              Multicast Listener Extensions for Mobile IPv6 (MIPv6) and
                   Proxy Mobile IPv6 (PMIPv6) Fast Handovers

Abstract

   Fast handover protocols for Mobile IPv6 (MIPv6) and Proxy Mobile IPv6
   (PMIPv6) define mobility management procedures that support unicast
   communication at reduced handover latency. Fast handover base
   operations do not affect multicast communication and, hence, do not
   accelerate handover management for native multicast listeners. Many
   multicast applications like IPTV or conferencing, though, comprise
   delay-sensitive, real-time traffic and will benefit from fast
   handover completion. This document specifies extension of the Mobile
   IPv6 Fast Handovers (FMIPv6) and the Fast Handovers for Proxy Mobile
   IPv6 (PFMIPv6) protocols to include multicast traffic management in
   fast handover operations. This multicast support is provided first
   at the control plane by management of rapid context transfer between
   access routers and second at the data plane by optional fast traffic
   forwarding that may include buffering. An FMIPv6 access router
   indicates support for multicast using an updated Proxy Router
   Advertisements message format.

   This document updates RFC 5568, "Mobile IPv6 Fast Handovers".

Status of This Memo

   This document is not an Internet Standards Track specification; it is
   published for examination, experimental implementation, and
   evaluation.

   This document defines an Experimental Protocol for the Internet
   community. This document is a product of the Internet Engineering
   Task Force (IETF). It represents the consensus of the IETF
   community. It has received public review and has been approved for
   publication by the Internet Engineering Steering Group (IESG). Not
   all documents approved by the IESG are a candidate for any level of
   Internet Standard; see Section 2 of RFC 5741.

   Information about the current status of this document, any errata,
   and how to provide feedback on it may be obtained at
   http://www.rfc-editor.org/info/rfc7411.

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1. Introduction

   Mobile IPv6 [RFC6275] defines a network-layer mobility protocol
   involving participation by Mobile Nodes, while Proxy Mobile IPv6
   [RFC5213] provides a mechanism without requiring mobility protocol
   operations at a Mobile Node (MN). Both protocols introduce traffic
   disruptions on handovers that may be intolerable in many real-time
   application scenarios such as gaming or conferencing. Mobile IPv6
   Fast Handovers (FMIPv6) [RFC5568] and Fast Handovers for Proxy Mobile
   IPv6 (PFMIPv6) [RFC5949] improve the performance of handovers for
   unicast communication. Delays are reduced to the order of the
   maximum of the link switching delay and the signaling delay between
   Access Routers (ARs) or Mobile Access Gateways (MAGs)
   [FMIPv6-Analysis].

   No dedicated treatment of seamless IP multicast [RFC1112] data
   service has been proposed by any of the above protocols. MIPv6 only
   roughly defines multicast for Mobile Nodes using a remote
   subscription approach or a home subscription through bidirectional
   tunneling via the Home Agent (HA). Multicast forwarding services
   have not been specified in [RFC5213] but are subject to separate
   specifications: [RFC6224] and [RFC7287]. It is assumed throughout
   this document that mechanisms and protocol operations are in place to
   transport multicast traffic to ARs. These operations are referred to
   as 'JOIN/LEAVE' of an AR, while the explicit techniques to manage
   multicast transmission are beyond the scope of this document.

   Mobile multicast protocols need to support applications such as IPTV
   with high-volume content streams and allow distribution to
   potentially large numbers of receivers. They should thus preserve
   the multicast nature of packet distribution and approximate optimal
   routing [RFC5757]. It is undesirable to rely on home tunneling for
   optimizing multicast. Unencapsulated, native multicast transmission
   requires establishing forwarding state, which will not be transferred
   between access routers by the unicast fast handover protocols. Thus,
   multicast traffic will not experience expedited handover performance,
   but an MN -- or its corresponding MAG in PMIPv6 -- can perform remote
   subscriptions in each visited network.

   This document specifies extensions to FMIPv6 and PFMIPv6 that include
   multicast traffic management for fast handover operations in the
   presence of any-source or source-specific multicast. The protocol
   extensions were designed under the requirements that

   o multicast context transfer shall be transparently included in
      unicast fast handover operations;

   o neither unicast mobility protocols nor multicast routing shall be
      modified or otherwise affected; and

   o no active participation of MNs in PMIPv6 domains is defined.

   The solution common to both underlying unicast protocols defines the
   per-group or per-channel transfer of multicast contexts between ARs
   or MAGs. The protocol defines corresponding message extensions
   necessary for carrying (*,G) or (S,G) context information independent
   of the particular handover protocol. ARs or MAGs are then enabled to
   treat multicast traffic according to fast unicast handovers and with
   similar performance. No protocol changes are introduced that prevent
   a multicast-unaware node from performing fast handovers with
   multicast-aware ARs or MAGs.

   The specified mechanisms apply when a Mobile Node has joined and
   maintains one or several multicast group subscriptions prior to
   undergoing a fast handover. It does not introduce any requirements
   on the multicast routing protocols in use, nor are the ARs or MAGs
   assumed to be multicast routers. It assumes network conditions,
   though, that allow native multicast reception in both the previous
   and new access network. Methods to bridge regions without native
   multicast connectivity are beyond the scope of this document.

   Section 5.1 of this memo updates the Proxy Router Advertisements
   (PrRtAdv) message format defined in Section 6.1.2 of [RFC5568] to
   allow an FMIPv6 AR to indicate support for multicast.

1.1. Use Cases and Deployment Scenarios

   Multicast extensions for fast handovers enable multicast services in
   domains that operate either of the unicast fast handover protocols:
   [RFC5568] or [RFC5949]. Typically, fast handover protocols are
   activated within an operator network or within a dedicated service
   installation.

   Multicast group communication has a variety of dominant use cases.
   One traditional application area is infotainment with voluminous
   multimedia streams delivered to a large number of receivers (e.g.,
   IPTV). Other time-critical services, such as news items or stock-
   exchange prices, are commonly transmitted via multicast to support
   fair and fast updates. Both of these use cases may be mobile, and
   both largely benefit from fast handover operations. Mobile operators
   may therefore enhance their operational quality or offer premium
   services by enabling fast handovers.

   Another traditional application area for multicast is conversational
   group communication in scenarios like conferencing or gaming as well
   as in dedicated collaborative environments or teams. Machine-to-
   machine communication in the emerging Internet of Things is expected
   to generate various additional mobile use cases (e.g., among cars).
   High demands on transmission quality and rapidly moving parties may
   require fast handovers.

   Most of the deployment scenarios above are bound to a fixed
   infrastructure with consumer equipment at the edge. Today, they are
   thus likely to follow an operator-centric approach like PFMIPv6.
   However, Internet technologies evolve for adoption in
   infrastructureless scenarios, for example, disaster recovery, rescue,
   crisis prevention, and civil safety. Mobile end-to-end communication
   in groups is needed in Public Protection and Disaster Relief (PPDR)
   scenarios, where mobile multicast communication needs to be supported
   between members of rescue teams, police officers, fire brigade teams,
   paramedic teams, and command control offices in order to support the
   protection and health of citizens. These use cases require fast and
   reliable mobile services that cannot rely on operator infrastructure.
   They are thus expected to benefit from running multicast with FMIPv6.

2. 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 [RFC2119].

   This document uses the terminology for mobility entities in
   [RFC5568], [RFC5949], [RFC6275], and [RFC5213].

   A multicast group is any group (*,G) or (S,G) multicast channel
   listed in a Multicast Listener Report Message.

3. Protocol Overview

   This section provides an informative overview of the protocol
   mechanisms without normative specifications.

