Internet Engineering Task Force (IETF)
Request for Comments: 6224
Category: Informational
ISSN: 2070-1721
T. Schmidt
HAW Hamburg
M. Waehlisch
link-lab & FU Berlin
S. Krishnan
Ericsson
April 2011

# Base Deployment for Multicast Listener Support in Proxy Mobile IPv6 (PMIPv6) Domains

## Abstract

This document describes deployment options for activating multicast listener functions in Proxy Mobile IPv6 domains without modifying mobility and multicast protocol standards. Similar to home agents in Mobile IPv6, Local Mobility Anchors of Proxy Mobile IPv6 serve as multicast subscription anchor points, while Mobile Access Gateways provide Multicast Listener Discovery (MLD) proxy functions. In this scenario, mobile nodes remain agnostic of multicast mobility operations. Support for mobile multicast senders is outside the scope of this document.

## Status of This Memo

Table of Contents

1. Introduction . . . . . . . . . . . . . . . . . . . . . . . . 3
2. Terminology . . . . . . . . . . . . . . . . . . . . . . . . 3
3. Overview . . . . . . . . . . . . . . . . . . . . . . . . . . 4
4. Deployment Details . . . . . . . . . . . . . . . . . . . . . 8
4.1. Operations of the Mobile Node . . . . . . . . . . . . . . 8
4.2. Operations of the Mobile Access Gateway . . . . . . . . . 8
4.3. Operations of the Local Mobility Anchor . . . . . . . . . 10
4.4. IPv4 Support . . . . . . . . . . . . . . . . . . . . . . 10
4.5. Multihoming Support . . . . . . . . . . . . . . . . . . . 11
4.6. Multicast Availability throughout the Access Network . . . 12
4.7. A Note on Explicit Tracking . . . . . . . . . . . . . . . 12
5. Message Source and Destination Address . . . . . . . . . . . 13
5.1. Query . . . . . . . . . . . . . . . . . . . . . . . . . . 13
5.2. Report/Done . . . . . . . . . . . . . . . . . . . . . . . 13
6. Security Considerations . . . . . . . . . . . . . . . . . . 13
7. Acknowledgements . . . . . . . . . . . . . . . . . . . . . . 14
8. References . . . . . . . . . . . . . . . . . . . . . . . . . 14
8.1. Normative References . . . . . . . . . . . . . . . . . . 14
8.2. Informative References . . . . . . . . . . . . . . . . . 15
Appendix A. Initial MLD Queries on Upcoming Links . . . . . . . . 16
Appendix B. State of IGMP/MLD Proxy Implementations . . . . . . . 16
Appendix C. Comparative Evaluation of Different Approaches . . . 17

## 1. Introduction

Proxy Mobile IPv6 (PMIPv6) [RFC5213] extends Mobile IPv6 (MIPv6) [RFC3775] 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 the Local Mobility Anchor (LMA) and Mobile Access Gateways (MAGs), are responsible for managing IP mobility on behalf of the mobile node (MN).

With these entities in place, the mobile node experiences an exceptional access topology towards the static Internet in the sense that the MAG introduces a routing hop in situations where the LMA architecturally acts as the next hop (or designated) router for the MN. In the particular case of multicast communication, group membership management, as signaled by the Multicast Listener Discovery (MLD) protocol [RFC3810] [RFC2710], requires dedicated treatment at the network side.

Multicast routing functions need to be placed carefully within the PMIPv6 domain in order to augment unicast transmission with group communication services. [RFC5213] does not explicitly address multicast communication. Bidirectional home tunneling, the minimal multicast support arranged by MIPv6, cannot be directly transferred to network-based management scenarios, since a mobility-unaware node will not initiate such a tunnel after movement. Consequently, even minimal multicast listener support in PMIPv6 domains requires an explicit deployment of additional functions.

This document describes options for deploying multicast listener functions in Proxy Mobile IPv6 domains without modifying mobility and multicast protocol standards. Similar to home agents in Mobile IPv6, PMIPv6 Local Mobility Anchors serve as multicast subscription anchor points, while Mobile Access Gateways provide MLD proxy functions. In this scenario, mobile nodes remain agnostic of multicast mobility operations. This document does not address specific optimizations and efficiency improvements of multicast routing for network-based mobility discussed in [RFC5757], as such solutions would require changes to the base PMIPv6 protocol [RFC5213]. Support for mobile multicast senders is also outside the scope of this document.

