  Mobile Multicast Sender Support in Proxy Mobile IPv6 (PMIPv6) Domains

Abstract

   Multicast communication can be enabled in Proxy Mobile IPv6 (PMIPv6)
   domains via the Local Mobility Anchors by deploying Multicast
   Listener Discovery (MLD) proxy functions at Mobile Access Gateways,
   by using direct traffic distribution within an ISP's access network,
   or by selective route optimization schemes. This document describes
   a base solution and an experimental protocol to support mobile
   multicast senders in PMIPv6 domains for all three scenarios.
   Protocol optimizations for synchronizing PMIPv6 with PIM, as well as
   a peering function for MLD proxies are defined. Mobile sources
   always remain agnostic of multicast mobility operations.

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1. Introduction

   Proxy Mobile IPv6 (PMIPv6) [RFC5213] extends Mobile IPv6 (MIPv6)
   [RFC6275] by network-based management functions that enable IP
   mobility for a host without requiring its participation in any
   mobility-related signaling. Additional network entities called Local
   Mobility Anchor (LMAs) and Mobile Access Gateways (MAGs) are
   responsible for managing IP mobility on behalf of the mobile node
   (MN). An MN connected to a PMIPv6 domain, which only operates
   according to the base specifications of [RFC5213], cannot participate
   in multicast communication, as MAGs will discard group packets.

   Multicast support for mobile listeners can be enabled within a PMIPv6
   domain by deploying MLD proxy functions at Mobile Access Gateways,
   and multicast routing functions at Local Mobility Anchors [RFC6224].
   This base deployment option is the simplest way to PMIPv6 multicast
   extensions in the sense that it follows the common PMIPv6 traffic
   model and neither requires new protocol operations nor additional
   infrastructure entities. Standard software functions need to be
   activated on PMIPv6 entities, only, at the price of possibly non-
   optimal multicast routing.

   Alternate solutions leverage performance optimization by providing
   multicast routing at the access gateways directly [MULTI-EXT] or by
   using selective route optimization schemes [RFC7028]. Such
   approaches (partially) follow the model of providing multicast data
   services in parallel to PMIPv6 unicast routing [RFC7161].

   Multicast listener support satisfies the needs of receptive use cases
   such as IPTV or server-centric gaming on mobiles. However, current
   trends in the Internet develop towards user-centric, highly
   interactive group applications like user-generated streaming,
   conferencing, collective mobile sensing, etc. Many of these popular
   applications create group content at end systems and can largely
   profit from a direct data transmission to a multicast-enabled
   network.

   This document describes the support of mobile multicast senders in
   Proxy Mobile IPv6 domains for the base deployment scenario [RFC6224],
   for direct traffic distribution within an ISP's access network, as
   well as for selective route optimization schemes. The source
   mobility problem as discussed in [RFC5757] serves as a foundation of
   this document. Mobile nodes in this setting remain agnostic of
   multicast mobility operations.

2. Terminology

This document uses the terminology as defined for the mobility
protocols [RFC6275], [RFC5213], and [RFC5844], as well as the
multicast routing [RFC4601] and edge-related protocols [RFC3376],
[RFC3810], and [RFC4605].

Throughout this document, we use the following acronyms:

HNP   Home Network Prefix as defined in [RFC5213].

MAG   Mobile Access Gateway as defined in [RFC5213].

MLD   Multicast Listener Discovery as defined in [RFC2710] and
          [RFC3810].

PIM   Protocol Independent Multicast as defined in [RFC4601].

PMIPv6   Proxy Mobile IPv6 as defined in [RFC5213].

2.1. Requirements Language

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 [RFC2119].

3. Base Solution for Source Mobility and PMIPv6 Routing

3.1. Overview

The reference scenario for multicast deployment in Proxy Mobile IPv6
domains is illustrated in Figure 1. It displays the general setting
for source mobility -- mobile nodes (MNs) with Home Network Prefixes
(HNPs) that receive services via tunnels, which are spanned between a
Local Mobility Anchor Address (LMAA) and a Proxy Care-of-Address
(Proxy-CoA) at a Mobility Access Gateway (MAG). MAGs play the role
of first-hop access routers that serve multiple MNs on the downstream
while running an MLD/IGMP proxy instance for every LMA upstream
tunnel.

```
                      +-------------+
                      |  Multicast  |
                      |  Listeners  |
                      +-------------+
                             |
                   ***   *** *** ***
                  *   **   **   **   *
                 *                     *
                *     Fixed Internet    *
                *                       *
                 *   **   **   **   *
                   ***   *** *** ***
                  /               \
              +----+           +----+
              |LMA1|           |LMA2|            Multicast Anchor
              +----+           +----+
         LMAA1  |                |  LMAA2
                |                |
               \\            //\\
                \\          // \\
                 \\        //   \\               Unicast Tunnel
                  \\      //     \\
                   \\    //       \\
        Proxy-CoA1 ||             ||  Proxy-CoA2
              +----+           +----+
              |MAG1|           |MAG2|            MLD Proxy
              +----+           +----+
         MN-HNP1 |   | MN-HNP2     |  MN-HNP3
                 |   |             |
                MN1 MN2           MN3

              Multicast Sender + Listener(s)
```
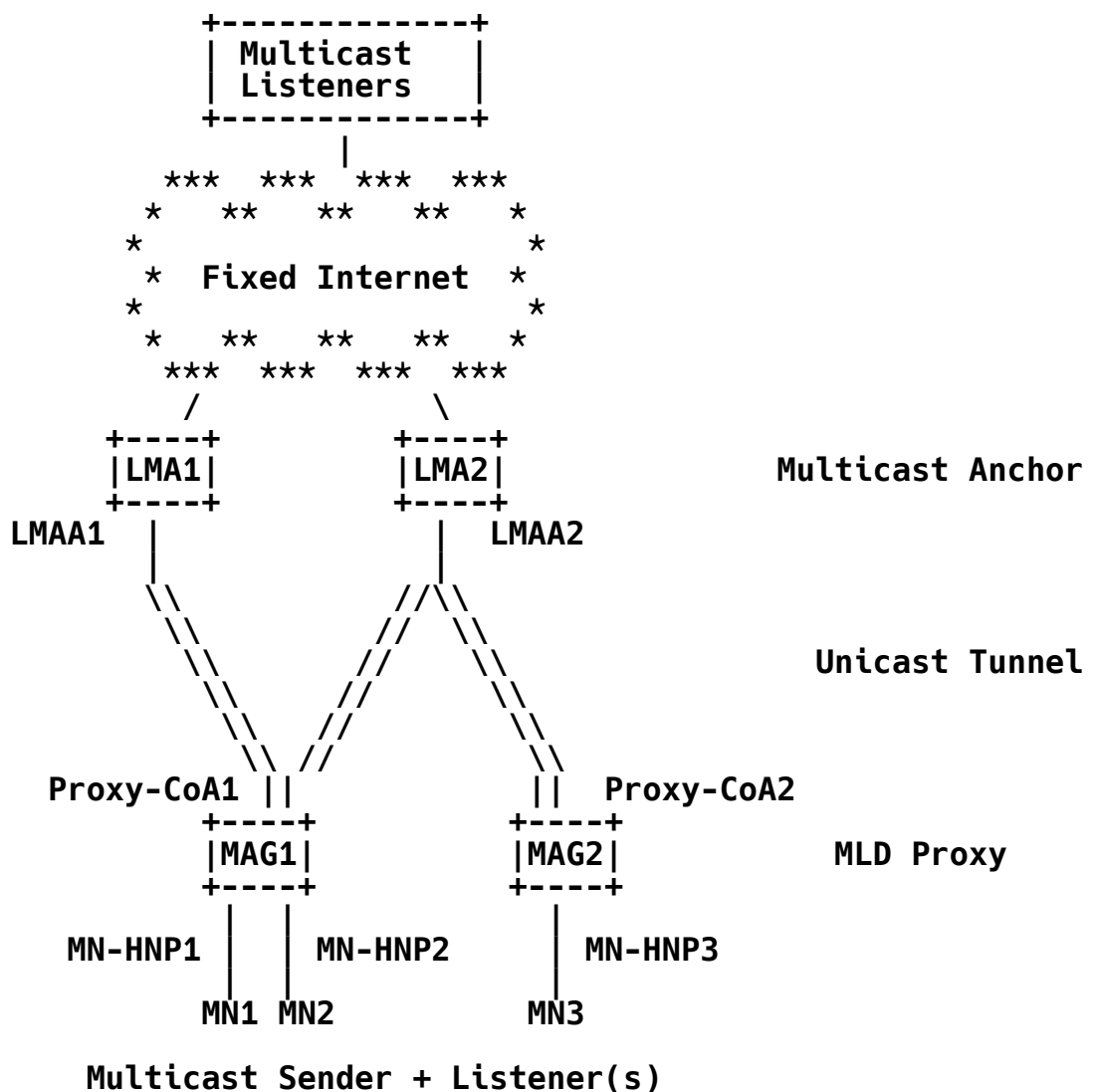
Figure 1: Reference Network for Multicast Deployment in PMIPv6