   The reference scenario for multicast fast handover is illustrated in
   Figure 1. A Mobile Node is initially attached to the previous access
   network (P-AN) via the Previous Access Router (PAR) or Previous
   Mobile Access Gateway (PMAG) and moves to the new access network
   (N-AN) connected via a New AR (NAR) or New MAG (NMAG).

```
                      ***  ***  ***  ***
                    *    **   **   **    *
                  *                         *
                  *   Multicast Cloud *
                  *                         *
                    *    **   **   **    *
                      ***  ***  ***  ***
                       /          \
                      /            \
                     /              \
      +........../..+       +..\..........+
      . +-------+-+ ._____. +-+-------+ .
      . |   PAR   |()_____)|   NAR   | .
      . | (PMAG)  | .       . | (NMAG)  | .
      . +----+----+ .       . +----+----+ .
      .      |      .       .      |      .
      .    ___|___  .       .    ___|___  .
      .   /       \ .       .   /       \ .
      .  (  P-AN   ) .       .  (  N-AN   ) .
      .   _____/ .       .   _____/ .
      .      |      .       .      |      .
      .    +----+   .       .    +----+   .
      .    | MN |  ---------->  | MN |   .
      .    +----+   .       .    +----+   .
      +.............+       +.............+
```
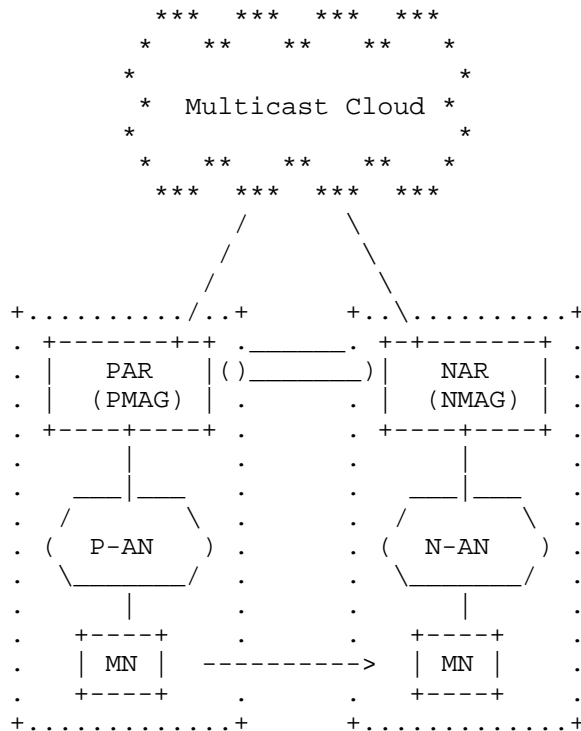
                 Figure 1: Reference Network for Fast Handover

3.1. Multicast Context Transfer between Access Routers

   In a fast handover scenario (see Figure 1), ARs/MAGs establish a
   mutual binding and provide the capability to exchange context
   information concerning the MN. This context transfer will be
   triggered by detecting the forthcoming movement of an MN to a new AR
   and assists the MN to immediately resume communication on the new
   subnet using its previous IP address. In contrast to unicast,
   multicast flow reception does not primarily depend on address and
   binding cache management but requires distribution trees to adapt so
   that traffic follows the movement of the MN. This process may be
   significantly slower than fast handover management [RFC5757]. To
   accelerate the handover, a multicast listener may offer a twofold
   advantage of including the multicast groups under subscription in the
   context transfer. First, the NAR can proactively join the subscribed
   groups as soon as it gains knowledge of them. Second, multicast
   flows can be included in traffic forwarding via the tunnel that is
   established from the PAR to the NAR by the unicast fast handover
   protocol.

There are two modes of operation in FMIPv6 and in PFMIPv6. The
predictive mode allows for AR-binding and context transfer prior to
an MN handover, while in the reactive mode, these steps are executed
after detection that the MN has reattached to a NAR (NMAG). Details
of the signaling schemes differ between FMIPv6 and PFMIPv6 and are
outlined in Sections 3.2 and 3.3.

In a predictive fast handover, the access router (i.e., PAR (PMAG) in
Figure 1) learns about the impending movement of the MN and
simultaneously about the multicast group context as specified in
Sections 3.2 and 3.3. Thereafter, the PAR will initiate an AR-
binding and context transfer by transmitting a Handover Initiation
(HI) message to the NAR (NMAG). The HI message is extended by
multicast group states carried in mobility header options, as defined
in Section 5.3. On reception of the HI message, the NAR returns a
multicast acknowledgement in its Handover Acknowledgement (HAck)
answer that indicates its ability to support each requested group
(see Section 5.4). The NAR (NMAG) expresses its willingness to
receive multicast traffic forwarded by the PAR using standard
Multicast Listener Discovery (MLD) signaling for IPv6 or the Internet
Group Management Protocol (IGMP) for an IPv4 compatibility case.

Nodes normally create forwarding state for each group requested.
There are several reasons why a node may decide not to forward a
specific group, e.g., the NAR could already have a native
subscription for the group(s) or capacity constraints can hinder
decapsulation of additional streams. At the previous network, there
may be policy or capacity constraints that make it undesirable to
forward the multicast traffic. The PAR can add the tunnel interface
obtained from the underlying unicast protocol to its multicast
forwarding database for those groups the MN wishes to receive, so
that multicast flows can be forwarded in parallel to the unicast
traffic.

The NAR implements an MLD proxy [RFC4605] providing host-side
behavior towards the upstream PAR. The proxy will submit an MLD
report to the upstream tunnel interface to signal the set of groups
to be forwarded. It will terminate multicast forwarding from the
tunnel when the group is natively received. In parallel, the NAR
joins all groups that are not already under subscription using its
native multicast upstream interface. While the MN has not arrived at
a downstream interface of the NAR, multicast subscriptions on behalf
of the MN are associated with a downstream loopback interface.
Reception of the Join at the NAR enables downstream native multicast
forwarding of the subscribed group(s).

In a reactive fast handover, the PAR will learn about the movement of
the MN after the latter has re-associated with the new access
network. Also, from the new link, it will be informed about the
multicast context of the MN. As group membership information is
present at the new access network prior to context transfer, MLD join
signaling can proceed in parallel to HI/HAck exchange. Following the
context transfer, multicast data can be forwarded to the new access
network using the PAR-NAR tunnel of the fast handover protocol.
Depending on the specific network topology, multicast traffic for
some groups may natively arrive before it is forwarded from the PAR.

In both modes of operation, it is the responsibility of the PAR
(PMAG) to properly apply multicast state management when an MN leaves
(i.e., to determine whether it can prune the traffic for any
unsubscribed group). Depending on the link type and MLD parameter
settings, methods for observing the departure of an MN need to be
applied (see [RFC5757]). While considering subscriptions of the
remaining nodes and from the tunnel interfaces, the PAR uses normal
multicast forwarding rules to determine whether multicast traffic can
be pruned.

This method allows an MN to participate in multicast group
communication with a handover performance that is comparable to
unicast handover. It is worth noting that tunnel management between
access routers in all modes is inherited from the corresponding
unicast fast handover protocols. Tunnels thus remain active until
unicast handover operations have been completed for the MN.

3.2. Protocol Operations Specific to FMIPv6

ARs that provide multicast support in FMIPv6 will advertise this
general service by setting an indicator bit ('M' bit) in its PrRtAdv
message, as defined in Section 5.1. Additional details about the
multicast service support, e.g., flavors and groups, will be
exchanged within HI/HAck dialogs later at handover.

An MN operating FMIPv6 will actively initiate the handover management
by submitting a Fast Binding Update (FBU). The MN, which is aware of
the multicast groups it wishes to maintain, will attach mobility
options containing its group states (see Section 5.3) to the FBU and
thereby inform ARs about its multicast context. ARs will use these
multicast context options for inter-AR context transfer.