## 2. Terminology

This document uses the terminology as defined for the mobility protocols [RFC3775], [RFC5213], and [RFC5844], as well as the multicast edge related protocols [RFC3376], [RFC3810], and [RFC4605].





## 3. Overview

The reference scenario for multicast deployment in Proxy Mobile IPv6 domains is illustrated in Figure 1. Below, LMAA and MN-HNP are the LMA Address and Mobile Node's Home Network Prefix as defined in [RFC5213].

```
                       +-------------+
                       | Content     |
                       | Source      |
                       +-------------+
                              |
                     ***  ***  ***  ***
                    *   **   **   **   *
                   *                    *
                    *  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
```

Figure 1: Reference Network for Multicast Deployment in PMIPv6

An MN in a PMIPv6 domain will decide on multicast group membership management completely independent of its current mobility conditions. It will submit MLD Report and Done messages, based on application triggers, using its link-local source address and multicast destination addresses according to [RFC3810] or [RFC2710]. These





link-local signaling messages will arrive at the currently active MAG via one of its downstream local (wireless) links. A multicast-unaware MAG would simply discard these MLD messages.

To facilitate multicast in a PMIPv6 domain, an MLD proxy function [RFC4605] needs to be deployed on the MAG that selects the tunnel interface corresponding to the MN's LMA for its upstream interface (cf., Section 6 of [RFC5213]). Thereby, each MAG-to-LMA tunnel interface defines an MLD proxy domain at the MAG, and it contains all downstream links to MNs that share this specific LMA. According to standard proxy operations, MLD Report messages will be aggregated and then forwarded up the tunnel interface to the MN's corresponding LMA.

Serving as the designated multicast router or an additional MLD proxy, the LMA will transpose any MLD message from a MAG into the multicast routing infrastructure. Correspondingly, the LMA will create appropriate multicast forwarding states at its tunnel interface. Traffic of the subscribed groups will arrive at the LMA, and the LMA will forward this traffic according to its group/source states. In addition, the LMA will act as an MLD querier, seeing its downstream tunnel interfaces as multicast-enabled links.

At the MAG, MLD queries and multicast data will arrive on the (tunnel) interface that is assigned to a group of access links as identified by its Binding Update List (cf., Section 6.1 of [RFC5213]). As specified for MLD proxies, the MAG will forward multicast traffic and initiate related signaling down the appropriate access links to the MNs. Hence, all multicast-related signaling and the data traffic will transparently flow from the LMA to the MN on an LMA-specific tree, which is shared among the multicast sources.

In case of a handover, the MN (unaware of IP mobility) will not send unsolicited MLD reports. Instead, the MAG is required to maintain group memberships in the following way. On observing a new MN on a downstream access link, the MAG sends a MLD General Query. Based on its outcome and the multicast group states previously maintained at the MAG, a corresponding Report will be sent to the LMA aggregating group membership states according to the proxy function. Additional Reports can be omitted when the previously established multicast forwarding states at the new MAG already cover the subscriptions of the MN.

In summary, the following steps are executed on handover:

1. The MAG-MN link comes up and the MAG discovers the new MN.

2. Unicast address configuration and PMIPv6 binding are performed after the MAG determines the corresponding LMA.





3. Following IPv6 address configuration, the MAG should send an (early) MLD General Query to the new downstream link as part of its standard multicast-enabled router operations.

4. The MAG should determine whether the MN is admissible to multicast services; if it's not, then stop here.

5. The MAG adds the new downstream link to the MLD proxy instance with up-link to the corresponding LMA.

6. The corresponding proxy instance triggers an MLD General Query on the new downstream link.

7. The MN Membership Reports arrive at the MAG, in response either to the early query or to the query sent by the proxy instance.