An MN in a PMIPv6 domain will decide on multicast data transmission
completely independent of its current mobility conditions. It will
send packets as initiated by applications, using its source address
with an HNP and a multicast destination address chosen by application
needs. Multicast packets will arrive at the currently active MAG via
one of its downstream local (wireless) links. A multicast-unaware
MAG would simply discard these packets in the absence of instructions
for packet processing, i.e., a Multicast Routing Information Base
(MRIB).

An MN can successfully distribute multicast data in PMIPv6, if MLD proxy functions are deployed at the MAG as described in [RFC6224]. In this setup, the MLD proxy instance serving a mobile multicast source has configured its upstream interface at the tunnel towards the MN's corresponding LMA. For each LMA, there will be a separate instance of an MLD proxy.

According to the specifications given in [RFC4605], multicast data arriving from a downstream interface of an MLD proxy will be forwarded to the upstream interface and to all but the incoming downstream interfaces that have appropriate forwarding states for this group. Thus, multicast streams originating from an MN will arrive at the corresponding LMA and directly at all mobile receivers co-located at the same MAG and MLD proxy instance. Serving as the designated multicast router or an additional MLD proxy, the LMA forwards data to the fixed Internet, whenever forwarding states are maintained by multicast routing. If the LMA is acting as another MLD proxy, it will forward the multicast data to its upstream interface and to downstream interfaces with matching subscriptions, accordingly.

In case of a handover, the MN (being unaware of IP mobility) can continue to send multicast packets as soon as network connectivity is re-established. At this time, the MAG has determined the corresponding LMA, and IPv6 unicast address configuration (including PMIPv6 bindings) has been completed. Still, multicast packets arriving at the MAG are discarded (if not buffered) until the MAG has completed the following steps.

