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# Multicast Routing Optimization by PIM-SM with PMIPv6
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Abstract

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 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 PIM-SM 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. Although MLDv2 specification [7] permits to use the unspecified address (::) for a host whose interface has not acquired a valid link-local address yet, MAG SHOULD send MLDv2 Report messages with a valid IPv6 link-local source address as defined in [13]. As well, MLDv2 Report messages MAY be sent with an IP destination address of FF02:0:0:0:0:0:0:16, to which all MLDv2-capable multicast routers listen, but the IP unicast address of the attached MAG SHALL be used for the destination of MLDv2 Report messages.

When the MAG operating as a PIM-SM router receives MLD Report messages from attached mobile nodes, it joins the multicast delivery tree by sending PIM Join messages to its neighboring routers (Figure 2). When the upstream router for the requested channel is LMA, the MAG sends the corresponding PIM Join messages to the LMA using M-Tunnel (described in Section 4), if the MAG has not joined to the requested multicast channel. When the upstream router for the requested channel is an adjacent router that is not the LMA, the MAG sends the corresponding PIM Join messages to the adjacent upstream router natively, if the MAG has not joined to the requested multicast channel. The LMA or the adjacent upstream router then joins the multicast delivery tree and forwards 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

The MAG selects only one upstream interface (either M-Tunnel interface or physical interface) for a multicast channel by the Reverse Path Forwarding (RPF) algorithm. This does not cause the tunnel convergence problem, because Multicast Routing Information Base (MRIB) used by PIM-SM selects only one upstream interface for each multicast channel 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 route 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 [14]. A MAG enabling PIM routing functions selects a path in the ECMP based on its own implementation specific choice, which may refer to the description in [14]. The PIM ECMP function chooses the PIM neighbor with the highest IP address, or picks the PIM neighbor with the best hash value over the destination and source addresses. When operators decide to use PIM ECMP to select a single upstream M-Tunnel from multiple M-Tunnels, both 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 Protocol-Independent Multicast - Sparse Mode (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 is the entity that 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 MAG also sends MLD Query messages to attached mobile nodes to maintain up-to-date membership states. Since the MAG may deal with a large number of the downstream mobile nodes, the MLD protocol scalability should be taken into account as described in [13]. Therefore it is RECOMMENDED that the explicit tracking function [15] is enabled on the MAG.

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 membersip 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 orgzanized 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 [16] and [17]. Whether the MN's Policy Profile or a hondover 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 [18] 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 [15]), 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.

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