8. The Proxy processes the MLD Report, updates states, and reports upstream if necessary.

After Re-Binding, the LMA is not required to issue a MLD General Query on the tunnel link to refresh forwarding states. Multicast state updates should be triggered by the MAG, which aggregates subscriptions of all its MNs (see the call flow in Figure 2).





```
   MN1             MAG1             MN2             MAG2             LMA
   |                |                |                |                |
   |    Join(G)     |                |                |                |
   +--------------->|                |                |                |
   |                |     Join(G)    |                |                |
   |                |<---------------+                |                |
   |                |                |                |                |
   |                |     Aggregated Join(G)          |                |
```

```
   |                +================================================>|
   |                |                |               |                |
   |                |   Mcast Data   |               |                |
   |                |<================================================+
   |                |                |               |                |
   |  Mcast Data    | Mcast Data     |               |                |
   |<---------------+--------------->|               |                |
   |                |                |               |                |
   |           <  Movement of MN 2 to MAG2  &  PMIP Binding Update  > |
   |                |                |               |                |
   |                |                |--- Rtr Sol -->|                |
   |                |                |<-- Rtr Adv ---|                |
   |                |                |               |                |
   |                |                |   MLD Query   |                |
   |                |                |<--------------+                |
   |                |                |               |                |
   |                |                |   Join(G)     |                |
   |                |                +-------------->|                |
   |                |                |               Aggregated Join(G)
   |                |                |               +===============>|
   |                |                |               |                |
   |                |   Mcast Data   |               |                |
   |                |<================================================+
   |                |                |               |   Mcast Data   |
   |                |                |               |<===============+
   |  Mcast Data    |                |               |                |
   |<---------------+                |  Mcast Data   |                |
   |                |                |<--------------+                |
   |                |                |               |                |
```

Figure 2: Call Flow of Multicast-Enabled PMIP
with "MLD Membership Report" Abbreviated by "Join"

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]. Such mobile nodes will use IGMP [RFC2236] [RFC3376] signaling for multicast, which is handled by an IGMP proxy function at the MAG in an analogous way.





Following these deployment steps, multicast management transparently interoperates with PMIPv6. It is worth noting that MNs -- while being attached to the same MAG, but associated with different LMAs -- can subscribe to the same multicast group. Thereby, data could be distributed redundantly in the network and duplicate traffic could arrive at a MAG. Additionally, in a point-to-point wireless link model, a MAG might be forced to transmit the same data over one wireless domain to different MNs. However, multicast traffic arriving at one interface of the MN will always remain unique, i.e., the mobile multicast distribution system will never cause duplicate packets arriving at an MN (see Appendix C for further considerations).

## 4. Deployment Details

Multicast activation in a PMIPv6 domain requires to deploy general multicast functions at PMIPv6 routers and to define their interaction with the PMIPv6 protocol in the following way.

### 4.1. Operations of the Mobile Node

A mobile node willing to manage multicast traffic will join, maintain, and leave groups as if located in the fixed Internet. No specific mobility actions nor implementations are required at the MN.

### 4.2. Operations of the Mobile Access Gateway

A Mobile Access Gateway is required to assist in MLD signaling and data forwarding between the MNs that it serves and the corresponding LMAs associated to each MN. It therefore needs to implement an instance of the MLD proxy function [RFC4605] for each upstream tunnel interface that has been established with an LMA. The MAG decides on the mapping of downstream links to a proxy instance (and hence an upstream link to an LMA) based on the regular Binding Update List as maintained by PMIPv6 standard operations (cf., Section 6.1 of [RFC5213]). As links connecting MNs and MAGs change under mobility, MLD proxies at MAGs must be able to dynamically add and remove downstream interfaces in their configurations.

On the reception of MLD reports from an MN, the MAG must identify the corresponding proxy instance from the incoming interface and perform regular MLD proxy operations: it will insert/update/remove multicast forwarding state on the incoming interface and will merge state updates into the MLD proxy membership database. It will then send an aggregated Report via the upstream tunnel to the LMA when the membership database (cf., Section 4.1 of [RFC4605]) changes. Conversely, on the reception of MLD queries, the MAG proxy instance will answer the Queries on behalf of all active downstream receivers maintained in its membership database. Queries sent by the LMA do not force the MAG to trigger corresponding messages immediately towards MNs. Multicast traffic arriving at the MAG on an upstream interface will be forwarded according to the group-specific or source-specific forwarding states as acquired for each downstream interface within the MLD proxy instance. At this stage, it is important to note that IGMP/MLD proxy implementations capable of multiple instances are expected to closely follow the specifications of Section 4.2 in [RFC4605], i.e., treat proxy instances in isolation of each other while forwarding. In providing isolated proxy instances, the MAG will uniquely serve its downstream links with exactly the data that belong to whatever group is subscribed on the particular interface.