1. The MAG has determined that the MN is admissible to multicast services.

2. The MAG has added the new downstream link to the MLD proxy instance with an uplink to the corresponding LMA.

As soon as the MN's uplink is associated with the corresponding MLD proxy instance, multicast packets are forwarded again to the LMA and eventually to receivers within the PMIP domain. (See the call flow in Figure 2.) In this way, multicast source mobility is transparently enabled in PMIPv6 domains that deploy the base scenario for multicast.

```
 MN1             MAG1             MN2             MAG2            LMA
  |               |               |               |               |
  |               |  Mcast Data   |               |               |
  |               |<--------------+               |               |
  |               |   Mcast Data  |               |               |
  |   Join(G)     +===============================================>|
  +-------------->|               |               |               |
  |  Mcast Data   |               |               |               |
  |<--------------+               |               |               |
  |               |               |               |               |
  |        <  Movement of MN 2 to MAG2  &  PMIP Binding Update  >  |
  |               |               |               |               |
  |               |               | --- Rtr Sol -->|              |
  |               |               |<-- Rtr Adv ---|               |
  |               |               |               |               |
  |               |               |    < MLD Proxy Configuration > |
  |               |               |               |               |
  |               |               | (MLD Query)   |               |
  |               |               |<--------------+               |
  |               |               |  Mcast Data   |               |
  |               |               +-------------->|               |
  |               |               |               |   Mcast Data  |
  |               |               |               +==============>|
  |               |  Mcast Data   |               |               |
  |               |<===============================================+
  |  Mcast Data   |               |               |               |
  |<--------------+               |               |               |
  |               |               |               |               |
```
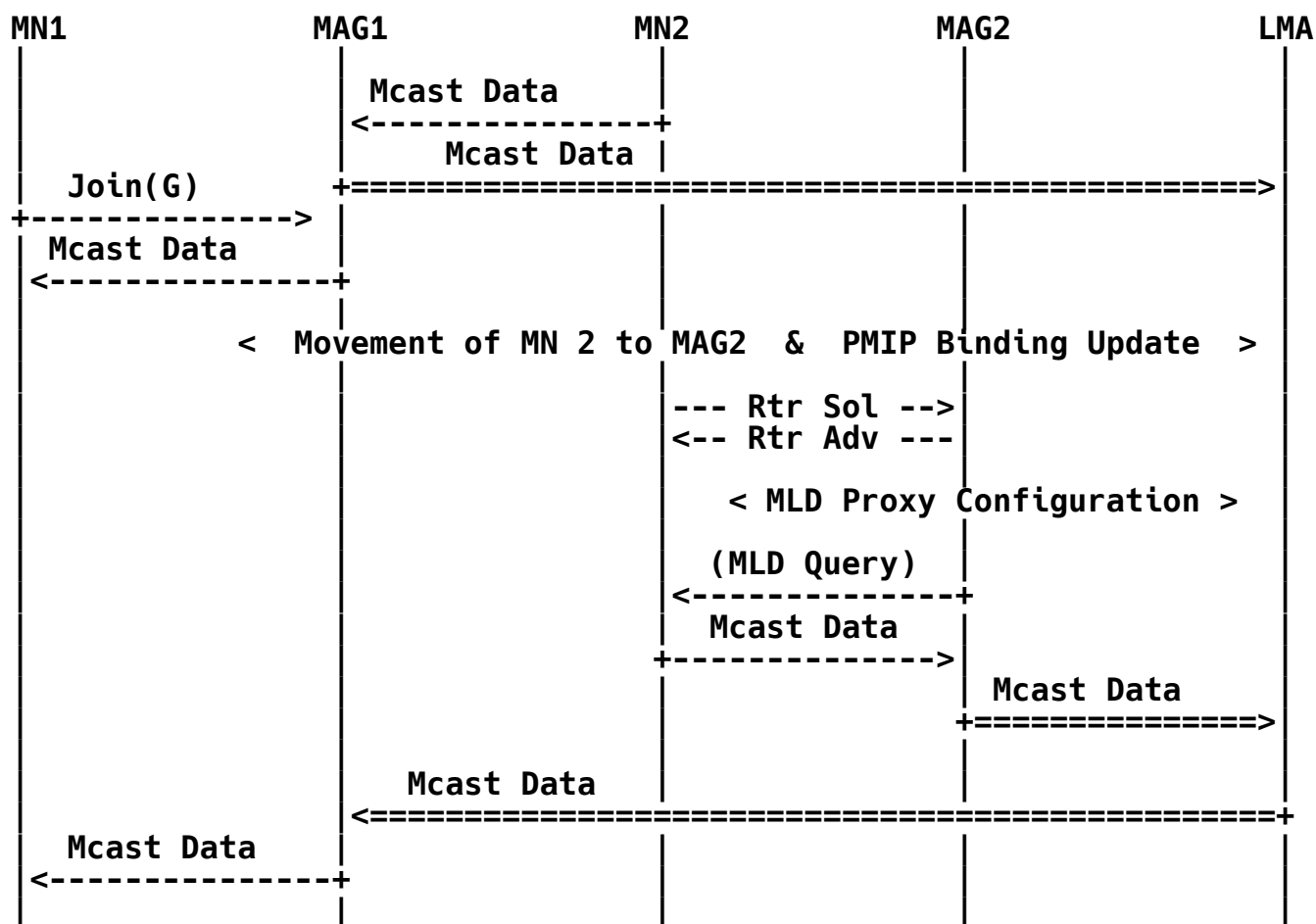
                   Legend: Rtr Sol - ICMPv6 Router Solicitation
                           Rtr Adv - ICMPv6 Router Advertisement

     Figure 2: Call Flow for Group Communication in Multicast-Enabled PMIP

     These multicast deployment considerations likewise apply for mobile
     nodes that operate with their IPv4 stack enabled in a PMIPv6 domain.
     PMIPv6 can provide IPv4 home address mobility support [RFC5844].
     IPv4 multicast is handled by an IGMP proxy function at the MAG in an
     analogous way.

     Following these deployment steps, multicast traffic distribution
     transparently interoperates with PMIPv6. It is worth noting that an
     MN -- while being attached to the same MAG as the mobile source, but
     associated with a different LMA -- cannot receive multicast traffic
     on a shortest path. Instead, multicast streams flow up to the LMA of

the mobile source, are transferred to the LMA of the mobile listener, and are tunneled downwards to the MAG again. (See Section 5 for further optimizations.)

3.2. Base Solution for Source Mobility: Details

Support of multicast source mobility in PMIPv6 requires that general multicast functions be deployed at PMIPv6 routers and that their interactions with the PMIPv6 protocol be defined as follows.

3.2.1. Operations of the Mobile Node

A mobile node willing to send multicast data will proceed as if attached to the fixed Internet. No specific mobility or other multicast-related functionalities are required at the MN.

3.2.2. Operations of the Mobile Access Gateway

A Mobile Access Gateway is required to have MLD proxy instances deployed, one for each tunnel to an LMA, which serves as its unique upstream link (cf. [RFC6224]). On the arrival of an MN, the MAG decides on the mapping of downstream links to a proxy instance and the upstream link to the LMA based on the regular Binding Update List as maintained by PMIPv6 standard operations. When multicast data is received from the MN, the MAG MUST identify the corresponding proxy instance from the incoming interface and forwards multicast data upstream according to [RFC4605].

The MAG MAY apply special admission control to enable multicast data transmission from an MN. It is advisable to take special care that MLD proxy implementations do not redistribute multicast data to downstream interfaces without appropriate subscriptions in place.

3.2.3. Operations of the Local Mobility Anchor

For any MN, the Local Mobility Anchor acts as the persistent Home Agent and at the same time as the default multicast upstream for the corresponding MAG. It will manage and maintain a multicast forwarding information base for all group traffic arriving from its mobile sources. It SHOULD participate in multicast routing functions that enable traffic redistribution to all adjacent LMAs within the PMIPv6 domain and thereby ensure a continuous receptivity while the source is in motion.

3.2.3.1. Local Mobility Anchors Operating PIM

Local Mobility Anchors that operate the Protocol Independent
Multicast - Sparse Mode (PIM-SM) routing protocol [RFC4601] will
require sources to be directly connected for sending PIM registers to
the Rendezvous Point (RP). This does not hold in a PMIPv6 domain, as
MAGs are routers intermediate to the MN and the LMA. In this sense,
MNs are multicast sources external to the PIM-SM domain.

To mitigate this incompatibility common to all subsidiary MLD proxy
domains, the LMA MUST act as a PIM Border Router and activate the
Border-bit. In this case, the DirectlyConnected(S) is treated as
being TRUE for mobile sources and the PIM-SM forwarding rule "iif ==
RPF_interface(S)" is relaxed to be TRUE, as the incoming tunnel
interface from MAG to LMA is not considered part of the PIM-SM
component of the LMA (see Appendix A.1 of [RFC4601]).