In predictive mode, the FBU is issued on the previous link and
received by the PAR as displayed in Figure 2. The PAR will extract
the multicast context options and append them to its HI message.
From the HAck message, the PAR will redistribute the multicast
acknowledgement by adding the corresponding mobility options to its

Fast Binding ACK (FBack) message. From receiving the FBack message,
the MN will learn about the multicast support for each group in the
new access network. If some groups or multicast service models are
not supported, it can decide to take actions to overcome a missing
service (e.g., by tunneling). Note that the proactive multicast
context transfer may proceed successfully, even if the MN misses the
FBack message on the previous link.

```
          MN                        PAR                        NAR
           |                         |                          |
           |------RtSolPr------->|                          |
           |<-----PrRtAdv--------|                          |
           |                         |                          |
           |                         |                          |
           |---------FBU-------->|----------HI--------->|
           |  (Multicast MobOpt)  |  (Multicast MobOpt)   |
           |                         |                          |
           |                         |<--------HAck---------|
           |                         |  (Multicast AckOpt)  |
           |                         |              Join to
           |                         |              Multicast
           |                         |              Groups
           |                         |                          |
           |       <-----FBack---|--FBack------>          |
           |  (Multicast AckOpt)  |  (Multicast AckOpt)   |
           |                         |                          |
       disconnect            optional                    |
           |                 packet  ===============>|
           |               forwarding                   |
           |                         |                          |
       connect                      |                          |
           |                         |                          |
           |-----------UNA --------------------------->|
           |<================================ deliver packets
           |                         |                          |
```
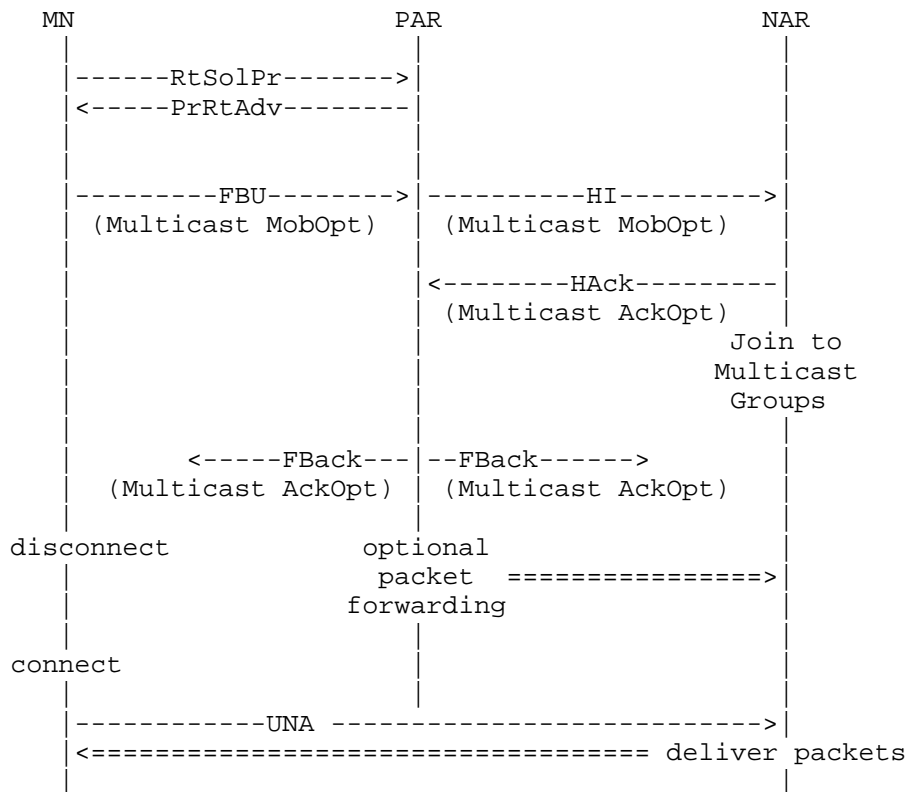
          Figure 2: Predictive Multicast Handover for FMIPv6

   The flow diagram for reactive mode is depicted in Figure 3. After
   attaching to the new access link and performing an Unsolicited
   Neighbor Advertisement (UNA), the MN issues an FBU that the NAR
   forwards to the PAR without processing. At this time, the MN is able
   to rejoin all subscribed multicast groups without relying on AR
   assistance. Nevertheless, multicast context options are exchanged in
   the HI/HAck dialog to facilitate intermediate forwarding of the
   requested multicast flows. The multicast traffic could arrive from
   an MN subscription at the same time that the NAR receives the HI
   message. Such multicast flows may be transparently excluded from

forwarding by setting an appropriate Multicast Acknowledgement
Option. In either case, to avoid duplication, the NAR MUST ensure
that not more than one flow of the same group is forwarded to the MN.

```
          MN                      PAR                      NAR
          |                        |                        |
          |------RtSolPr-------->|                        |
          |<-----PrRtAdv--------|                        |
          |                        |                        |
      disconnect                 |                        |
          |                        |                        |
          |                        |                        |
      connect                    |                        |
          |-------UNA----------|-------------------->|
          |-------FBU----------|-------------------->)|
          |  (Multicast MobOpt)  |<-------FBU----------)|
          |                        |                        |
       Join to                   |                        |
      Multicast                  |                        |
       Groups                    |                        |
          |                        |----------HI--------->|
          |                        |   (Multicast MobOpt)  |
          |                        |<-------HAck----------|
          |                        |   (Multicast AckOpt)  |
          |                        |                        |
          |                        |(HI/HAck if necessary)|
          |                        |                        |
          |             FBack, optional                |
          |             packet forwarding  =========>|
          |                        |                        |
          |<================================ deliver packets
          |                        |                        |
```

                Figure 3: Reactive Multicast Handover for FMIPv6

3.3. Protocol Operations Specific to PFMIPv6

   In a proxy mobile IPv6 environment, the MN remains agnostic of
   network layer changes, and fast handover procedures are operated by
   the access routers or MAGs to which MNs are connected via node-
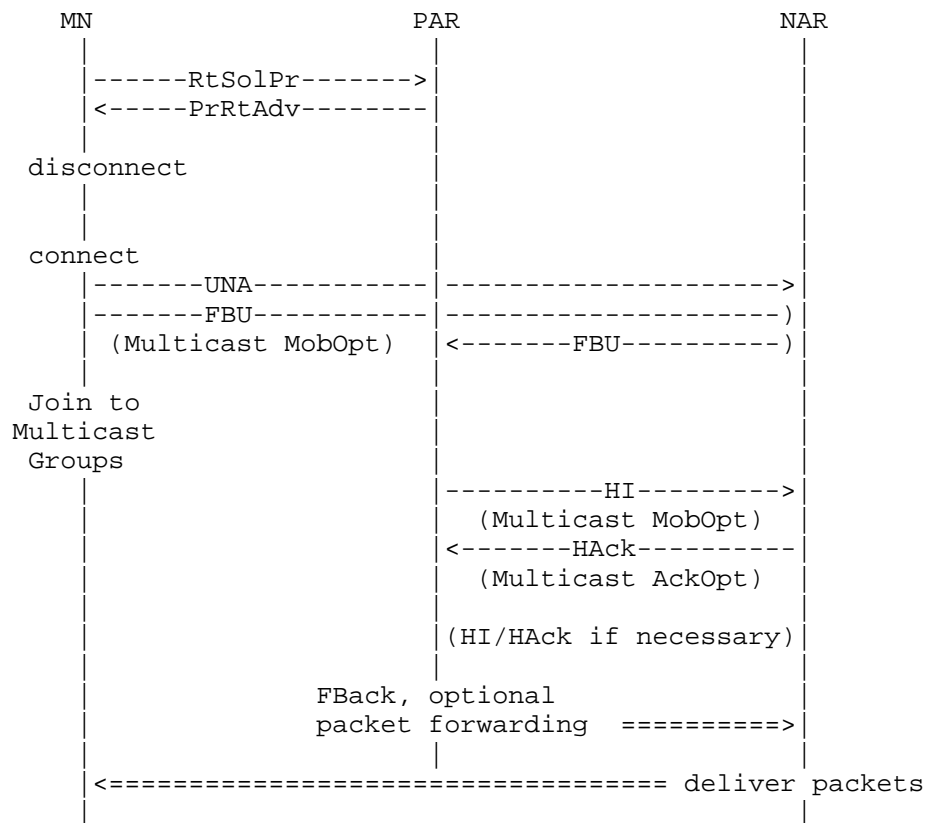   specific point-to-point links. The handover initiation, or the re-
   association, is managed by the access networks. Consequently, access
   routers need to be aware of multicast membership state at the Mobile
   Node. There are two ways to obtain the multicast membership of an
   MN.

   o MAGs may perform explicit tracking (see [RFC4605] and [RFC6224])
      or extract membership status from forwarding states at node-
      specific links.

   o routers can issue a general MLD query at handovers. Both methods
      are equally applicable. However, a router that does not provide
      explicit membership tracking needs to query its downstream links
      after a handover. The MLD membership information then allows the
      PMAG to learn the multicast group subscriptions of the MN.