After a handover, the MAG will continue to manage upstream tunnels and downstream interfaces as specified in the PMIPv6 specification. It must dynamically associate new access links to proxy instances that include the upstream connection to the corresponding LMA. The MAG detects the arrival of a new MN by receiving a router solicitation message and by an upcoming link. To learn about multicast groups subscribed by a newly attaching MN, the MAG should send a General Query to the MN's link. Querying an upcoming interface is a standard operation of MLD queriers (see Appendix A) and is performed immediately after address configuration. In addition, an MLD query should be initiated by the proxy instance, as soon as a new interface has been configured for downstream. In case the access link between MN and MAG goes down, interface-specific multicast states change. Both cases may alter the composition of the membership database and this will trigger corresponding Reports towards the LMA. Note that the actual observable state depends on the access link model in use.

An MN may be unable to answer MAG multicast membership queries due to handover procedures, or its report may arrive before the MAG has configured its link as the proxy downstream interface. Such occurrences are equivalent to a General Query loss. To prevent erroneous query timeouts at the MAG, MLD parameters should be carefully adjusted to the mobility regime. In particular, MLD timers and the Robustness Variable (see Section 9 of [RFC3810]) should be chosen to be compliant with the time scale of handover operations and proxy configurations in the PMIPv6 domain.

In proceeding this way, the MAG is able to aggregate multicast subscriptions for each of its MLD proxy instances. However, this deployment approach does not prevent multiple identical streams arriving from different LMA upstream interfaces. Furthermore, a multipoint channel forwarding into the wireless domain is prevented by the point-to-point link model in use.





### 4.3. 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 querier for the corresponding MAG. It implements the function of the designated multicast router or a further MLD proxy. According to MLD reports received from a MAG (on behalf of the MNs), the LMA establishes/maintains/removes group-/source-specific multicast forwarding states at its corresponding downstream tunnel interfaces. At the same time, it procures for aggregated multicast membership maintenance at its upstream interface. Based on the multicast-transparent operations of the MAGs, the LMA treats its tunnel interfaces as multicast-enabled downstream links, serving zero to many listening nodes. Multicast traffic arriving at the LMA is transparently forwarded according to its multicast forwarding information base.

After a handover, the LMA will receive Binding De-Registrations and Binding Lifetime Extensions that will cause a re-mapping of home network prefix(es) to a new Proxy-CoA in its Binding Cache (see Section 5.3 of [RFC5213]). The multicast forwarding states require updating, as well, if the MN within an MLD proxy domain is the only receiver of a multicast group. Two different cases need to be considered:

1. The mobile node is the only receiver of a group behind the interface at which a De-Registration was received: the membership database of the MAG changes, which will trigger a Report/Done sent via the MAG-to-LMA interface to remove this group. The LMA thus terminates multicast forwarding.

2. The mobile node is the only receiver of a group behind the interface at which a Lifetime Extension was received: the membership database of the MAG changes, which will trigger a Report sent via the MAG-to-LMA interface to add this group. The LMA thus starts multicast distribution.

In proceeding this way, each LMA will provide transparent multicast support for the group of MNs it serves. It will perform traffic aggregation at the MN-group level and will assure that multicast data streams are uniquely forwarded per individual LMA-to-MAG tunnel.

### 4.4. IPv4 Support

An MN in a PMIPv6 domain may use an IPv4 address transparently for communication as specified in [RFC5844]. For this purpose, LMAs can register IPv4-Proxy-CoAs in its Binding Caches, and MAGs can provide IPv4 support in access networks. 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 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.

A particular note is worth giving the scenario of [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.

MLD/IGMP signaling between MNs and the MAG is on point-to-point links (identical to unicast). Aggregated MLD/IGMP signaling between the MAG proxy instance and the LMA remains link-local between the routers and independent of any individual MN. So the MAG-proxy and the LMA should not use GRE key identifiers, but plain GRE to exchange MLD queries and reports. Similarly, multicast traffic sent from an LMA to MAGs proceeds as router-to-router forwarding according to the multicast forwarding information base (MFIB) of the LMA and independent of MN's unicast addresses, while the MAG proxy instance distributes multicast data down the point-to-point links (interfaces) according to its own MFIB, independent of MN's IP addresses.

It remains an open issue how communication proceeds in a multi-operator scenario, i.e., from which network the LMA pulls multicast traffic. This could be any mobility Operator itself, or a third party. However, this backbone routing in general is out of scope of the document, and most likely a matter of contracts.