In addition, an LMA serving as the PIM Designated Router (DR) is
connected to MLD proxies via individual IP tunnel interfaces and will
experience changing PIM source states on handover. As the incoming
interface connects to a point-to-point link, PIM Assert contention is
not active, and incoming interface validation is only performed by
Reverse Path Forwarding (RPF) checks. Consequently, a PIM DR SHOULD
update incoming source states, as soon as RPF inspection succeeds,
i.e., after the PMIPv6 forwarding state update. Consequently, PIM
routers SHOULD be able to manage these state changes, but some
implementations are expected to incorrectly refuse packets until the
previous state has timed out.

Notably, running Bidirectional PIM (BIDIR-PIM) [RFC5015] on LMAs
remains robust with respect to source location and does not require
special configurations or state management for sources.

3.2.4. IPv4 Support

An MN in a PMIPv6 domain may use an IPv4 address transparently for
communication as specified in [RFC5844]. For this purpose, an LMA
can register an IPv4-Proxy-CoA in its Binding Cache, and the MAG can
provide IPv4 support in its access network. Correspondingly,
multicast membership management will be performed by the MN using
IGMP. For multicast support on the network side, an IGMP proxy
function needs to be deployed at MAGs in exactly the same way as for
IPv6. [RFC4605] defines IGMP proxy behavior in full agreement with
IPv6/MLD. Thus, IPv4 support can be transparently provided following
the obvious deployment analogy.

For a dual-stack IPv4/IPv6 access network, the MAG proxy instances
SHOULD choose multicast signaling according to address configurations
on the link, but they MAY submit IGMP and MLD queries in parallel, if
needed. It should further be noted that the infrastructure cannot
identify two data streams as identical when distributed via an IPv4
and IPv6 multicast group. Thus, duplicate data may be forwarded on a
heterogeneous network layer.

The following points are worth noting about the scenario in [RFC5845]
in which overlapping private address spaces of different operators
can be hosted in a PMIP domain by using Generic Routing Encapsulation
(GRE) with key identification. This scenario implies that unicast
communication in the MAG-LMA tunnel can be individually identified
per MN by the GRE keys. This scenario still does not impose any
special treatment of multicast communication for the following
reasons.

Multicast streams from and to MNs arrive at a MAG on point-to-point
links (identical to unicast). Multicast data transmission from the
MAG to the corresponding LMA is link-local between the routers and
routing/forwarding remains independent of any individual MN. So, the
MAG-proxy and the LMA SHOULD NOT use GRE key identifiers, but plain
GRE in multicast communication (including MLD queries and reports).
Multicast traffic is transmitted using router-to-router forwarding
via the MAG-to-LMA tunnels and according to the MRIB of the MAG or
the LMA. It remains independent of MN's unicast addresses, while the
MAG proxy instance redistributes multicast data down the point-to-
point links (interfaces) according to its local subscription states,
independent of IP addresses of the MN.

3.2.5. Efficiency of the Distribution System

The distribution system of the base solution directly follows PMIPv6
routing rules and organizes multicast domains with respect to LMAs.
Thus, no coordination between address spaces or services is required
between the different instances, provided their associated LMAs
belong to disjoint multicast domains. Routing is optimal for
communication between MNs of the same domain or stationary
subscribers.

In the following situations, efficiency-related issues remain.

Multicast reception at LMA
    In the current deployment scenario, the LMA will receive all
    multicast traffic originating from its associated MNs. There is
    no mechanism to suppress upstream forwarding in the absence of
    receivers.

MNs on the same MAG using different LMAs
     For a mobile receiver and a source that use different LMAs, the
     traffic has to go up to one LMA, cross over to the other LMA, and
     then be tunneled back to the same MAG, causing redundant flows in
     the access network and at the MAG.

These remaining deficits in routing efficiency can be resolved by
adding peering functions to MLD proxies as described in Section 5.

4. Direct Multicast Routing

There are deployment scenarios, where multicast services are
available throughout the access network independent of the PMIPv6
routing system [RFC7028]. In these cases, the visited networks grant
a local content distribution service (in contrast to LMA-based home
subscription) with locally optimized traffic flows. It is also
possible to deploy a mixed service model of local and LMA-based
subscriptions, provided that a unique way of service selection is
implemented. For example, access routers (MAGs) could decide on
service access based on the multicast address G or the source-
specific multicast (SSM) channel (S,G) under request. (See
Appendix A for further discussions.)

4.1. Overview

Direct multicast access can be supported by

o native multicast routing provided by one multicast router that is
   neighboring MLD proxies deployed at MAGs within a flat access
   network, or via tunnel uplinks,

o a multicast routing protocol such as PIM-SM [RFC4601] or BIDIR-PIM
   [RFC5015] deployed at the MAGs.

```
                    ***   ***   ***   ***
                   *    **   **   **    *
                  *                      *
                  *     Multicast        *
     +----+       *   Infrastructure     *                         +----+
     |LMA |        *    **   **   **    *                          |LMA |
     +----+         ***   ***   ***   ***                          +----+
        |            |    //  \\                                      |
     PMIP  \\       //      \\      // PMIP (unicast)   \\  **  *** *** **   //
  (unicast) \\     //        \\    //                   \\ *   **   **    ** //
             \\   //          \\  //                     \\*    Multicast  *//
              || ||            || ||                   *  ||    Routing    || *
     +----+          +----+          +----+          * +----+          +----+ *
 MLD Proxy |MAG1|          |MAG2|          * |MAG1|          |MAG2| *
     +----+          +----+          +----+          *+----+ **     ** +----+*
        | |            |              | |              |***  ***   ***|
        | |            |              | |              |
       MN1 MN2        MN3            MN1 MN2          MN3

  (a) Multicast Access at Proxy Uplink     (b) Multicast Routing at MAG
```
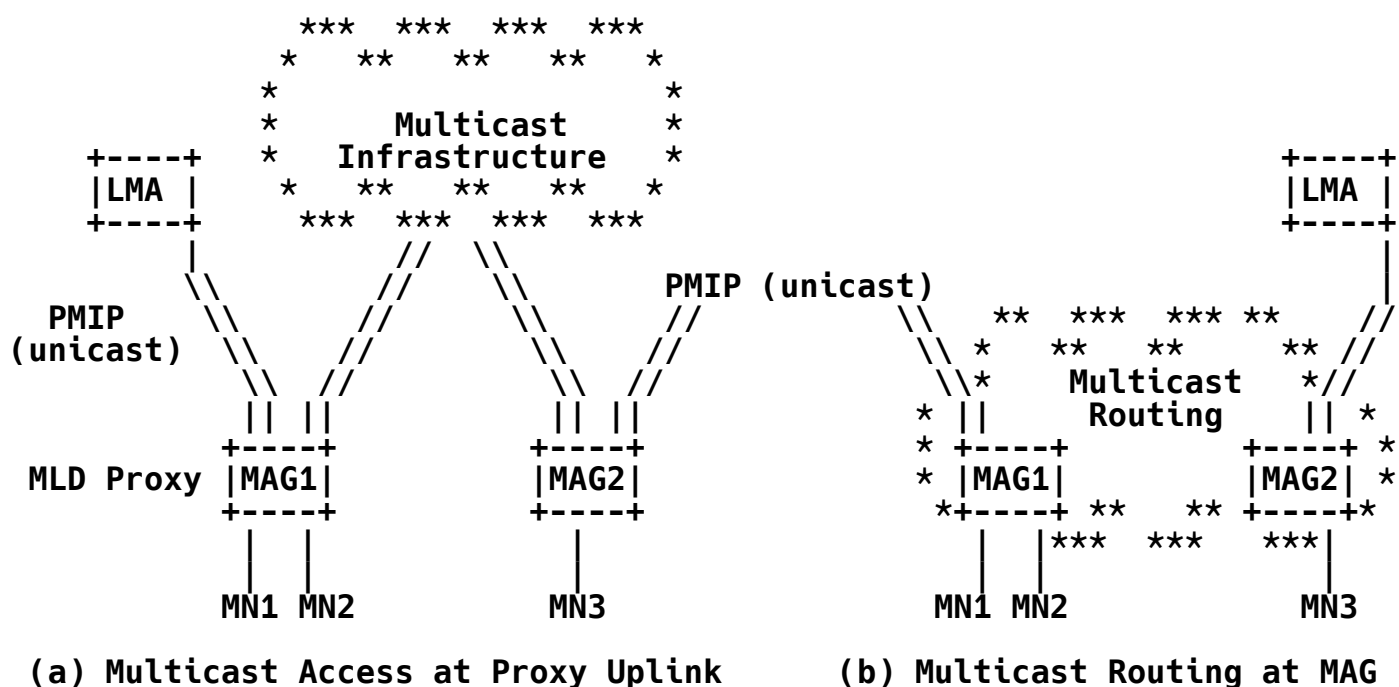
       Figure 3: Reference Networks for (a) Proxy-Assisted Direct Multicast
              Access and (b) Dynamic Multicast Routing at MAGs

