Multicast Mobility in MIPv6: Problem Statement and Brief Survey
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IPR Statement

Status of this Memo

Abstract

   This document discusses current mobility extensions to IP layer
   multicast. It describes problems arising from mobile group
   communication in general, the case of multicast listener mobility,
   and for mobile senders using Any Source Multicast and Source Specific
   Multicast. Characteristic aspects of multicast routing and deployment
   issues for fixed IPv6 networks are summarized. Specific properties
   and interplays with the underlying network access are surveyed with
   respect to the relevant technologies in the wireless domain. It

outlines the principal approaches to multicast mobility, together
with a comprehensive exploration of the mobile multicast problem and
solution space. This document concludes with a conceptual roadmap for
initial steps in standardization for use by future mobile multicast
protocol designers.

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1. Introduction and Motivation

   Group communication forms an integral building block of a wide
   variety of applications, ranging from content broadcasting and
   streaming, voice and video conferencing, collaborative environments
   and massive multiplayer gaming, up to the self-organization of
   distributed systems, services or autonomous networks. Network layer
   multicast support will be needed whenever globally distributed,
   scalable, serverless or instantaneous communication is required.

   The early idea of Internet multicasting [2] soon lead to a wide
   adoption of Deering's host group model [3]. Broadband media delivery
   is emerging as a typical mass scenario that demands scalability and
   bandwidth efficiency from multicast routing. Although multicast
   mobility has been a concern for about ten years [4] and has led to
   numerous proposals, there is as yet no generally accepted solution.
   Multicast network support will be of particular importance to mobile
   environments, where users commonly share frequency bands of limited
   capacity. Reception of 'infotainment' streams may soon require wide
   deployment of mobile multicast services.

   Mobility in IPv6 [5] is standardized in the Mobile IPv6 RFCs [6,7].
   MIPv6 [6] only roughly defines multicast mobility for Mobile Nodes
   (MN), using a remote subscription approach or through bi-directional
   tunneling via the Home Agent (HA). Remote subscription suffers from
   slow handovers, relying on multicast routing to adapt to handovers.
   Bi-directional tunneling introduces inefficient overhead and delay
   due to triangular forwarding, i.e., instead of traveling on shortest
   paths, packets are routed through the Home Agent. Therefore these

approaches have not been optimized for a large scale deployment. A
mobile multicast service for a future Internet should provide 'close
to optimal' routing at predictable and limited cost, offering
robustness combined with a service quality compliant to real-time
media distribution.

Intricate multicast routing procedures are not easily extensible to
satisfy the requirements for mobility. A client subscribed to a group
while performing mobility handovers, requires the multicast traffic
to follow to its new location; a mobile source needs the entire
delivery tree to comply with or to adapt to its changing position.
Significant effort has already been invested in protocol designs for
mobile multicast receivers; only limited work has been dedicated to
multicast source mobility, which poses the more delicate problem
[63].

In multimedia conference scenarios, games or collaborative
environments each member commonly operates as a receiver and as a
sender for multicast group communication. In addition, real-time
communication such as conversational voice or video places severe
temporal requirement on mobility protocols: Typical seamless handover
scenarios are expected to limit disruptions or delay to less than 100
ms. Jitter disturbances should not exceed 50 ms. Note that 100 ms is
about the duration of a spoken syllable in real-time audio. This
problem statement is intended to also be applicable to a range of
other scenarios with a range of delivery requirements appropriate to
the general Internet.

1.1 Document Scope

This document defines the problem scope for multicast mobility
management, which may be elaborated in future work. It is subdivided
to present the various challenges according to their originating
aspects, and identifies existing proposals and major bibliographic
references.

When considering multicast node mobility, two basic scenarios are of
interest: Single-hop mobility (shown in figure 1.a) and multi-hop
mobile routing (figure 1.b). Single-hop mobility is the focus of this
document, which coincides with the perspective of MIPv6 [6]. The key
issues of mobile multicast membership control, and the interplay of
mobile and multicast routing will be illustrated using this simple
scenario.

Multi-hop network mobility is a subsidiary scenario. All major
aspects are inherited from the single-hop problem, while additional
complexity is incurred from traversing a mobile cloud. This may be
solved by either encapsulation or flooding ([8] provides a general

overview). Specific issues arising from (nested) tunneling or

flooding, especially the preservation of address transparency,
require treatment analogous to MIPv6.