## 4.5. Multihoming Support

An MN can connect to a PMIPv6 domain through multiple interfaces and experience transparent unicast handovers at all interfaces (cf., Section 5.4 of [RFC5213]). In such simultaneous access scenarios, it can autonomously assign multicast channel subscriptions to individual interfaces (see [RFC5757] for additional details). While doing so,





multicast mobility operations described in this document will transparently preserve the association of channels to interfaces in the following way.

Multicast listener states are kept per interface in the MLD state table. An MN will answer to an MLD General Query received on a specific (re-attaching) interface according to the specific interface's state table. Thereafter, multicast forwarding is resumed for channels identical to those under subscription prior to handover. Consequently, an MN in a PMIPv6 domain may use multiple interfaces to facilitate load balancing or redundancy, but cannot follow a 'make-before-break' approach to service continuation on handovers.

## 4.6. Multicast Availability throughout the Access Network

There may be deployment scenarios where multicast services are available throughout the access network, independent of the PMIPv6 infrastructure. Direct multicast access at MAGs may be supported through native multicast routing within a flat access network that includes a multicast router, via dedicated (tunnel or VPN) links between MAGs and designated multicast routers, or by deploying Automatic Multicast Tunneling (AMT) [AUTO-MULTICAST].

Multicast deployment can be simplified in these scenarios. A single proxy instance at MAGs with up-link to the multicast cloud, for instance, could serve group communication purposes. MAGs could operate as general multicast routers or AMT gateways as well.

Common to these solutions is that mobility management is covered by the dynamics of multicast routing, as initially foreseen in the Remote Subscription approach, i.e., join via a local multicast router as sketched in [RFC3775]. Care must be taken to avoid avalanche problems or service disruptions due to tardy multicast routing operations and to adapt to different link-layer technologies [RFC5757]. The different possible approaches should be carefully investigated beyond the initial sketch in Appendix C. Such work is beyond the scope of this document.

### 4.7. A Note on Explicit Tracking

An IGMPv3/MLDv2 Querier may operate in combination with explicit tracking as described in Appendix A.2 of [RFC3376], or Appendix A.2 of [RFC3810]. This mechanism allows routers to monitor each multicast receiver individually. Even though this procedure is not standardized yet, it is widely implemented by vendors as it supports faster leave latencies and reduced signaling.





Enabling explicit tracking on downstream interfaces of the LMA and MAG would track a single MAG and MN respectively per interface. It may be used to preserve bandwidth on the MAG-MN link.

## 5. Message Source and Destination Address

This section describes source and destination addresses of MLD messages and encapsulating outer headers when deployed in the PMIPv6 domain. This overview is for clarification purposes only and does not define a behavior different from referenced standards in any way.

The interface identifier A-B denotes an interface on node A, which is connected to node B. This includes tunnel interfaces. Destination addresses for MLD/IGMP messages shall be as specified in Section 8 of [RFC2710] for MLDv1, and Sections 5.1.15 and 5.2.14 of [RFC3810] for MLDv2.

### 5.1. Query

| Interface | Source Address | Destination Address | Header |
|---|---|---|---|
| LMA-MAG | LMAA | Proxy-CoA | outer |
| | LMA-link-local | [RFC2710], [RFC3810] | inner |
| MAG-MN | MAG-link-local | [RFC2710], [RFC3810] | -- |

## 5.2. Report/Done

| Interface | Source Address | Destination Address | Header |
|---|---|---|---|
| MN-MAG | MN-link-local | [RFC2710], [RFC3810] | -- |
| MAG-LMA | Proxy-CoA | LMAA | outer |
| | MAG-link-local | [RFC2710], [RFC3810] | inner |

# 6. Security Considerations

This document does not introduce additional messages or novel protocol operations. Consequently, no additional threats are introduced by this document beyond those identified as security concerns of [RFC3810], [RFC4605], [RFC5213], and [RFC5844].





However, 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 arrive from rapid state changes, as well as from high-volume data streams routed into access networks of limited capacities. In addition to proper authorization checks of MNs, rate controls at replicators may be required to protect the agents and the downstream networks. In particular, MLD proxy implementations at MAGs should carefully procure automatic multicast state extinction on the departure of MNs, as mobile multicast listeners in the PMIPv6 domain will not actively terminate group membership prior to departure.