   Figure 3 displays the corresponding deployment scenarios that
   separate multicast from PMIPv6 unicast routing. It is assumed
   throughout these scenarios that all MAGs (MLD proxies) are linked to
   a single multicast routing domain. Notably, this scenario requires
   coordination of multicast address utilization and service bindings.

   Multicast traffic distribution can be simplified in these scenarios.
   A single proxy instance at MAGs with uplinks into the multicast
   domain will serve as a first-hop multicast gateway and avoid traffic
   duplication or detour routing. Multicast routing functions at MAGs
   will seamlessly embed access gateways within a multicast cloud.
   However, mobility of the multicast source in this scenario will
   require some multicast routing protocols to rebuild distribution
   trees. This can cause significant service disruptions or delays (see
   [RFC5757] for further aspects). Deployment details are specific to
   the multicast routing protocol in use; this is described below for
   common protocols.

4.2. MLD Proxies at MAGs

   In a PMIPv6 domain, single MLD proxy instances can be deployed at
   each MAG that enable multicast service at the access via an uplink to
   a multicast service infrastructure (see Figure 3(a)). To avoid

service disruptions on handovers, the uplinks of all proxies SHOULD
be adjacent to the same next-hop multicast router. This can either
be achieved by arranging proxies within a flat access network or by
using upstream tunnels that terminate at a common multicast router.

Multicast data submitted by a mobile source will reach the MLD proxy
at the MAG that subsequently forwards flows to the upstream and to
all downstream interfaces with appropriate subscriptions. Traversing
the upstream will transfer traffic into the multicast infrastructure
(e.g., to a PIM Designated Router) that will route packets to all
local MAGs that have joined the group, as well as further upstream
according to protocol procedures and forwarding states.

On handover, a mobile source will reattach to a new MAG and can
continue to send multicast packets as soon as PMIPv6 unicast
configurations have been completed. Like at the previous MAG, the
new MLD proxy will forward data upstream and downstream to
subscribers. Listeners local to the previous MAG will continue to
receive group traffic via the local multicast distribution
infrastructure following aggregated listener reports of the previous
proxy. In general, traffic from the mobile source continues to be
transmitted via the same next-hop multicast router using the same
source address and thus remains unchanged when seen from the wider
multicast infrastructure.

4.2.1. Considerations for PIM-SM on the Upstream

A mobile source that transmits data via an MLD proxy will not be
directly connected to a PIM Designated Router as discussed in
Section 3.2.3.1. Countermeasures apply correspondingly.

A PIM Designated Router that is connected to MLD proxies via
individual IP tunnel interfaces will experience invalid PIM source
states on handover. In some implementations of PIM-SM, this could
lead to an interim packet loss (see Section 3.2.3.1). This problem
can be mitigated by aggregating proxies on a lower layer.

4.2.2. SSM Considerations

Source-specific subscriptions invalidate with routes, whenever the
source moves from or to the MAG/proxy of a subscriber. Multicast
forwarding states will rebuild with unicast route changes. However,
this may lead to noticeable service disruptions for locally
subscribed nodes.

4.3. PIM-SM at MAGs

   The full-featured multicast routing protocol PIM-SM MAY be deployed
   in the access network for providing multicast services in parallel to
   unicast routes (see Figure 3(b)). Throughout this section, it is
   assumed that the PMIPv6 mobility domain is part of a single PIM-SM
   multicast routing domain with PIM-SM routing functions present at all
   MAGs and all LMAs. The PIM routing instance at a MAG SHALL then
   serve as the Designated Router (DR) for all directly attached Mobile
   Nodes. For expediting handover operations, it is advisable to
   position PIM Rendezvous Points (RPs) in the core of the PMIPv6
   network domain. However, regular IP routing tables need not be
   present in a PMIPv6 deployment, and additional effort is required to
   establish reverse path forwarding rules as required by PIM-SM.

4.3.1. Routing Information Base for PIM-SM

   In this scenario, PIM-SM will rely on a Multicast Routing Information
   Base (MRIB) that is generated independently of the policy-based
   routing rules of PMIPv6. The granularity of mobility-related routing
   locators required in PIM depends on the complexity (specific phase)
   of its deployment.

   For all three phases in the operation of PIM (see [RFC4601]), the
   following information is needed.

   o All routes to networks and nodes (including RPs) that are not
      mobile members of the PMIPv6 domain MUST be defined consistently
      among PIM routers and MUST remain unaffected by node mobility.
      The setup of these general routes is expected to follow the
      topology of the operator network and is beyond the scope of this
      document.