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                                            ***  ***  ***   ***
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   +------+           +------+             *                    *
   |  MN  |  =====>    |  MN  |             *   Mobile Network  *
   +------+           +------+             *                    *
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     *                    *                   *                    *
      *  Fixed Internet  *                     *  Fixed Internet  *
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      *   **   **   **   *                     *   **   **   **   *
       ***  ***  ***  ***                       ***  ***  ***  ***

      a) Single-Hop Mobility                   b) Multi-Hop Mobility
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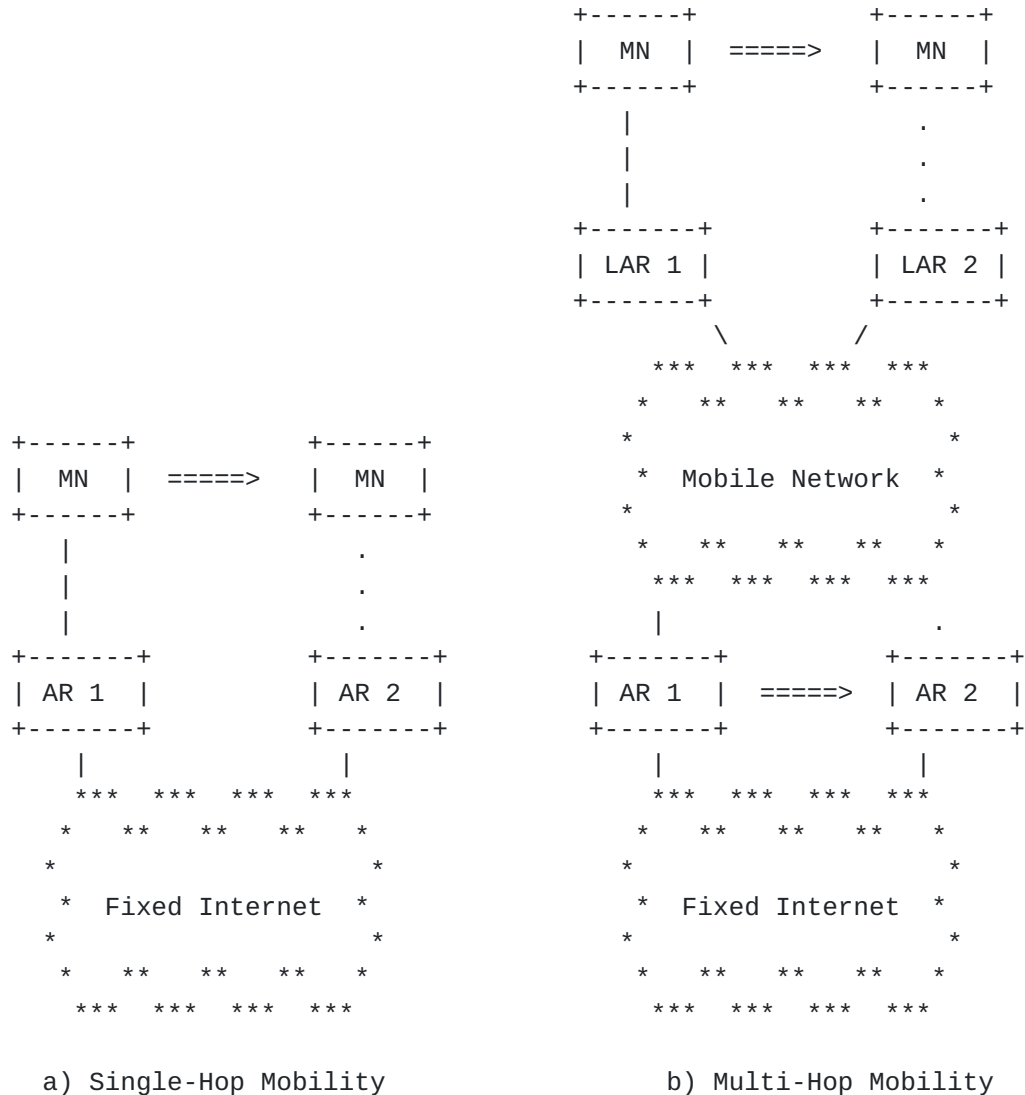
Figure 1: Mobility Scenarios

2. Problem Description

2.1 General Issues

Multicast mobility is a generic term, which subsumes a collection of
distinct functions. First, multicast communication is divided into
Any Source Multicast (ASM) [3] and Source Specific Multicast (SSM)
[9,10]. Second, the roles of senders and receivers are distinct and
asymmetric. Both may individually be mobile. Their interaction is
facilitated by a multicast routing protocol such as DVMRP [11], PIM-

SM/SSM [12,13], Bi-directional PIM [14],or inter-domain multicast
prefix advertisements via MBGP [15]. IPv6 clients interact using the
multicast listener discovery protocol (MLD and MLDv2) [16,17]. Other
multicast routing protocols without significant current deployment
include CBT [18], BGMP [19].

Any multicast mobility solution must take all of these functional
blocks into account. It should enable seamless continuity of
multicast sessions when moving from one IPv6 subnet to another. It
should preserve the multicast nature of packet distribution and
approximate optimal routing. It should support per-flow handover for
multicast traffic, because the properties and designations of flows
can be distinct. Such distinctions may result from differing
QoS/real-time requirements, but may also be caused by network
conditions that may differ for different groups.