## 7. Acknowledgements

This memo follows initial requirements work presented in "Multicast Support Requirements for Proxy Mobile IPv6" (July 2009), and is the outcome of extensive previous discussions and a follow-up of several initial documents on the subject. The authors would like to thank (in alphabetical order) Jari Arkko, Luis M. Contreras, Greg Daley, Gorry Fairhurst, Dirk von Hugo, Liu Hui, Seil Jeon, Jouni Korhonen, Guang Lu, Sebastian Meiling, Akbar Rahman, Imed Romdhani, Behcet Sarikaya, Pierrick Seite, Stig Venaas, and Juan Carlos Zuniga for advice, help, and reviews of the document. Funding by the German Federal Ministry of Education and Research within the G-LAB Initiative is gratefully acknowledged.

## 8. References

### 8.1. Normative References

[RFC2710] Deering, S., Fenner, W., and B. Haberman, "Multicast Listener Discovery (MLD) for IPv6", RFC 2710, October 1999.

[RFC3376] Cain, B., Deering, S., Kouvelas, I., Fenner, B., and A. Thyagarajan, "Internet Group Management Protocol, Version 3", RFC 3376, October 2002.

[RFC3775] Johnson, D., Perkins, C., and J. Arkko, "Mobility Support in IPv6", RFC 3775, June 2004.

[RFC3810] Vida, R. and L. Costa, "Multicast Listener Discovery Version 2 (MLDv2) for IPv6", RFC 3810, June 2004.





[RFC4605] Fenner, B., He, H., Haberman, B., and H. Sandick, "Internet Group Management Protocol (IGMP) / Multicast Listener Discovery (MLD)-Based Multicast Forwarding ("IGMP/MLD Proxying")", RFC 4605, August 2006.

[RFC5213] Gundavelli, S., Leung, K., Devarapalli, V., Chowdhury, K., and B. Patil, "Proxy Mobile IPv6", RFC 5213, August 2008.

[RFC5844] Wakikawa, R. and S. Gundavelli, "IPv4 Support for Proxy Mobile IPv6", RFC 5844, May 2010.

## 8.2. Informative References

[AUTO-MULTICAST] Thaler, D., Talwar, M., Aggarwal, A., Vicisano, L., and T. Pusateri, "Automatic IP Multicast Without Explicit Tunnels (AMT)", Work in Progress, March 2010.

[RFC2236] Fenner, W., "Internet Group Management Protocol, Version 2", RFC 2236, November 1997.

[RFC5757] Schmidt, T., Waehlisch, M., and G. Fairhurst, "Multicast Mobility in Mobile IP Version 6 (MIPv6): Problem Statement and Brief Survey", RFC 5757, February 2010.

[RFC5845] Muhanna, A., Khalil, M., Gundavelli, S., and K. Leung, "Generic Routing Encapsulation (GRE) Key Option for Proxy Mobile IPv6", RFC 5845, June 2010.

## Appendix A. Initial MLD Queries on Upcoming Links

According to [RFC3810] and [RFC2710], when an IGMP-/MLD-enabled multicast router starts operating on a subnet, by default it considers itself as querier and sends several General Queries. Such initial query should be sent by the router immediately, but could be delayed by a (tunable) Startup Query Interval (see Sections 7.6.2 and 9.6 of [RFC3810]).

Experimental tests on Linux and Cisco systems have revealed immediate IGMP Queries followed a link trigger event (within a fraction of 1 ms), while MLD queries immediately followed the autoconfiguration of IPv6 link-local addresses at the corresponding interface.

## Appendix B. State of IGMP/MLD Proxy Implementations

The deployment scenario defined in this document requires certain proxy functionalities at the MAGs that implementations of [RFC4605] need to contribute. In particular, a simultaneous support of IGMP and MLD is needed, as well as a configurable list of downstream interfaces that may be altered during runtime, and the deployment of multiple proxy instances at a single router that can operate independently on separated interfaces.

A brief experimental trial undertaken in February 2010 revealed the following divergent statuses of selected IGMP/MLD proxy implementations.

Cisco Edge Router: Software-based commodity edge routers (test device from the 26xx-Series) implement IGMPv2/v3 proxy functions only in combination with Protocol Independent Multicast - Sparse Mode (PIM-SM). There is no support of MLD proxy. Interfaces are dynamically configurable at runtime via the command line interface, but multiple proxy instances are not supported.