   The following route entries are required at a PIM-operating MAG when
   phase two or three of PIM or PIM-SSM is in operation.

   o Local routes to the Home Network Prefixes (HNPs) of all MNs
      associated with their corresponding point-to-point attachments
      that MUST be included in the local MRIB.

   o All routes to MNs that are attached to distant MAGs of the PMIPv6
      domain point towards their corresponding LMAs. These routes MUST
      be made available in the MRIB of all PIM routers (except for the
      local MAG of attachment), but they MAY be eventually expressed by
      an appropriate default entry.

4.3.2. Operations of PIM in Phase One (RP Tree)

A new mobile source S will transmit multicast data of group G towards its MAG of attachment. Acting as a PIM DR, the access gateway will unicast-encapsulate the multicast packets and forward the data to the Virtual Interface (VI) with encapsulation target RP(G), a process known as "PIM source registering". The RP will decapsulate and natively forward the packets down the RP-based distribution tree towards (mobile and stationary) subscribers.

On handover, the point-to-point link connecting the mobile source to the old MAG will go down and all (S,*) flows terminate. In response, the previous DR (MAG) deactivates the data encapsulation channels for the transient source (i.e., all DownstreamJPState(S,*,VI) are set to NoInfo state). After reattaching and completing unicast handover negotiations, the mobile source can continue to transmit multicast packets, while being treated as a new source at its new DR (MAG). Source register encapsulation will be immediately initiated, and (S,G) data continue to flow natively down the (*,G) RP-based tree.

Source handover management in PIM phase one admits low complexity and remains transparent to receivers. In addition, the source register tunnel management of PIM is a fast protocol operation that introduces little overhead. In a PMIPv6 deployment, PIM RPs MAY be configured to uninitiated (S,G) shortest path trees for mobile sources, and thus remain in phase one of the protocol. The price to pay for such simplified deployment lies in possible routing detours by an overall RP-based packet distribution.

4.3.3. Operations of PIM in Phase Two (Register-Stop)

After receiving source register packets, a PIM RP eventually will initiate a source-specific Join for creating a shortest path tree to the (mobile) source S and issue a source register stop at the native arrival of data from S. For initiating an (S,G) tree, the RP, as well as all intermediate routers, require route entries for the HNP of the MN that -- unless the RP coincides with the MAG of S -- point towards the corresponding LMA of S. Consequently, the (S,G) tree will proceed from the RP via the (stable) LMA, down the LMA-MAG tunnel to the mobile source. This tree can be of lower routing efficiency than the PIM source register tunnel established in phase one.

On handover, the mobile source reattaches to a new MAG (DR), and PMIPv6 unicast management will transfer the LMA-MAG tunnel to the new point of attachment. However, in the absence of a corresponding multicast forwarding state, the new DR will treat S as a new source and initiate a source registering of PIM phase one with the RP. In

response, the PIM RP will recognize the known source at a new
(tunnel) interface and will immediately respond with a register stop.
As the RP had previously joined the shortest path tree towards the
source via the LMA, it will see an RPF change when data arrives at a
new interface. This is implementation dependent and can trigger an
update of the PIM MRIB as well as a new PIM Join message that will
install the multicast forwarding state missing at the new MAG.
Otherwise, the tree is periodically updated by Joins transmitted
towards the new MAG on a path via the LMA. In proceeding this way, a
quick recovery of PIM transition from phase one to two will be
performed per handover.

4.3.4. Operations of PIM in Phase Three (Shortest-Path Tree)

In response to an exceeded threshold of packet transmission, DRs of
receivers eventually will initiate a source-specific Join for
creating a shortest path tree to the (mobile) source S, thereby
transitioning PIM into the final shortcut phase three. For all
receivers not sharing a MAG with S, this (S,G) tree will range from
the receiving DR via the (stable) LMA, the LMA-MAG tunnel, and the
serving MAG to the mobile source. This tree is of higher routing
efficiency than that established in the previous phase two, but it
need not outperform the PIM source register tunnel established in
phase one. It provides the advantage of immediate data delivery to
receivers that share a MAG with S.

On handover, the mobile source reattaches to a new MAG (DR), and
PMIPv6 unicast management will transfer the LMA-MAG tunnel to the new
point of attachment. However, in the absence of a corresponding
multicast forwarding state, the new DR will treat S as a new source
and initiate a source registering of PIM phase one. A PIM
implementation compliant with this change can recover phase three
states in the following way. First, the RP recovers to phase two as
described in the previous section and will not forward data arriving
via the source register tunnel. Tree maintenance eventually
triggered by the RPF change (see Section 4.3.3) will generate proper
states for a native forwarding from the new MAG via the LMA.
Thereafter, packets arriving at the LMA without source register
encapsulation are forwarded natively along the shortest path tree
towards receivers.

In consequence, the PIM transitions from phase one to two to three
will be quickly recovered per handover but still lead to an enhanced
signaling load and intermediate packet loss.

4.3.5. PIM-SSM Considerations

Source-specific Joins of receivers will guide PIM to operate in SSM
mode and lead to an immediate establishment of source-specific
shortest path trees. Such (S,G) trees will equal the distribution
system of PIM's final phase three (see Section 4.3.4). However, on
handover and in the absence of RP-based data distribution, SSM data
delivery cannot be resumed via source registering as in PIM phase
one. Consequently, data packets transmitted after a handover will be
discarded at the MAG until regular tree maintenance has reestablished
the (S,G) forwarding state at the new MAG.

4.3.6. Handover Optimizations for PIM

Source-specific shortest path trees are constructed in PIM-SM (phase
two and three) and in PIM-SSM. These RPF-trees traverse LMA-MAG
tunnels towards a source. As PIM remains unaware of source mobility
management, these trees invalidate under handovers with each tunnel
re-establishment at a new MAG. Regular tree maintenance of PIM will
recover the states, but it remains unsynchronized and too slow to
seamlessly preserve PIM data distribution services.

A method to quickly recover PIM (S,G) trees under handover SHOULD
synchronize multicast state maintenance with unicast handover
operations and can proceed as follows. On handover, an LMA reads all
(S,G) Join states from its corresponding tunnel interface and
identifies those source addresses S_i that match moving HNPs. After
re-establishing the new tunnel, it SHOULD associate the $(S_i,*)$ Join
states with the new tunnel endpoint and immediately trigger a state
maintenance (PIM Join) message. In proceeding this way, the source-
specific PIM states are transferred to the new tunnel endpoint and
propagated to the new MAG in synchrony with unicast handover
procedures.