The host group model extends the capability of the network layer
unicast service. In common with the architecture of fixed networks,
multicast mobility management should transparently utilize or
smoothly extend the unicast functions of MIPv6 [6], its security
extensions [7,20], its expediting schemes FMIPv6 [21] and HMIPv6
[22], its context transfer protocols [23], its multihoming
capabilities [24,25], emerging protocols like PMIPv6 [61] or future
developments. From the perspective of an integrated mobility
architecture, it is desirable to avoid multicast-specific as well as
unicast-restricted solutions, whenever general approaches can be
derived that can jointly support unicast and multicast.

Multicast routing dynamically adapts to the topology of the sender(s)
and receiver(s) participating in a multicast session, which then may
change under mobility. However, depending on the topology and the
protocol in use, current multicast routing protocols may require a
time close to seconds, or even minutes, to converge following a
change in receiver or sender location. This is far too slow to
support seamless handovers for interactive or real-time media
sessions. The actual temporal behavior strongly depends on the
multicast routing protocol in use, the configuration of routers, and
on the geometry of the current distribution tree. A mobility scheme
that re-adjusts routing, i.e., partially changes or fully
reconstructs a multicast tree, is forced to comply with the time
scale for protocol convergence. Specifically, it needs to consider a
possible rapid movement of the mobile node, as this may occur at much
higher rates than common protocol state updates.

The mobility of hosts using IP multicast can impact the service
presented to the higher-layer protocols. IP layer multicast packet
distribution is an unreliable service that is bound to connectionless
transport protocols. Where applications are sensitive to packet loss

or jitter, countermeasures must be performed (loss recovery, content

recoding, concealment, etc) by the multicast transport or
application. Mobile multicast handovers should not introduce
significant additional packet drops. Due to statelessness, the bi-
casting of multicast flows does not cause foreseeable degradations at
the transport layer.

IP multicast applications can be designed to adapt the multicast
stream to prevailing network conditions (adapting the sending rate to
the level of congestion, adaptive tuning of clients in response to
measured delay, dynamic suppression of feedback messages, etc). An
adaptive application may also use more than one multicast group
(e.g., layered multicast in which a client selects a set of multicast
groups based on perceived available network capacity). A mobility
handover may temporarily disrupt the operation of these higher-layer
functions. The handover can invalidate assumptions about the
forwarding path (e.g., acceptable delivery rate, round trip delay),
which could impact an application and level of network traffic. Such
effects need to be considered in the design of multicast applications
and in the design of network-layer mobility. Specifically, mobility
mechanisms need to be robust to transient packet loss that may result
from invalid path expectations following a handover of an MN to a
different network.

Group addresses in general are location transparent, even though they
may be scoped and methods can embed unicast prefixes or Rendezvous
Point addresses [26]. The addresses of sources contributing to a
multicast session are interpreted by the routing infrastructure and
by receiver applications, which frequently are aware of source
addreses. Multicast therefore inherits the mobility address duality
problem of MIPv6 for source addresses: Addresses being a logical node
identifier, i.e., the home address (HoA) on the one hand, and a
topological locator, the care-of-address (CoA), on the other. At the
network layer, the elements that comprise the delivery tree, i.e.,
multicast senders, forwarders and receivers, need to carefully
account for address duality issues, e.g., by using binding caches,
extended multicast states or signaling.

Multicast sources in general operate decoupled from their receivers
in the following sense: A multicast source sends packets to a group
of unknown receivers and thus operates without a feedback channel. It
neither has means to inquire about the properties of its delivery
trees, nor is it able to learn about the network-layer state of its
receivers. In the event of an inter-tree handover, a mobile multicast
source therefore is vulnerable to loosing connectivity to receivers
without noticing. (Appendix A describes implicit source notification
approaches). Applying a MIPv6 mobility binding update or return
routability procedure will similarly break the semantic of a receiver
group remaining unidentified by the source and thus cannot be applied

in unicast analogy.

Despite the complexity of the requirements, multicast mobility
management should seek lightweight solutions with easy deployment.
Realistic, sample deployment scenarios and architectures should be
provided in future solution documents.

2.2 Multicast Listener Mobility

2.2.1 Node & Application Perspective

A mobile multicast listener entering a new IP subnet requires
multicast reception following a handover in real-time. This needs to
transfer the multicast membership context from its old to its new
point of attachment. This can either be achieved by (re-)
establishing a tunnel or by transferring the MLD Listening State
information of the MN's moving interface(s) to the new upstream
router(s). In the latter case, it may encounter either one of the
following conditions: The new network may not be multicast-enabled or
the specific multicast service may be unavailable, e.g. unsupported
or prohibited. Alternatively, the requested multicast service may be
supported and enabled in the visited network, but the multicast
groups under subscription may not be forwarded to it. This means that
current distribution trees for the desired groups may only be re-
joined at a large routing distance. The simplest scenario is when
packets of some, or all, of the subscribed groups of the mobile node
are already received by one or several group members in the
destination network, and thus multicast streams natively flow after
the MN arrives at the new network.