   In predictive mode, the PMAG will learn about the upcoming movement
   of the Mobile Node, including its new Access Point Identifier (New AP
   ID). Without explicit tracking, it will immediately submit a general
   MLD query and receive MLD reports indicating the multicast address
   listening state of the subscribed group(s). As displayed in
   Figure 4, it will initiate binding and context transfer with the NMAG
   by issuing a HI message that is augmented by multicast contexts in
   the mobility options defined in Section 5.3. NMAG will extract
   multicast context information and act as described in Section 3.1.

```
                                            PMAG          NMAG
        MN            P-AN        N-AN      (PAR)         (NAR)
        |             |           |           |            |
        |    Report   |           |           |            |
        |---(MN ID,-->|           |           |            |
        |  New AP ID) |           |           |            |
        |             |      HO Indication    |            |
        |             |--(MN ID, New AP ID)-->|            |
        |             |           |           |            |
        |             |           |     Optional:          |
        |             |           |     MLD Query          |
        |             |           |           |            |
        |             |           |           |------HI---->|
        |             |           |           | (Multicast MobOpt)
        |             |           |           |            |
        |             |           |           |<---HAck-----|
        |             |           |           | (Multicast AckOpt)
        |             |           |           |            |
        |             |           |           |       Join to
        |             |           |           |       Multicast
        |             |           |           |        Groups
        |             |           |           |            |
        |             |           |           |HI/HAck(optional)
        |             |           |           |<- - - - - ->|
        |             |           |           |            |
        |             |           |    optional packet     |
        |             |           |     forwarding ======>|
        |             |           |           |            |
    disconnect        |           |           |            |
        |             |           |           |            |
     connect          |           |           |            |
        |     MN-AN connection    |    AN-MAG connection    |
        |<----establishment----->|<----establishment------>|
        |             |           |    (substitute for UNA) |
        |             |           |           |            |
        |<======================================= deliver packets
        |             |           |           |            |
```
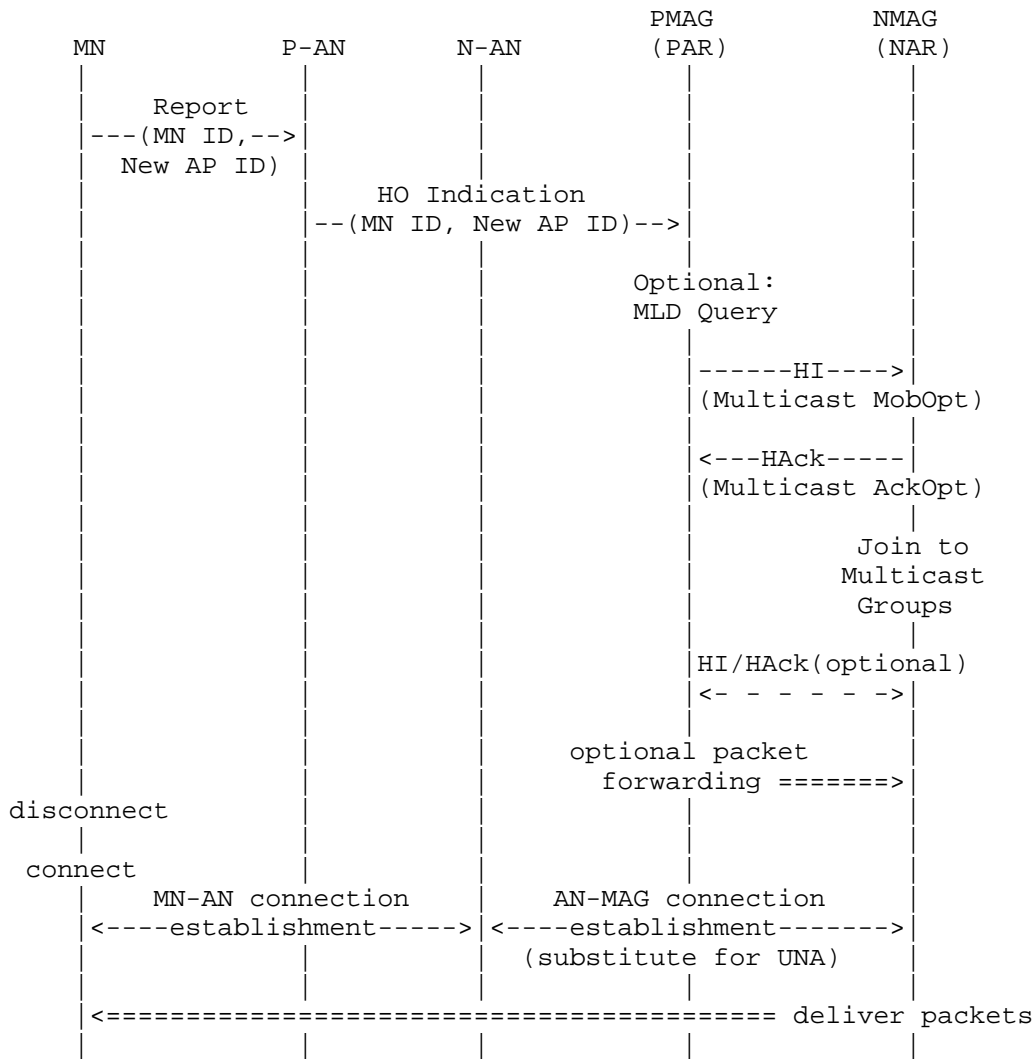
                Figure 4: Predictive Multicast Handover for PFMIPv6

   In reactive mode, the NMAG will learn the attachment of the MN to the
   N-AN and establish connectivity using the PMIPv6 protocol operations.
   However, it will have no knowledge about multicast state at the MN.
   Triggered by an MN attachment, the NMAG will send a general MLD query
   and thereafter join the groups for which it receives multicast
   listener report messages. In the case of a reactive handover, the
   binding is initiated by the NMAG, and the HI/HAck message semantic is
   inverted (see [RFC5949]). For multicast context transfer, the NMAG
   attaches to its HI message those group identifiers it requests to be

