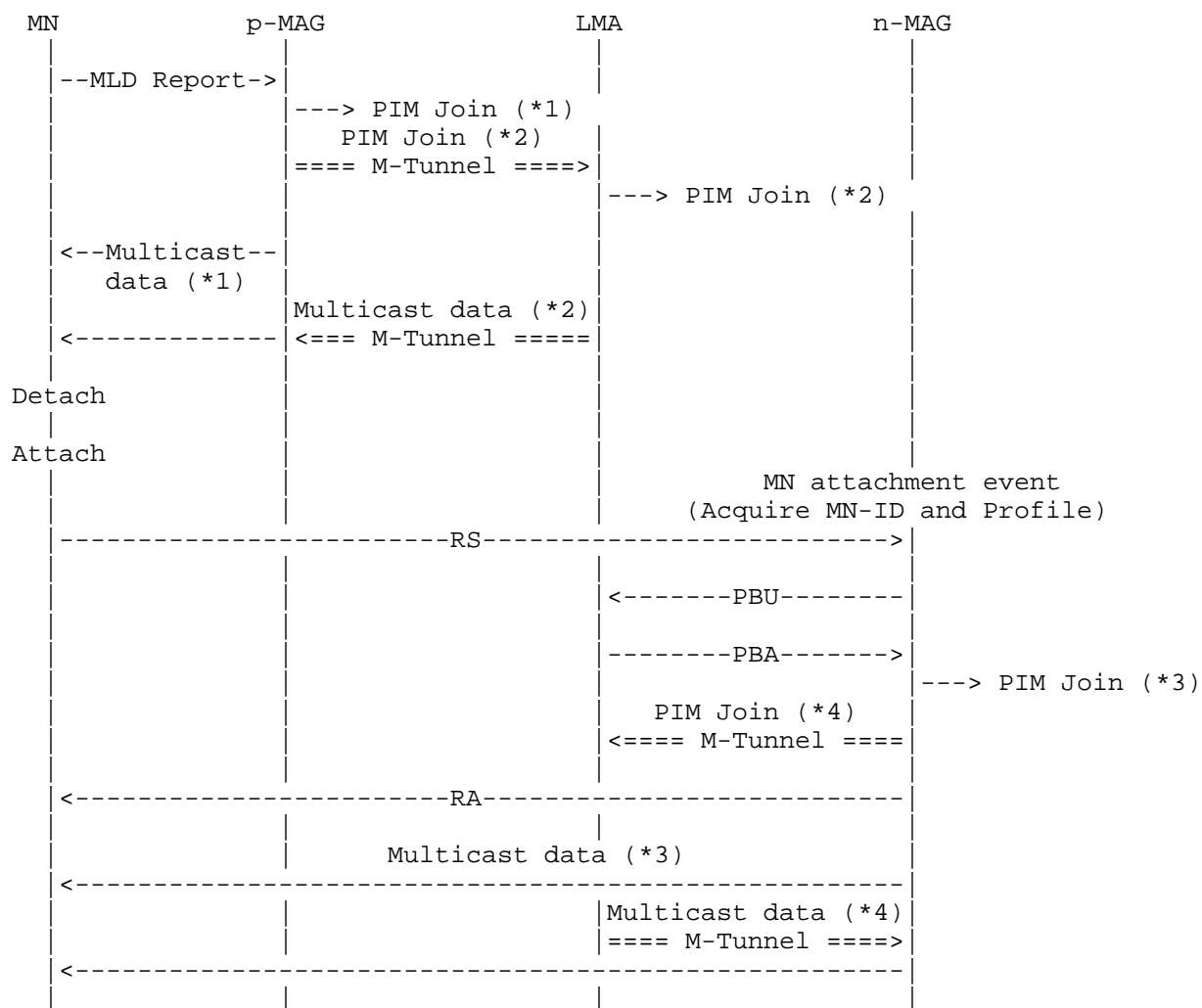
Figure 6: Handover with MN's Policy Profile

   After MN attaches to n-MAG, the multicast data will be delivered to
   the MN immediately. MN's multicast membership state is maintained
   with MLD Query and Report messages exchanged by MN and n-MAG. If
   p-MAG thinks that the moving mobile node is the last member of
   multicast channel(s) (according to the membership record maintained
   by the explicit tracking function [17] or similar mechanism), p-MAG
   confirms it by sending MLD query. After the confirmation, p-MAG
   leaves the channel(s) by sending the PIM Prune message to its
   upstream router.

10. IANA Considerations

   This document has no actions for IANA.

11. Security Considerations

   TBD.

12. Acknowledgements

   Many of the specifications described in this document are discussed
   and provided by the multimob mailing-list. Also, extensive comments
   were received from Sergio Figueiredo, Dirk von Hugo, and Stig Venaas.

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