The problem of achieving seamless multicast listener handovers is
thus threefold:
  o Ensure multicast reception, even in visited networks, without
    appropriate multicast support.
  o Minimize multicast forwarding delay to provide seamless
    and fast handovers for real-time services. Dependant on layer 2
    and 3 handover performance, the time available for multicast
    mobility operations is typically bound to a fraction of 100 ms.
  o Minimize packet loss and reordering that result from multicast
    handover management.

Moreover, in many wireless regimes it is also desirable to minimize
multicast-related signaling to preserve the limited resources of
battery powered mobile devices and the constrained transmission
capacities of the networks. This may lead to a desire to restrict MLD
queries towards the MN. Multihomed MNs may ensure smooth handoffs by
using a 'make-before-break' approach, which requires a per interface
subscription, facilitated by an MLD JOIN operating on a pre-selected
IPv6 interface.

Encapsulation on the path between the upstream router and the
receiver may result in MTU size conflicts, since path-MTU discovery
is often not supported for multicast and can reduce scalability in
networks with many different MTU sizes or introduce potential denial
of service vulnerabilities (since the originating addresses of ICMPv6
messages can not be verified for multicast). In the absence of
fragmentation at tunnel entry points, this may prevent the group
being forwarded to the destination.

2.2.2 Network Perspective

The infrastructure providing multicast services is required to keep
traffic following the MN without compromising network functionality.
Mobility solutions thus have to face some immediate problems:

   o Realize native multicast forwarding, and where applicable
     conserve network resources and utilize link layer multipoint
     distribution to avoid data redundancy.
   o Activate link multipoint services, even if the MN performs
     only a layer 2 / vertical handover.
   o Ensure routing convergence, even when the MN moves rapidly
     and performs handovers at a high frequency.
   o Avoid avalanche problems and n-casting, which potentially result
     from replicated tunnel initiation or redundant forwarding at
     network nodes.

There are additional implications for the infrastructure: In changing
its point of attachment, an exclusive mobile receiver may cause
initiation in the new network and termination of a group distribution
service in the previous network. Mobility management may issue
traffic directives that lead to suboptimal routing, i.e., erroneous
subscriptions following predictive handover operations, or slow
effective leaves caused by MLD querying, or by departure of the MN
from a previous network without leaving the subscribed groups.
Finally, packet duplication and re-ordering may follow a change of
topology.

2.3 Multicast Source Mobility

2.3.1 Any Source Multicast Mobility

A node submitting data to an ASM group either forms the root of a
source specific shortest path tree (SPT), distributing data towards a
rendezvous point (RP) or receivers, or it forwards data directly down
a shared tree, e.g., via encapsulated PIM Register messages, or using
bi-directional PIM routing. Native forwarding along source specific
delivery trees will be bound to the source's topological network
address, due to reverse path forwarding (RPF) checks. A mobile

multicast source moving to a new subnetwork is only able to either

inject data into a previously established delivery tree, which may be
a rendezvous point based shared tree, or to (re)initiate the
construction of a multicast distribution tree for its new network
location. In the latter case, the mobile sender will have to precede
without knowing whether the new tree has regained ability to forward
traffic to the group, due to the decoupling of sender and receivers.

A mobile multicast source must therefore provide address transparency
at two layers: To comply with RPF checks, it has to use an address
within the source field of the IPv6 basic header, which is in
topological agreement with the employed multicast distribution tree.
For application transparency the logical node identifier, commonly
the HoA, must be presented as the packet source address to the
transport layer at the receiver side.

The address transparency and temporal handover constraints pose major
problems for route optimizing mobility solutions. Additional issues
arise from possible packet loss and from multicast scoping. A mobile
source away from home must respect scoping restrictions that arise
from its home and its visited location [6].

Intra-domain multicast routing may allow the use of shared trees that
can reduce mobility-related complexity. A static rendezvous point may
allow a mobile source to continuously send data to the group by
encapsulating packets to the RP with its previous topologically
correct or home source address. Intra-domain mobility is
transparently provided by bi-directional shared domain-spanning
trees, when using bi-directional PIM, eliminating the need for
tunneling to the corresponding RP (in contrast to IPv4, IPv6 ASM
multicast groups are associated with a specific RP/RPs).

Issues arise in inter-domain multicast, whenever notification of
source addresses is required between distributed instances of shared
trees. A new CoA acquired after a mobility handover will necessarily
be subject to inter-domain record exchange. In the presence of an
embedded rendezvous point address [26], e.g., the primary rendezvous
point for inter-domain PIM-SM will be globally appointed and the
signaling requirements obsolete.

2.3.2 Source Specific Multicast Mobility

Source Specific Multicast has been designed for multicast senders
with static source addresses. The source addresses in a client
subscription to an SSM group is directly used to route
identification. Any SSM subscriber is thus forced to know the
topological address of the contributor to the group it wishes to
join. The SSM source identification becomes invalid when the
topological source address changes under mobility. Hence client

implementations of SSM source filtering must be MIPv6 aware in the

sense that a logical source identifier (HoA) is correctly mapped to
its current topological correspondent (CoA).