forwarded from PMAG. Using the identical syntax in its Multicast
Mobility Option headers, as defined in Section 5.4, the PMAG
acknowledges the set of requested groups in a HAck answer, indicating
the group(s) it is willing to forward. The corresponding call flow
is displayed in Figure 5.

```
                                          PMAG          NMAG
         MN          P-AN        N-AN     (PAR)         (NAR)
         |           |           |         |             |
     disconnect      |           |         |             |
         |           |           |         |             |
      connect        |           |         |             |
         |           |           |         |             |
         |     MN-AN connection  |    AN-MAG connection  |
         |<---establishment---->|<----establishment------>|
         |           |           |    (substitute for UNA & FBU)|
         |           |           |         |             |
         |           |           |         |          MLD Query
         |           |           |         |             |
         |           |           |         |          Join to
         |           |           |         |          Multicast
         |           |           |         |           Groups
         |           |           |         |             |
         |           |           |         |<------HI----|
         |           |           |         |(Multicast MobOpt)
         |           |           |         |             |
         |           |           |         |---HAck----->|
         |           |           |         |(Multicast AckOpt)
         |           |           |         |             |
         |           |           |         |             |
         |           |           |         |HI/HAck(optional)
         |           |           |         |<- - - - - ->|
         |           |           |         |             |
         |           |           |      optional packet  |
         |           |           |        forwarding ======>|
         |           |           |         |             |
         |<======================================= deliver packets
         |           |           |         |             |
```
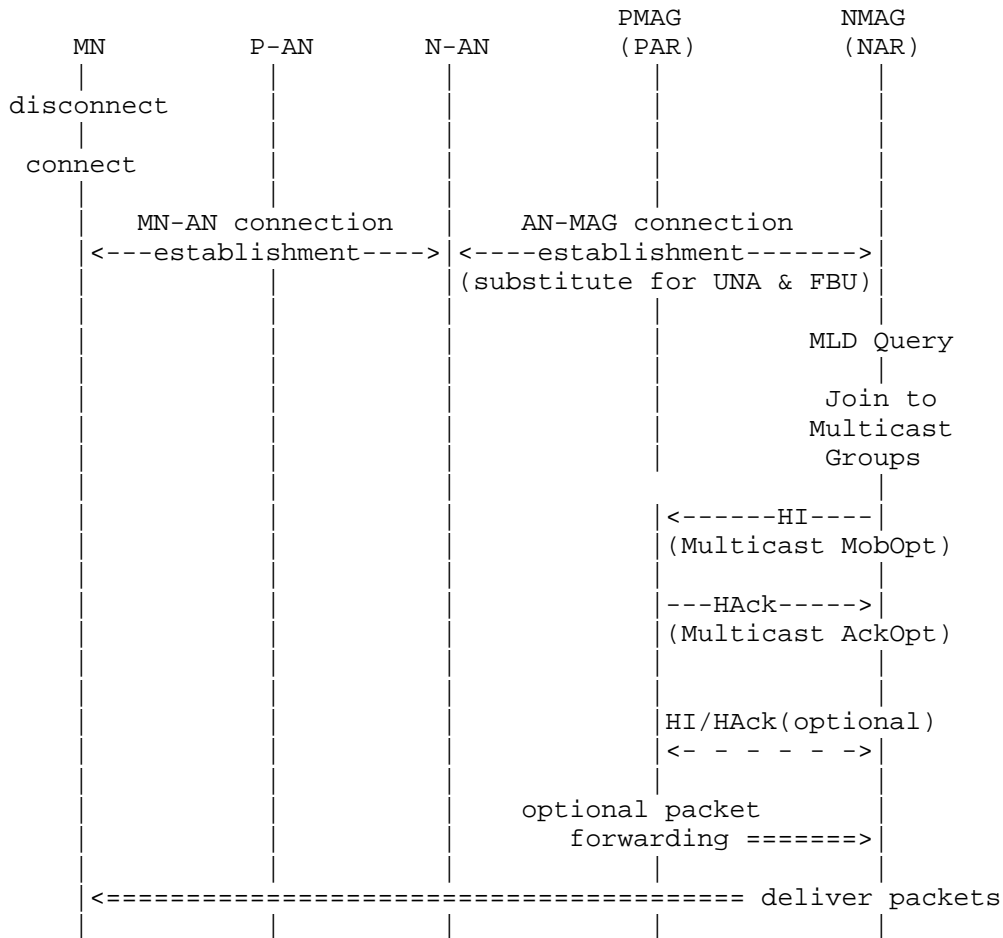
          Figure 5: Reactive Multicast Handover for PFMIPv6

4. Protocol Details

   This section provides a normative definition of the protocol
   operations.

4.1. Protocol Operations Specific to FMIPv6

4.1.1. Operations of the Mobile Node

   A Mobile Node willing to manage multicast traffic by fast handover
   operations MUST transfer its MLD listener state records within fast
   handover negotiations.

   When sensing a handover in predictive mode, an MN MUST build a
   Multicast Mobility Option, as described in Section 5.3, that contains
   the MLD or IGMP multicast listener state and append it to the Fast
   Binding Update (FBU) prior to signaling with PAR.

   The MN will receive the Multicast Acknowledgement Option(s) as a part
   of the Fast Binding Acknowledge (FBack) (see Section 5.4) and learn
   about unsupported or prohibited groups at the NAR. The MN MAY take
   appropriate actions such as home tunneling to enable reception of
   groups that are not available via the NAR. Beyond standard FMIPv6
   signaling, no multicast-specific operation is required by the MN when
   reattaching in the new network.

   In reactive mode, the MN MUST append the identical Multicast Mobility
   Option to the FBU sent after its reconnect. In response, it will
   learn about the Multicast Acknowledgement Option(s) from the FBack
   and expect corresponding multicast data. Concurrently, it joins all
   subscribed multicast groups directly on its newly established access
   link.

4.1.2. Operations of the Previous Access Router

   A PAR that supports multicast advertises that support by setting the
   'M' bit in the Proxy Router Advertisement (PrRtAdv) message, as
   specified in Section 5.1 of this document. This indicator
   exclusively informs the MNs about the capability of the PAR to
   process and exchange Multicast Mobility Options during fast handover
   operations.

   In predictive mode, a PAR will receive the multicast listener state
   of an MN prior to handover from the Multicast Mobility Option
   appended to the FBU. It forwards these records to the NAR within HI
   messages and will expect Multicast Acknowledgement Option(s) in a
   HAck, which is itself returned to the MN as an appendix to the FBack.
   In performing the multicast context exchange, the PAR is instructed

to include the PAR-to-NAR tunnel obtained from unicast handover
management in its multicast downstream interfaces and awaits
reception of multicast listener report messages from the NAR. In
response to receiving multicast subscriptions, the PAR SHOULD forward
group data acting as a regular multicast router or proxy. However,
the PAR MAY refuse to forward some or all of the multicast flows
(e.g., due to administrative configurations or load conditions).

In reactive mode, the PAR will receive the FBU augmented by the
Multicast Mobility Option from the new network but continues with an
identical multicast record exchange in the HI/HAck dialog. As in the
predictive case, it configures the PAR-to-NAR tunnel for the
multicast downstream. It then (if capable) forwards data according
to the group membership indicated in the multicast listener report
messages received from NAR.

In both modes, the PAR MUST interpret the first of the two events --
the departure of the MN or the reception of the Multicast
Acknowledgement Option(s) -- as if the MN had sent a multicast LEAVE
message and react according to the signaling scheme deployed in the
access network (i.e., MLD querying, explicit tracking).

4.1.3. Operations of the New Access Router

A NAR that supports multicast advertises that support by setting the
'M' bit in PrRtAdv as specified in Section 5.1 of this document.
This indicator exclusively serves the purpose of informing MNs about
the capability of the NAR to process and exchange Multicast Mobility
Options during fast handover operations.

In predictive mode, a NAR will receive the multicast listener state
of an expected MN from the Multicast Mobility Option appended to the
HI message. It will extract the multicast group membership records
from the message and match the request subscription with its
multicast service offer. Further on, it will join the requested
groups using a downstream loopback interface. This will lead to
suitable regular subscriptions to a native multicast upstream
interface without additional forwarding. Concurrently, the NAR
builds a Multicast Acknowledgement Option(s) (see Section 5.4)
listing the set of groups that are unsupported on the new access link
and returns this list within a HAck. As soon as there is an
operational bidirectional tunnel from the PAR to NAR, the NAR joins
the groups requested by the MN, which are then forwarded by the PAR
using the tunnel link.

In reactive mode, the NAR will learn about the multicast listener
state of a new MN from the Multicast Mobility Option appended to each
HI message after the MN has already performed local subscriptions of

the multicast service. Thus, the NAR solely determines the
intersection of requested and supported groups and issues a join
request for each group forwarding this on the PAR-NAR tunnel
interface.