4.4. BIDIR-PIM

BIDIR-PIM MAY be deployed in the access network for providing
multicast services in parallel to unicast routes. Throughout this
section, it is assumed that the PMIPv6 mobility domain is part of a
single BIDIR-PIM multicast routing domain with BIDIR-PIM routing
functions present at all MAGs and all LMAs. The PIM routing instance
at a MAG SHALL then serve as the Designated Forwarder (DF) for all
directly attached Mobile Nodes. For expediting handover operations,
it is advisable to position BIDIR-PIM Rendezvous Point Addresses
(RPAs) in the core of the PMIPv6 network domain. As regular IP
routing tables need not be present in a PMIPv6 deployment, reverse
path forwarding rules as required by BIDIR-PIM need to be
established.

4.4.1. Routing Information Base for BIDIR-PIM

   In this scenario, BIDIR-PIM will rely on a Multicast Routing
   Information Base (MRIB) that is generated independently of the
   policy-based routing rules of PMIPv6. The following information is
   needed.

   o All routes to networks and nodes (including RPAs) that are not
      mobile members of the PMIPv6 domain MUST be defined consistently
      among BIDIR-PIM routers and remain unaffected by node mobility.
      The setup of these general routes is expected to follow the
      topology of the operator network and is beyond the scope of this
      document.

4.4.2. Operations of BIDIR-PIM

   BIDIR-PIM will establish spanning trees across its network domain in
   conformance to its pre-configured RPAs and the routing information
   provided. Multicast data transmitted by a mobile source will
   immediately be forwarded by its DF (MAG) onto the spanning tree for
   the multicast group without further protocol operations.

   On handover, the mobile source reattaches to a new MAG (DF), which
   completes unicast network configurations. Thereafter, the source can
   immediately proceed with multicast packet transmission onto the pre-
   established distribution tree. BIDIR-PIM does not require protocol
   signaling or additional reconfiguration delays to adapt to source
   mobility, and it can be considered the protocol of choice for mobile
   multicast operations in the access network. As multicast streams
   always flow up to the Rendezvous Point Link, some care should be
   taken to configure RPAs compliant with network capacities.

5. MLD Proxy Peering Function for Optimized Source Mobility in PMIPv6

   A deployment of MLD proxies (see [RFC4605]) at MAGs has proven a
   useful and appropriate approach to multicast in PMIPv6; see [RFC6224]
   and [RFC7028]. However, deploying unmodified standard proxies can go
   along with significant performance degradation for mobile senders as
   discussed in this document. To overcome these deficits, an optimized
   approach to multicast source mobility based on extended peering
   functions among proxies is defined in this section. Based on such
   direct data exchange between proxy instances at MAGs, triangular
   routing is avoided and multicast streams can be disseminated directly
   within a PMIPv6 access network, and in particular within MAG routing
   machines. Prior to presenting the solution, we will summarize the
   relevant requirements.

5.1. Requirements

   Solutions that extend MLD proxies by additional uplinking functions
   need to comply to the following requirements.

   Prevention of routing loops
      In the absence of a full-featured routing logic at an MLD proxy,
      simple and locally decidable rules need to prevent source traffic
      from traversing the network in loops that would be potentially
      enabled by multiple uplinks.

   Unique coverage of receivers
      Listener functions at proxies require simple, locally decidable
      rules to initiate a unique delivery of multicast packets to all
      receivers.

   Following local filtering techniques, these requirements are met in
   the following solution.

5.2. Overview

   A peering interface for MLD proxies allows for a direct data exchange
   of locally attached multicast sources. Such peering interfaces can
   be configured -- as a direct link or a bidirectional tunnel --
   between any two proxy instances (locally deployed as in [RFC6224] or
   remotely deployed). Peerings remain as silent virtual links in
   regular proxy operations. Data is exchanged on such links only in
   cases where one peering proxy on its downstream directly connects to
   a source of multicast traffic to which the other peering proxy
   actively subscribes. In such cases, the proxy connected to the
   source will receive a listener report on its peering interface and
   will forward traffic from its local source accordingly. It is worth
   noting that multicast traffic distribution on peering links does not
   follow reverse unicast paths to sources. In the following,
   operations are defined for Any-Source Multicast (ASM) and SSM, but
   they provide superior performance in the presence of source-specific
   signaling (IGMPv3/MLDv2) [RFC4604].

5.3. Operations in Support of Multicast Senders

   An MLD proxy with the perspective of a sender will see peering
   interfaces as restricted downstream interfaces. It will install and
   maintain source filters at its peering links that will restrict data
   transmission to those packets that originate from a source that is
   locally attached at one of its downstream interfaces.

In detail, a proxy will extract from its configuration the network
prefixes attached to its downstream interfaces and MUST implement a
source filter base at its peering interfaces that restricts data
transmission to IP source addresses from its local prefixes. This
filter base MUST be updated if and only if the downstream
configuration changes (e.g., due to mobility). Multicast packets
that arrive from the upstream interface of the proxy are thus
prevented from traversing any peering link, but they are only
forwarded to regular downstream interfaces with appropriate
subscription states. In this way, multihop forwarding on peering
links is prevented.

Multicast traffic arriving from a locally attached source will be
forwarded to the regular upstream interface and all downstream
interfaces with appropriate subscription states (i.e., regular proxy
operations). In addition, multicast packets of local origin are
transferred to those peering interfaces with appropriate subscription
states.

5.4. Operations in Support of Multicast Listeners

On the listener side, peering interfaces appear as preferred upstream
links. The multicast proxy will attempt to receive multicast
services on peering links for as many groups (channels) as possible.
The general upstream interface configured according to [RFC4605] will
be used only for retrieving those groups (channels) that remain
unavailable from peerings. From this extension of [RFC4605], an MLD
proxy with peering interconnects will exhibit several interfaces for
pulling remote traffic: the regular upstream and the peerings.
Traffic available from any of the peering links will be mutually
disjoint but normally also available from the upstream. To prevent
duplicate traffic from arriving at the listener side, the proxy

o MAY delay aggregated reports to the upstream, and

o MUST apply appropriate filters to exclude duplicate streams.

In detail, an MLD proxy instance at a MAG first issues listener
reports (in parallel) to all of its peering links. These links span
at most one (virtual) hop. Whenever certain group traffic (SSM
channels) does not arrive from the peerings after a waiting time
(default: 10 ms (node-local) and 25 ms (remote)), additional reports
(complementary reports, in the case of SSM) are sent to the standard
upstream interface.

Whenever traffic from a peering link arrives, an MLD proxy MUST
install source filters at its upstream interfaces (as described in
RFC 4605) in the following way.

ASM with IGMPv2/MLDv1: In the presence of ASM using IGMPv2/MLDv1,
    only, the proxy cannot signal source filtering to its upstream.
    Correspondingly, it applies (S,*) ingress filters at its upstream
    interface for all sources S seen in traffic on the peering links.
    It is noteworthy that unwanted traffic is still replicated to the
    proxy via the (wired) provider backbone, but it is not forwarded
    into the wireless access network.