As a consequence, source mobility for SSM requires a conceptual
treatment beyond the problem scope of mobile ASM. A listener
subscribes to an (S,G) channel membership and routers establish an
(S,G)-state shortest path tree rooted at source S, therefore any
change of source addresses under mobility requires state updates at
all routers on the upstream path and at all receivers in the group.
On source handover, a new SPT needs to be established that will share
paths with the previous SPT, e.g., at the receiver side. As the
principle multicast decoupling of a sender from its receivers holds
for SSM, the client updates needed for switching trees become a
severe burden.

An SSM listener may subscribe to or exclude any specific multicast
source, and thereby wants to rely on the topological correctness of
network operations. The SSM design permits trust in equivalence to
the correctness of unicast routing tables. Any SSM mobility solution
should preserve this degree of confidence. Binding updates for SSM
sources thus should have to prove address correctness in the unicast
routing sense, which is equivalent to binding update security with a
correspondent node in MIPv6 [6].

The above methods add significant complexity to provide a robust SSM
mobility solution, which needs to converge to optimal routes and, for
efficiency, should avoid data encapsulation. Like ASM, handover
management is a time-critical operation. The routing distance between
subsequent points of attachment, the 'step size' of the mobile from
previous to next designated router, may serve as an appropriate
measure of complexity [27,28].

Finally, Source Specific Multicast has been designed as a light-
weight approach to group communication. In adding mobility
management, it is desirable to preserve the leanness of SSM by
minimizing additional signaling overhead.

2.4 Deployment Issues

IP multicast deployment in general has been hesitant over the past 15
years, even though all major router vendors and operating systems
offer implementations that support multicast [29]. While many
(walled) domains or enterprise networks operate point-to-multipoint
services, IP multicast rollout is currently limited in public inter-
domain scenarios [30]. A dispute arose on the appropriate layer,
where group communication service should reside, and the focus of the
research community turned towards application layer multicast. This
debate on "efficiency versus deployment complexity" now overlaps the

mobile multicast domain [31]. Garyfalos and Almeroth [32] derived

from fairly generic principles that when mobility is introduced, the
performance gap between IP and application layer multicast widens in
different metrics up to a factor of four.

Facing deployment complexity, it is desirable that any solution for
mobile multicast should leave routing protocols unchanged. Mobility
management in such a deployment-friendly scheme should preferably be
handled at edge nodes, preserving a mobility-agnostic routing
infrastructure. Future research needs to search for such simple,
infrastructure transparent solutions, even though there are
reasonable doubts, whether this can be achieved in all cases.

Nevertheless, multicast services in mobile environments may soon
become indispensable, when multimedia distribution services such as
DVB-H [33,34] or IPTV develop a strong business case for IP
portables. As IP mobility becomes an important service and as
efficient link utilization is of a larger impact in costly radio
environments, the evolution of multicast protocols will naturally
follow mobility constraints.

3.Characteristics of Multicast Routing Trees under Mobility

Multicast distribution trees have been studied from a focus of
network efficiency. Grounded on empirical observations Chuang and
Sirbu [35] proposed a scaling power-law for the total number of links
in a multicast shortest path tree with m receivers (proportional to
m^k). The authors consistently identified the scale factor to attain
the independent constant k = 0.8. The validity of such universal,
heavy-tailed distribution suggests that multicast shortest path trees
are of self-similar nature with many nodes of small, but few of
higher degrees. Trees consequently would be shaped rather tall than
wide.

Subsequent empirical and analytical work [36,37] debated the
applicability of the Chuang and Sirbu scaling law. Van Mieghem et al.
[36] proved that the proposed power law cannot hold for an increasing
Internet or very large multicast groups, but is indeed applicable for
moderate receiver numbers and the current Internet size $N = 10^5$ core
nodes. Investigating self-similarity Janic and Van Mieghem [38] semi-
empirically substantiated that multicast shortest path trees in the
Internet can be modeled with reasonable accuracy by uniform recursive
trees (URT) [39], provided m remains small compared to N.

The mobility perspective on shortest path trees focus on their
alteration, i.e., the degree of topological changes induced by
movement. For receivers, and more interestingly for sources this may
serve as an outer measure for routing complexity. Mobile listeners

moving to neighboring networks will only alter tree branches

extending over a few hops. Source specific multicast trees
subsequently generated from source handover steps are not
independent, but highly correlated. They most likely branch to
identical receivers at one or several intersection points. By the
self-similar nature, the persistent sub-trees (of previous and next
distribution tree), rooted at any such intersection point, exhibit
again the scaling law behavior, are tall-shaped with nodes of mainly
low degree and thus likely to coincide. Tree alterations under
mobility have been studied in [28], both analytically and by
simulations. It was found that even in large networks and for
moderate receiver numbers more than 80 % of the multicast router
states remain invariant under a source handover.

4. Link Layer Aspects

4.1 General Background

Scalable group data distribution has the highest potential in leaf
networks, where large numbers of end systems reside. Consequently, it
is not surprising that most LAN network access technologies natively
support point-to-multipoint or multicast services. Of focal interest
to the mobility domain are wireless access technologies, which always
operate on a shared medium with limited frequency and bandwidth.