In both modes, the NAR MUST send a LEAVE message to the tunnel when
it is no longer needed to forward a group, e.g., after arrival of
native multicast traffic or termination of a group membership from
the MN. Although the message can be delayed, immediately sending the
LEAVE message eliminates the need for the PAR and NAR to process
traffic that is not to be forwarded.

4.1.4. Buffering Considerations

Multicast packets may be lost during handover. For example, in
predictive mode, as illustrated by Figure 2, packets may be lost
while the MN is -- already or still -- detached from the networks,
even though they are forwarded to the NAR. In reactive mode as
illustrated by Figure 3, the situation may be worse, since there will
be a delay before joining the multicast group after the MN reattaches
to the NAR. Multicast packets cannot be delivered during this time.
Buffering the multicast packets at the PAR can reduce multicast
packet loss but may then increase resource consumption and delay in
packet transmission. Implementors should balance the different
requirements in the context of predominant application demands (e.g.,
real-time requirements or loss sensitivity).

4.2. Protocol Operations Specific to PFMIPv6

4.2.1. Operations of the Mobile Node

A Mobile Node willing to participate in multicast traffic will join,
maintain, and leave groups as if located in the fixed Internet. It
will cooperate in handover indication as specified in [RFC5949] and
required by its access link-layer technology. No multicast-specific
mobility actions nor implementations are required at the MN in a
PMIPv6 domain.

4.2.2. Operations of the Previous MAG

A MAG receiving a handover indication for one of its MNs follows the
same predictive fast handover mode as a PMAG. It MUST issue an MLD
General Query immediately on its corresponding link unless it
performs explicit membership tracking on that link. After knowledge
of the multicast subscriptions of the MN is acquired, the PMAG builds
a Multicast Mobility Option, as described in Section 5.3, that
contains the MLD and IGMP multicast listener state. If not empty,
this Mobility Option is appended to the regular fast handover HI

messages. In the case when a unicast HI message is submitted prior
to multicast state detection, the multicast listener state is sent in
an additional HI message to the NMAG.

The PMAG then waits until it receives the Multicast Acknowledgement
Option(s) with a HAck message (see Section 5.4) and the bidirectional
tunnel with the NMAG is created. After the HAck message is received,
the PMAG adds the tunnel to its downstream interfaces in the
multicast forwarding database. For those groups reported in the
Multicast Acknowledgement Option(s), i.e., not supported in the new
access network, the PMAG normally takes appropriate actions (e.g.,
forwarding and termination) according to the network policy. It
SHOULD start forwarding multicast traffic down the tunnel interface
for the groups indicated in the multicast listener reports received
from NMAG. However, it MAY deny forwarding some or all groups
included in the multicast listener reports (e.g., due to
administrative configurations or load conditions).

After the departure of the MN and on the reception of a LEAVE
message, it is RECOMMENDED that the PMAG terminates forwarding of the
specified groups and updates its multicast forwarding database. It
correspondingly sends a LEAVE message to its upstream link for any
group where there are no longer any active listeners on any
downstream link.

A MAG receiving a HI message with the Multicast Mobility Option for a
currently attached node follows the reactive fast handover mode as a
PMAG. It will return a Multicast Acknowledgement Option(s) (see
Section 5.4) within a HAck message listing the groups for which it
does not provide forwarding support to the NMAG. It will add the
bidirectional tunnel with NMAG to its downstream interfaces and will
start forwarding multicast traffic for the groups listed in the
multicast listener report messages from the NMAG. On reception of a
LEAVE message for a group, the PMAG terminates forwarding for the
specific group and updates its multicast forwarding database.
According to its multicast forwarding state, it sends a LEAVE message
to its upstream link for any group where there are no longer any
active listeners on any downstream link.

In both modes, the PMAG will interpret the departure of the MN as a
multicast LEAVE message of the MN and react according to the
signaling scheme deployed in the access network (i.e., MLD querying
and explicit tracking).

4.2.3. Operations of the New MAG

   A MAG receiving a HI message with a Multicast Mobility Option for a
   currently unattached node follows the same predictive fast handover
   mode as an NMAG. It will decide the multicast groups to be forwarded
   from the PMAG and build a Multicast Acknowledgement Option (see
   Section 5.4) that enumerates only unwanted groups. This Mobility
   Option is appended to the regular fast handover HAck messages or, in
   the case of a unicast HAck message being submitted prior to multicast
   state acknowledgement, sent in an additional HAck message to the
   PMAG. Immediately thereafter, the NMAG SHOULD update its MLD
   membership state based on the membership reported in the Multicast
   Mobility Option. Until the MN reattaches, the NMAG uses its Loopback
   interface for downstream and MUST NOT forward traffic to the
   potential link of the MN. The NMAG SHOULD issue JOIN messages for
   those newly selected groups to its regular multicast upstream
   interface. As soon as the bidirectional tunnel with PMAG is
   established, the NMAG additionally joins those groups on the tunnel
   interface requested to be forwarded from the PMAG.

   A MAG experiencing a connection request for an MN without prior
   reception of a corresponding Multicast Mobility Option is operating
   in the reactive fast handover mode as an NMAG. Following the
   reattachment, it SHOULD immediately issue an MLD General Query to
   learn about multicast subscriptions of the newly arrived MN. Using
   standard multicast operations, the NMAG joins groups not currently
   forwarded using its regular multicast upstream interface.
   Concurrently, it selects groups for forwarding from PMAG and builds a
   Multicast Mobility Option, as described in Section 5.3, that contains
   the multicast listener state. If not empty, this Mobility Option is
   appended to the regular fast handover HI messages with the F flag set
   or, in the case of unicast HI message being submitted prior to
   multicast state detection, sent in an additional HI message to the
   PMAG. Upon reception of the Multicast Acknowledgement Option and
   establishment of the bidirectional tunnel, the NMAG additionally
   joins the set of groups on the tunnel interface that it wishes to
   receive by forwarding from the PMAG. When multicast flows arrive,
   the NMAG forwards data to the appropriate downlink(s).

   In both modes, the NMAG MUST send a LEAVE message to the tunnel when
   forwarding of a group is no longer needed, e.g., after native
   multicast traffic arrives or group membership of the MN terminates.
   Although the message can be delayed, immediately sending the LEAVE
   message eliminates the need for PAR and NAR to process traffic that
   is not to be forwarded.

4.2.4. IPv4 Support Considerations

   An MN in a PMIPv6 domain MAY use an IPv4 address transparently for
   communication, as specified in [RFC5844]. For this purpose, Local
   Mobility Anchors (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 multiprotocol multicast support on the
   network side, IGMPv3 router functions are required at both MAGs (see
   Section 5.6 for compatibility considerations with previous IGMP
   versions). Context transfer between MAGs can transparently proceed
   in the HI/HAck message exchanges by encapsulating IGMP multicast
   state records within Multicast Mobility Options (see Sections 5.3 and
   5.4 for details on message formats).

   The deployment of IPv4 multicast support SHOULD be homogeneous across
   a PMIP domain. This avoids multicast service breaks during
   handovers.

   It is worth mentioning the scenarios of a dual-stack IPv4/IPv6 access
   network and the use of Generic Routing Encapsulation (GRE) tunneling
   as specified in [RFC5845]. Corresponding implications and operations
   are discussed in the PMIP Multicast Base Deployment document (see
   [RFC6224]).