ASM with IGMPv3/MLDv2: In the presence of source-specific signaling
    (IGMPv3/MLDv2), the upstream interface is set to (S,*) exclude
    mode for all sources S seen in traffic of the peering links. The
    corresponding source-specific signaling will prevent forwarding of
    duplicate traffic throughout the access network.

SSM: In the presence of Source-Specific Multicast, the proxy will
    subscribe on its uplink interface to those (S,G) channels, only,
    that do not arrive via the peering links.

MLD proxies will install data-driven timers (source-timeout) for each
source but common to all peering interfaces to detect interruptions
of data services from individual sources at proxy peers. Termination
of source-specific flows may be application specific, but also may be
due to a source handover or a transmission failure. After a
handover, a mobile source may reattach at another MLD proxy with a
peering relation to the listener, or at a proxy that does not peer.
While in the first case, traffic reappears on another peering link;
in the second case, data can only be retrieved via the regular
upstream. To account for the latter, the MLD proxy revokes the
source-specific filter(s) at its upstream interface, after the
source-timeout expires (default: 50 ms). Corresponding traffic will
then be pulled from the regular upstream interface. Source-specific
filters MUST be reinstalled whenever traffic of this source arrives
at any peering interface.

There is a noteworthy trade-off between traffic minimization and
available traffic at the upstream that is locally filtered at the
proxy. Implementors can use this relation to optimize for service-
specific requirements.

In proceeding this way, multicast group data will arrive from peering
interfaces first, while only peer-wise unavailable traffic is
retrieved from the regular upstream interface.

6. Security Considerations

   This document defines multicast sender mobility based on PMIPv6 and
   common multicast routing protocols. Consequently, threats identified
   as security concerns in [RFC2236], [RFC2710], [RFC3810], [RFC4605],
   [RFC5213], and [RFC5844] are inherited by this document.

   In addition, particular attention should be paid to implications of
   combining multicast and mobility management at network entities. As
   this specification allows mobile nodes to initiate the creation of
   multicast forwarding states at MAGs and LMAs while changing
   attachments, threats of resource exhaustion at PMIP routers and
   access networks arise from rapid state changes, as well as from high-
   volume data streams routed into access networks of limited
   capacities. In cases of PIM-SM deployment, handover operations of
   the MNs include re-registering sources at the Rendezvous Points at
   possibly high frequency. In addition to proper authorization checks
   of MNs, rate controls at routing agents and replicators may be needed
   to protect the agents and the downstream networks. In particular,
   MLD proxy implementations at MAGs SHOULD automatically erase
   multicast state on the departure of MNs, as mobile multicast
   listeners in the PMIPv6 domain will in general not actively terminate
   group membership prior to departure.

   The deployment of IGMP/MLD proxies for multicast routing requires
   particular care, as routing loops on the upstream are not
   automatically detected. Peering functions between proxies extend
   this threat in the following way. Routing loops among peering and
   upstream interfaces are prevented by filters on local sources. Such
   filtering can fail whenever prefix configurations for downstream
   interfaces at a proxy are incorrect or inconsistent. Consequently,
   implementations of peering-enabled proxies SHOULD take particular
   care on keeping IP configurations consistent at the downstream in a
   reliable and timely manner. (See [RFC6224] for requirements on
   PMIPv6-compliant implementations of MLD proxies.)

7. Acknowledgements

8. References

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Appendix A. Multiple Upstream Interface Proxy

    In this section, we document upstream extensions for an MLD proxy
    that were originally developed during the work on this document.
    Multiple proxy instances deployed at a single MAG (see Section 3) can
    be avoided by adding multiple upstream interfaces to a single MLD
    proxy. In a typical PMIPv6 deployment, each upstream interface of a
    single proxy instance can interconnect to one of the LMAs. With such
    ambiguous upstream options, appropriate forwarding rules MUST be
    supplied to

    o unambiguously guide traffic forwarding from directly attached
       mobile sources, and

    o lead listener reports to initiating unique traffic subscriptions.

    This can be achieved by a complete set of source- and group-specific
    filter rules (e.g., (S,*), (*,G)) installed at proxy interfaces.
    These filters MAY be derived in part from PMIPv6 routing policies and
    can include a default behavior (e.g., (*,*)).

A.1. Operations for Local Multicast Sources

    Packets from a locally attached multicast source will be forwarded to
    all downstream interfaces with appropriate subscriptions, as well as
    up the interface with the matching source-specific filter.

    Typically, the upstream interface for a mobile multicast source is
    chosen based on the policy routing (e.g., the MAG-LMA tunnel
    interface for LMA-based routing or the interface towards the
    multicast router for direct routing), but alternate configurations
    MAY be applied. Packets from a locally attached multicast source
    will be forwarded to the corresponding upstream interface with the
    matching source-specific filter, as well as all the downstream
    interfaces with appropriate subscriptions.

A.2. Operations for Local Multicast Subscribers

    Multicast listener reports are group-wise aggregated by the MLD
    proxy. The aggregated report is issued to the upstream interface
    with a matching group/channel-specific filter. The choice of the
    corresponding upstream interface for aggregated group membership
    reports MAY be additionally based on some administrative scoping
    rules for scoped multicast group addresses.

    In detail, a Multiple Upstream Interface proxy will provide and
    maintain a Multicast Subscription Filter Table that maps source- and
    group-specific filters to upstream interfaces. The forwarding

decision for an aggregated MLD listener report is based on the first
matching entry from this table, with the understanding that for
IGMPv3/MLDv2 the MLD proxy performs a state decomposition, if needed
(i.e., a (*,G) subscription is split into (S,G) and (* \ S,G) in the
presence of (*,G) after (S,G) interface entries), and that
(S,*)-filters are always false in the absence of source-specific
signaling, i.e., in IGMPv2/MLDv1 only domains.

In typical deployment scenarios, specific group services (channels)
are either

o   associated with selected uplinks to remote LMAs, while a (*,*)
    default subscription entry (in the last table line) is bound to a
    local routing interface, or

o   configured as local services first, while a (*,*) default entry
    (in the last table line) points to a remote uplink that provides
    the general multicast support.

Appendix B. Implementation

An implementation of the extended IGMP/MLD proxy has been provided
within the MCPROXY project (http://mcproxy.realmv6.org/). This open-
source software is written in C++ and uses forwarding capabilities of
the Linux kernel. It supports all regular operations according to
[RFC4605] and allows for multiple proxy instances on one node,
dynamically changing downstream links, proxy-to-proxy peerings, and
multiple upstream links with individual configurations. The software
can be downloaded from GitHub at
<https://github.com/mcproxy/mcproxy>. Based on this software, an
experimental performance evaluation of the proxy peering function has
been reported in [PEERING-ANALYSIS].

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