Linux igmpproxy: IGMPv2 Proxy implementation that permits a static configuration of downstream interfaces (simple bug fix required). Multiple instances are prevented by a lock (corresponding code reused from a previous Distance Vector Multicast Routing Protocol (DVMRP) implementation). IPv6/MLD is unsupported. Project page: http://sourceforge.net/projects/igmpproxy/.

Linux gproxy: IGMPv3 Proxy implementation that permits configuration of the upstream interface, only. Downstream interfaces are collected at startup without dynamic extension of this list. No support of multiple instances or MLD.

Linux ecmh: MLDv1/2 Proxy implementation without IGMP support that inspects IPv4 tunnels and detects encapsulated MLD messages. Allows for dynamic addition of interfaces at runtime and multiple instances. However, downstream interfaces cannot be configured. Project page: http://sourceforge.net/projects/ecmh/

## Appendix C. Comparative Evaluation of Different Approaches

In this section, we briefly evaluate two orthogonal PMIP concepts for multicast traffic organization at LMAs. In scenario A, multicast is provided by combined unicast/multicast LMAs as described in this document. Scenario B directs traffic via a dedicated, central multicast router ("LMA-M") that tunnels packets to MAGs independent of unicast handoffs.

Neither approach establishes native multicast distribution between the LMA and MAG; instead, they use tunneling mechanisms. In scenario A, a MAG is connected to different multicast-enabled LMAs and can receive the same multicast stream via multiple paths depending on the group subscriptions of MNs and their associated LMAs. This problem, a.k.a. the tunnel convergence problem, may lead to redundant traffic at the MAGs. In contrast, scenario B configures MAGs to establish a tunnel to a single, dedicated multicast LMA for all attached MNs and relocates overhead costs to the multicast anchor. This eliminates redundant traffic but may result in an avalanche problem at the LMA.

We quantify the costs of both approaches based on two metrics: the amount of redundant traffic at MAGs and the number of simultaneous streams at LMAs. Realistic values depend on the topology and the group subscription model. To explore scalability in a large PMIP domain of 1,000,000 MNs, we consider the following two extreme multicast settings.

1. All MNs participate in distinct multicast groups.

2. All MNs join the same multicast group.

A typical PMIP deployment approximately allows for 5,000 MNs attached to one MAG, while 50 MAGs can be served by one LMA. Hence 1,000,000 MNs require approximately 200 MAGs backed by 4 LMAs for unicast transmission. In scenario A, these LMAs also forward multicast streams, while in scenario B one additional dedicated LMA (LMA-M) serves multicast. In the following, we calculate the metrics described above. In addition, we display the number of packet streams that cross the interconnecting (wired) network within a PMIPv6 domain.





Setting 1:

| PMIP multicast scheme | # of redund. streams at MAG | # of simul. streams at LMA/LMA-M | # of total streams in the network |
|---|---|---|---|
| Combined Unicast/ Multicast LMA | 0 | 250,000 | 1,000,000 |
| Dedicated Multicast LMA | 0 | 1,000,000 | 1,000,000 |

1,000,000 MNs are subscribed to distinct multicast groups.

Setting 2:

| PMIP multicast scheme | # of redund. streams at MAG | # of simul. streams at LMA/LMA-M | # of total streams in the network |
|---|---|---|---|
| Combined Unicast/ Multicast LMA | 3 | 200 | 800 |
| Dedicated Multicast LMA | 0 | 200 | 200 |

1,000,000 MNs are subscribed to the same multicast group.

These considerations of extreme settings show that packet duplication and replication effects apply in changing intensities for different use cases of multicast data services. However, tunnel convergence, i.e., duplicate data arriving at a MAG, does cause much smaller problems in scalability than the stream replication at LMAs (avalanche problem). For scenario A, it should also be noted that the high stream replication requirements at LMAs in setting 1 can be attenuated by deploying additional LMAs in a PMIP domain, while scenario B does not allow for distributing the LMA-M, as no handover management is available at LMA-M.





## Authors' Addresses

Thomas C. Schmidt
HAW Hamburg
Berliner Tor 7
Hamburg 20099
Germany

EMail: schmidt@informatik.haw-hamburg.de
URI: http://inet.cpt.haw-hamburg.de/members/schmidt

Matthias Waehlisch
link-lab & FU Berlin
Hoenower Str. 35
Berlin 10318
Germany

EMail: mw@link-lab.net

Suresh Krishnan
Ericsson
8400 Decarie Blvd.
Town of Mount Royal, QC
Canada

EMail: suresh.krishnan@ericsson.com