5. Message Formats

5.1. Multicast Indicator for Proxy Router Advertisement (PrRtAdv)

   This document updates the Proxy Router Advertisements (PrRtAdv)
   message format defined in Section 6.1.2 of [RFC5568]. The update
   assigns the first bit of the Reserved field to carry the 'M' bit, as
   defined in Figure 6. An FMIPv6 AR indicates support for multicast by
   setting the 'M' bit to a value of 1.

```
         0                   1                   2                   3
         0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
        |     Type      |     Code      |           Checksum            |
        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
        |    Subtype    |M|  Reserved   |            Identifier         |
        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
        |     Options ...
        +-+-+-+-+-+-+-+-+-+-+-
```
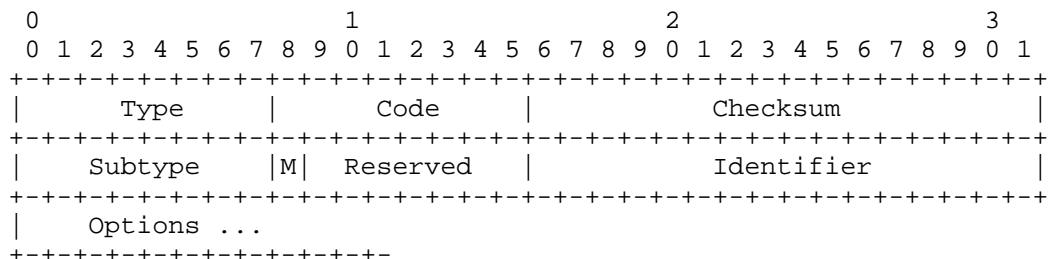
       Figure 6: Multicast Indicator Bit for Proxy Router Advertisement
                          (PrRtAdv) Message

This document updates the Reserved field to include the 'M' bit. It
is specified as follows.

   M = 1 indicates that the specifications of this document apply.

   M = 0 indicates that the behavior during fast handover proceeds
   according to [RFC5568].

The default value (0) of this bit indicates a non-multicast-capable
service.

5.2. Extensions to Existing Mobility Header Messages

The fast handover protocols use an IPv6 header type called Mobility
Header, as defined in [RFC6275]. Mobility Headers can carry variable
Mobility Options.

The multicast listener context of an MN is transferred in fast
handover operations from PAR/PMAG to NAR/NMAG within a new Multicast
Mobility Option and MUST be acknowledged by a corresponding Multicast
Acknowledgement Option. Depending on the specific handover scenario
and protocol in use, the corresponding option is included within the
mobility option list of HI/HAck only (PFMIPv6) or of FBU/FBack/HI/
HAck (FMIPv6).

5.3. New Multicast Mobility Option

This section defines the Multicast Mobility Option. It contains the
current listener state record of the MN obtained from the MLD
Multicast Listener Report message and has the format displayed in
Figure 7.

```
     0                   1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |      Type     |     Length    |  Option-Code  |   Reserved    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                                                               |
    +                                                               +
    |                                                               |
    +                MLD or IGMP Report Payload                     +
    ~                                                               ~
    ~                                                               ~
    |                                                               |
    +                                                               +
    |                                                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
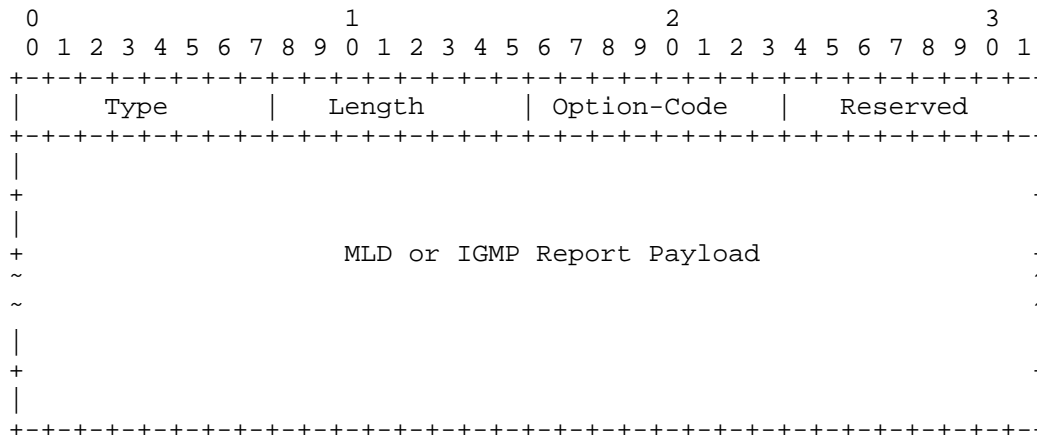
                Figure 7: Mobility Header Multicast Option

   Type: 60

   Length: 8-bit unsigned integer. The length of this option in 32-bit
   words, not including the Type, Length, Option-Code, and Reserved
   fields.

   Option-Code:

      1: IGMPv3 Payload Type

      2: MLDv2 Payload Type

      3: IGMPv3 Payload Type from IGMPv2 Compatibility Mode

      4: MLDv2 Payload Type from MLDv1 Compatibility Mode

   Reserved: MUST be set to zero by the sender and MUST be ignored by
   the receiver.

   MLD or IGMP Report Payload: This field is composed of the Membership
   Report message after stripping its ICMP header. This Report Payload
   always contains an integer number of multicast records.
   Corresponding message formats are defined for MLDv2 in [RFC3810] and
   for IGMPv3 in [RFC3376]. This field MUST always contain the first
   header line (Reserved field and No of Mcast Address Records).

   Figure 8 shows the Report Payload for MLDv2 (see Section 5.2 of
   [RFC3810] for the definition of Multicast Address Records). When
   IGMPv3 is used, the payload format is defined according to IGMPv3
   Group Records (see Section 4.2 of [RFC3376] for the definition of
   Group Records).

```
     0                   1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            Reserved           |No of Mcast Address Records (M)|
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                                                               |
    .                                                               .
    .               Multicast Address Record (1)                    .
    .                                                               .
    |                                                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                                                               |
    .                                                               .
    .               Multicast Address Record (2)                    .
    .                                                               .
    |                                                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                               .                               |
    .                               .                               .
    |                               .                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                                                               |
    .                                                               .
    .               Multicast Address Record (M)                    .
    .                                                               .
    |                                                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
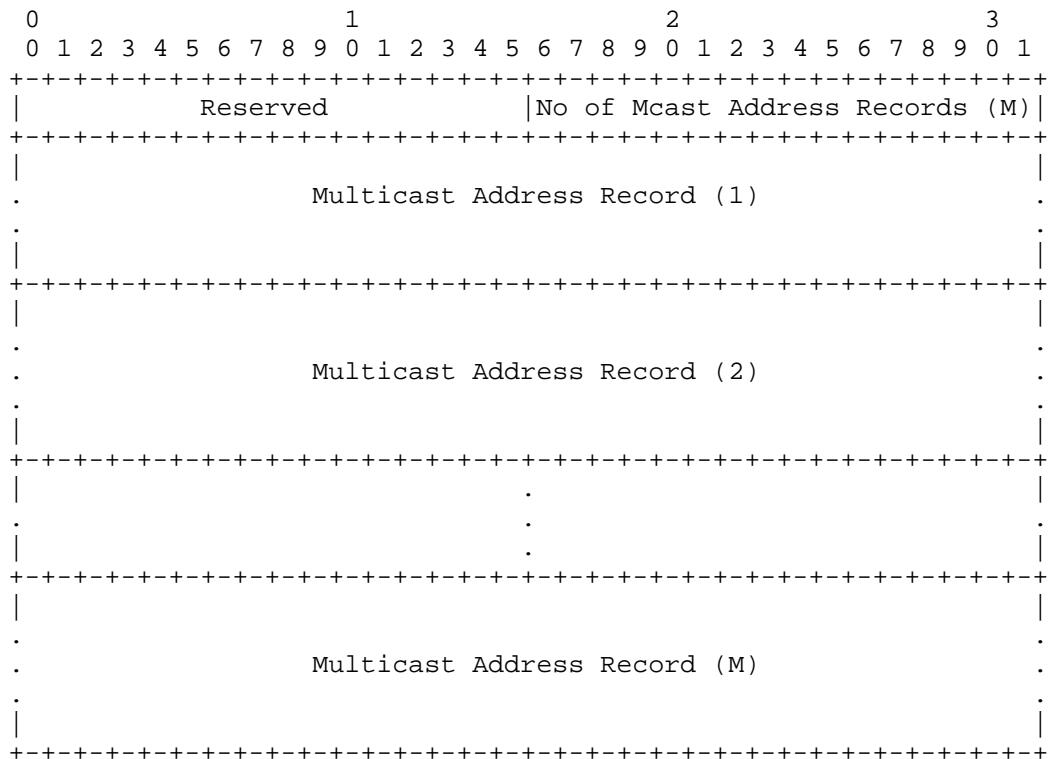
                     Figure 8: MLDv2 Report Payload