Several aspects need consideration: First, dissimilar network access
radio technologies cause distinct group traffic transmissions. There
are:

  o connection-less link services of a broadcast type, which mostly
    are bound to limited reliability;

  o connection-oriented link services of a point-to-multipoint type,
    which require more complex control and frequently exhibit reduced
    efficiency;

  o connection-oriented link services of a broadcast type, which are
    restricted to unidirectional data transmission.

Second, point-to-multipoint service activation at the network access
layer requires a mapping mechanism from network layer requests. This
function is commonly achieved by L3 awareness, i.e., IGMP/MLD
snooping [67] or proxy [40], which occasionally is complemented by
Multicast VLAN Registration (MVR). MVR allows sharing of a single
multicast IEEE 802.1Q Virtual LAN in the network, while subscribers
remain in separate VLANs. This layer 2 separation of multicast and
unicast traffic can be employed as a workaround for point-to-point
link models to establish a common multicast link.

Third, an address mapping between the layers is needed for common
group identification. Address resolution schemes depend on framing
details for the technologies in use, but commonly cause a significant
address overlap at the lower layer.

4.2 Multicast for Specific Technologies

4.2.1 802.11 WLAN

IEEE 802.11 WLAN is a broadcast network of Ethernet type. This
inherits multicast address mapping concepts from 802.3. In
infrastructure mode an access point operates as repeater, only
bridging data between the Base (BSS) and the Extended Service Set
(ESS). A mobile node submits multicast data to an access point in
point-to-point acknowledged unicast mode (when the ToDS bit is set).
An access point receiving multicast data from a MN simply repeats
multicast frames to the BSS and propagates them to the ESS as
unacknowledged broadcast. Multicast frames received from the ESS
receive similar treatment.

Multicast frame delivery has the following characteristics:

 o As an unacknowledged service it offers limited reliability.
   Frames (and hence packet) loss arise from interference,
   collision, or time-varying channel properties.

 o Data distribution may be delayed, as unicast power saving
   synchronization via Traffic Indication Messages (TIM) does not
   operate in multicast mode. Access points buffer multicast packets
   while waiting for a larger DTIM interval, whenever stations use
   the power saving mode.

 o Multipoint data may cause congestion, because the distribution
    system floods multicast, without further control. All access
   points of the same subnet replicate multicast frames.

To limit or prevent the latter, many vendors have implemented a
configurable rate limit for forwarding multicast packets.
Additionally, an IGMP/MLD snooping or proxy may be active at the
bridging layer between the BSS and the ESS or at switches
interconnecting access points.

4.2.2 802.16 WIMAX

IEEE 802.16 WIMAX combines a family of connection-oriented radio
transmission services, operating in distinguished, unidirectional
channels. The channel assignment is controlled by Base Stations,
which assign channel IDs (CIDs) within service flows to the
subscriber stations. Service flows may provide an optional Automatic

Repeat Request (ARQ) to improve reliability and may operate in point-
to-point or point-to-multipoint (restricted to downlink and without
ARQ) mode.

A WIMAX Base Station operates as a L2 switch in full duplex mode,
where switching is based on CIDs. Two possible IPv6 link models for
mobile access deployment scenarios exist: Shared IPv6 prefix and
point-to-point link model [41]. The latter treats each connection to
a mobile node as a single link and is recommended in the IPv6
Convergence Sublayer [42], while MAC separation within a shared
prefix is applied in the IP over Ethernet CS [43]. The point-to-point
link model on the IP layer conflicts with a consistent group
distribution via a shared medium (cf. section 4.1 for MVR as a
workaround).

To invoke a multipoint data channel, the base station assigns a
common CID to all Subscriber Stations in the group. An IPv6 multicast
address mapping to these 16 bit IDs is proposed by copying either the
4 lowest bits, while sustaining the scope field, or by utilizing the
8 lowest bits derived from Multicast on Ethernet CS [44]. For
selecting group members, a Base Station may implement IGMP/MLD
snooping or proxy as foreseen in 802.16e-2005 [45].

A Subscriber Station will send multicast data to a Base Station as a
point-to-point unicast stream, which - in the presence of the IPv6 CS
- is forwarded to the upstream access router. The access router or -
in the presence of the IP over Ethernet CS - the Base Station may
return multicast data to the downstream Base Station by feeding into
a multicast service channel. On reception, a Subscriber Station
cannot distinguish multicast from unicast streams.

Multicast services have the following characteristics:

 o Multicast CIDs are unidirectional and available only in the
   downlink direction. Thus a native broadcast-type forwarding model
   is not available.

 o The mapping of multicast addresses to CIDs needs standardization,
   since different entities (Access Router, Base Station) may have
   to perform the mapping.

 o CID collisions for different multicast groups are very likely due
   to the short ID space. As a consequence, multicast data
   transmission may occur in joint point-to-multipoint groups of
   reduced selectiveness.

 o The point-to-point link model for mobile access contradicts a
   consistent mapping of IP layer multicast onto 802.16
   point-to-multipoint services.

o Multipoint channels cannot operate ARQ service and thus
  experience a reduced reliability.