5.4. New Multicast Acknowledgement Option

   The Multicast Acknowledgement Option reports the status of the
   context transfer and contains the list of state records that could
   not be successfully transferred to the next access network. It has
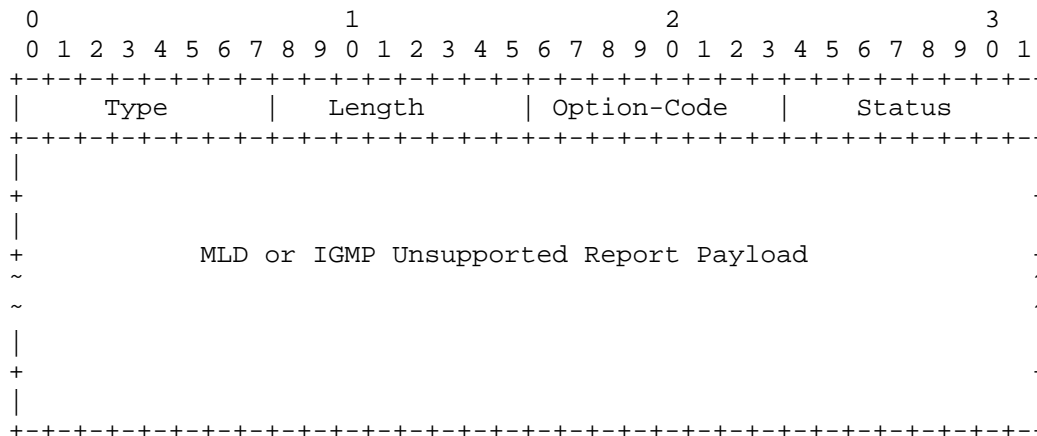   the format displayed in Figure 9.

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |     Type      |     Length    |  Option-Code  |    Status     |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   +                                                               +
   |                                                               |
   +           MLD or IGMP Unsupported Report Payload              +
   ~                                                               ~
   ~                                                               ~
   |                                                               |
   +                                                               +
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

          Figure 9: Mobility Header Multicast Acknowledgement Option

   Type: 61

   Length: 8-bit unsigned integer. The length of this option in 32-bit
   words, not including the Type, Length, Option-Code, and Status
   fields.

   Option-Code: 0

   Status:

      1: Report Payload type unsupported

      2: Requested group service unsupported

      3: Requested group service administratively prohibited

   MLD or IGMP Unsupported Report Payload: This field is syntactically
   identical to the MLD and IGMP Report Payload field described in
   Section 5.3 but is only composed of those Multicast Address Records
   that are not supported or prohibited in the new access network. This
   field MUST always contain the first header line (Reserved field and
   No of Mcast Address Records) but MUST NOT contain any Mcast Address
   Records if the status code equals 1.

Note that group subscriptions to specific sources may be rejected at
the destination network; thus, the composition of multicast address
records may differ from initial requests within an MLD or IGMP Report
Payload option.

5.5. Length Considerations: Number of Records and Addresses

Mobility Header messages exchanged in HI/HAck and FBU/FBack dialogs
impose length restrictions on multicast context records due to the
8-bit Length field. The maximal payload length available in FBU/
FBack messages is 4 octets (Mobility Option header line) + 1024
octets (MLD Report Payload). For example, not more than 51 Multicast
Address Records of minimal length (without source states) may be
exchanged in one message pair. In typical handover scenarios, this
number reduces further according to unicast context and Binding
Authorization data. A larger number of MLD reports that exceeds the
available payload size MAY be sent within multiple HI/HAck or FBU/
FBack message pairs. In PFMIPv6, context information can be
fragmented over several HI/HAck messages. However, a single MLDv2
Report Payload MUST NOT be fragmented. Hence, for a single Multicast
Address Record, the number of source addresses (S,.) is limited to
62.

5.6. MLD and IGMP Compatibility Requirements

Access routers (MAGs) MUST support MLDv2 and IGMPv3. To enable
multicast service for MLDv1 and IGMPv2 listeners, the routers MUST
follow the interoperability rules defined in [RFC3810] and [RFC3376]
and appropriately set the Multicast Address Compatibility Mode.

When the Multicast Address Compatibility Mode is MLDv1 or IGMPv2, a
router internally translates the subsequent MLDv1 and IGMPv2 messages
for that multicast address to their MLDv2 and IGMPv3 equivalents and
uses these messages in the context transfer. The current state of
Compatibility Mode is translated into the code of the Multicast
Mobility Option, as defined in Section 5.3. A NAR (NMAG) receiving a
Multicast Mobility Option during handover will switch to the lowest
level of MLD and IGMP Compatibility Mode that it learned from its
previous and new option values. This minimal compatibility agreement
is used to allow for continued operation.

6. Security Considerations

   Security vulnerabilities that exceed issues discussed in the base
   protocols mentioned in this document ([RFC5568], [RFC5949],
   [RFC3810], and [RFC3376]) are identified as follows.

   Multicast context transfer at predictive handovers implements group
   states at remote access routers and may lead to group subscriptions
   without further validation of the multicast service requests.
   Thereby, a NAR (NMAG) is requested to cooperate in potentially
   complex multicast rerouting and may receive large volumes of traffic.
   Malicious or inadvertent multicast context transfers may result in a
   significant burden of route establishment and traffic management onto
   the backbone infrastructure and the access router itself. Rapid
   rerouting or traffic overload can be mitigated by a rate control at
   the AR that restricts the frequency of traffic redirects and the
   total number of subscriptions. In addition, the wireless access
   network remains protected from multicast data injection until the
   requesting MN attaches to the new location.

7. IANA Considerations

   This document defines two new mobility options that have been
   allocated from the "Mobility Options" registry at
   <http://www.iana.org/assignments/mobility-parameters>:

      60 Multicast Mobility Option, described in Section 5.3

      61 Multicast Acknowledgement Option, described in Section 5.4

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Appendix A. Considerations for Mobile Multicast Sources

   This document only specifies protocol operations for fast handovers
   for mobile listeners. In this appendix, we briefly discuss aspects
   of supporting mobile multicast sources.

   In a multicast-enabled Proxy Mobile IPv6 domain, multicast sender
   support is likely to be enabled by any one of the mechanisms
   described in [RFC7287]. In this case, multicast data packets from an
   MN are transparently forwarded either to its associated LMA or to a
   multicast-enabled access network. In all cases, a mobile source can
   continue to transmit multicast packets after a handover from PMAG to
   NMAG without additional management operations. Packets (with a
   persistent source address) will continue to flow via the LMA or the
   access network into the previously established distribution system.

   In contrast, an MN will change its Care-of Address while performing
   FMIPv6 handovers. Even though MNs are enabled to send packets via
   the reverse NAR-PAR tunnel using their previous Care-of Address for a
   limited time, multicast sender support in such a Mobile IPv6 regime
   will most likely follow one of the basic mechanisms described in
   Section 5.1 of [RFC5757]: (1) bidirectional tunneling, (2) remote
   subscription, or (3) agent-based solutions. A solution for multicast
   senders that is homogeneously deployed throughout the mobile access
   network can support seamless services during fast handovers, the
   details of which are beyond the scope of this document.

Acknowledgments

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