4.2.3 3GPP

The 3GPP System architecture spans a circuit switched (CS) and a
packet switched (PS) domain, the latter General Packet Radio Services
(GPRS) incorporates the IP Multimedia Subsystem (IMS) [46]. The 3GPP
PS is connection-oriented and based on the concept of Packet Data
Protocol (PDP) Contexts. PDPs define point-to-point links between the
Mobile Terminal and the Gateway GPRS Support Node (GGSN). Internet
service types are PPP, IPv4 and IPv6, where the recommendation for
IPv6 address assignment associates a prefix to each (primary) PDP
context [47]. Current packet filtering practice causes inter-working
problems between Mobile IPv6 nodes connected via GPRS [48].

In UMTS Rel. 6 the IMS was extended to include Multimedia Broadcast
and Multicast Services (MBMS). A point-to-multipoint GPRS connection
service is operated on radio links, while the gateway service to
Internet multicast is handled at the IGMP/MLD-aware GGSN. Local
multicast packet distribution is used within the GPRS IP backbone
resulting in the common double encapsulation at GGSN: global IP
multicast datagrams over GTP (with multipoint TID) over local IP
multicast.

The 3GPP MBMS has the following characteristics:

o There is no immediate layer 2 source-to-destination transition,
  resulting in transit of all multicast traffic at the GGSN.

o As GGSN commonly are regional, distant entities, triangular
  routing and encapsulation may cause a significant degradation of
  efficiency.

4.2.4 DVB-H / DVB-IPDC

Digital Video Broadcasting for Handhelds (DVB-H) is a unidirectional
physical layer broadcasting specification for the efficient delivery
of broadband, IP-encapsulated data streams, and published as an ETSI
standard [49] (see http://www.dvb-h.org). DVB uses a mechanism called
multi-protocol encapsulation (MPE), which enables a transport of
network layer protocols on top of a link layer built from MPEG-2
transport streams and includes link forward error correction (FEC).
In this model, DVB transmission networks not only support TV
broadcasting, but also offer an IP Datacast Service. DVB-IPDC [33]
consists of a number of individual, application layer specifications,
some of which continue to be developed. Transport Streams (TS) form
the basic logical channels, identified by a 13 bit TS ID (PID). This,

together with a multiplex service ID, is associated with IPv4 or IPv6
addresses [50] and used for selective traffic filtering at receivers.
Upstream channels may complement DVB-H using alternative transmission
technologies.

Multicast distribution services are defined by a mapping of groups
onto appropriate PIDs, which is managed at the IP Encapsulator [51].
To increase flexibility and avoid collisions, this address resolution
is facilitated by dynamic tables, provided within the self-consistent
MPEG-2 TS. Mobility is supported in the sense that changes of cell
ID, network ID or Transport Stream ID are foreseen [52]. A multicast
receiver thus needs to re-locate the multicast services it is
subscribed to, which is to be done in the synchronization phase, and
update its service filters. Its handover decision may depend on
service availability. An active service subscription (multicast join)
requires initiation at the IP Encapsulator / DVB-H Gateway, which
cannot be signaled in a pure DVB-H network.

4.3 Vertical Multicast Handovers

A mobile multicast node may operate homogeneous (horizontal) or
heterogeneous (vertical) layer 2 handovers with or without layer 3
network changes. Consequently, a dedicated context transfer of
multicast configuration is required at network access. Media
Independent Handover (MIH) is addressed in IEEE 802.21 [53], but is
relevant also beyond IEEE protocols. Mobility services transport for
MIH naturally reside on the network layer and are currently in the
process of specification [54].

MIH needs to assist in more than service discovery: There is a need
for complex, media dependent multicast adaptation, a possible absence
of MLD signaling in L2-only transfers and requirements originating
from predictive handovers, a multicast mobility services transport
needs to be sufficiently comprehensive and abstract to initiate a
seamless multicast handoff at network access.

Functions required for MIH include:

 o Service discovery.
 o Service context transformation.
 o Service context transfer.
 o Service invocation.

5. Solutions

5.1 General Approaches

Three approaches to mobile multicast are common [55]:

o Bi-directional Tunnelling, in which the mobile node tunnels all
  multicast data via its home agent. This fundamental multicast
  solution hides all movement and results in static multicast
  trees. It may be employed transparently by mobile multicast
  listeners and sources, at the cost of triangular routing and
  possibly significant performance degradation from widely spanned
  data tunnels.

o Remote Subscription forces the mobile node to re-initiate
  multicast distribution following handover, e.g., by submitting an
  MLD listener report to the subnet where a receiver attaches. This
  approach of tree discontinuation relies on multicast dynamics to
  adapt to network changes. It not only results in significant
  service disruption, but leads to mobility-driven changes of
  source addresses, and thus cannot support session persistence
  under multicast source mobility.

o Agent-based solutions attempt to balance between the previous two
  mechanisms. Static agents typically act as local tunnelling
  proxies, allowing for some inter-agent handover when the mobile
  node moves. A decelerated inter-tree handover, i.e. 'tree
  walking', will be the outcome of agent-based multicast mobility,
  where some extra effort is needed to sustain session persistence
  through address transparency of mobile sources.

MIPv6 [6] introduces bi-directional tunnelling as well as remote
subscription as minimal standard solutions. Various publications
suggest utilizing remote subscription for listener mobility only,
while advising bi-directional tunnelling as the solution for source
mobility. Such an approach avoids the 'tunnel convergence' or
'avalanche' problem [55], which refers to the responsibility of the
home agent to multiply and encapsulate packets for many receivers of
the same group, even if they are located within the same subnetwork.
However, this suffers from the drawback that multicast communication
roles are not explicitly known at the network layer and may change
unexpectedly.

None of the above approaches address SSM source mobility, except the
use of bi-directional tunnelling.

5.2 **Solutions for Multicast Listener Mobility**

5.2.1 **Agent Assistance**

There are proposals for agent-assisted handover for host-based
mobility, which complement the unicast real-time mobility
infrastructure of Fast MIPv6 [21], the M-FMIPv6 [56,57], and of

Hierarchical MIPv6 [22], the M-HMIPv6 [58], and to context transfer
[59], which have been thoroughly analyzed in [27,60].

Network based mobility management, PMIPv6 [61], at its current stage
of evolution is multicast transparent, as the MN experiences a point-
to-point home link fixed at its local mobility anchor (LMA). A PMIPv6
domain thereby inherits the tunnel convergence problem; future
optimizations and extensions to shared links should foresee native
multicast distribution towards the edge network, including context
transfer between access gateways to assist IP-mobility-agnostic MNs.

An approach based on dynamically negotiated inter-agent handovers is
presented in [62]. Aside from IETF work, countless publications
present proposals for seamless multicast listener mobility, e.g. [63]
provides a comprehensive overview.

5.2.2 Multicast Encapsulation

Encapsulation of multicast data packets is an established method to
shield mobility and to enable access to remotely located data
services, e.g., streams from the home network. Applying generic
packet tunnelling in IPv6 [64] using a unicast point-to-point method
will also allow multicast-agnostic domains to be transited, but does
inherit the tunnel convergence problem and may result in traffic
multiplication.

Multicast enabled environments may take advantage of point-to-
multipoint encapsulation, i.e., generic packet tunnelling using an
appropriate multicast destination address in the outer header. Such
multicast-in-multicast encapsulated packets similarly enable
reception of remotely located streams, but do not suffer from the
scaling overhead from using unicast tunnels.

The tunnel entry point performing encapsulation should provide
fragmentation of data packets to avoid issues resulting from MTU size
constraints within the network(s) supporting the tunnel(s).

5.2.3 Hybrid Architectures

There has been recent interest in seeking method that avoid the
complexity at the Internet core network, e.g. application layer and
overlay proposals for (mobile) multicast. The possibility of
integrating multicast distribution on the overlay into the network
layer is also being considered by the IRTF Scalable Adaptive
Multicast (SAM) Research Group.

An early hybrid architecture using reactively operating proxy-
gateways located at the Internet edges was introduced by Garyfalos
and Almeroth [32]. The authors presented an Intelligent Gateway

Multicast as a bridge between mobility-aware native multicast
management in access networks and mobility group distribution
services in the Internet core, which may be operated on the network
or application layer. The Hybrid Shared Tree approach [65] introduced
a mobility-agnostic multicast backbone on the overlay.

Current work in the SAM RG is developing general architectural
approaches for hybrid multicast solutions [66] that will require a
detailed design in future work.

5.2.4 MLD Extensions

The default timer values specified in MLD [17] were not designed for
the mobility context. This results in a slow reaction of the
multicast routing infrastructure (including layer-3-aware access
devices [67]) following a client leave. This may be a disadvantage
for wireless links, where performance may be improved by carefully
tuning the Query Interval. Some vendors have optimised performance by
implementing a listener node table at the access router that can
eliminate query timeouts on leaves (explicit receiver tracking).

A MN operating predictive handover, e.g., using FMIPv6, may
accelerate multicast service termination when leaving the previous
network by submitting an early Done message before handoff. MLD
router querying will allow the multicast forwarding state to be
restored in case of an erroneous prediction (i.e., an anticipated
move to a network that is not fulfilled). Backward context transfer
may otherwise ensure a leave is signaled. A further optimization was
introduced by Jelger and Noel [68] for the special case when the HA
is a multicast router. A Done message received through a tunnel from
the mobile end node (through a point-to-point link directly
connecting the MN, in general), should not initiate regular MLD
membership queries (with a subsequent timeout). Such explicit
treatment of point-to-point links will reduce traffic and accelerate
the control protocol. Explicit tracking will cause identical protocol
behavior.

While away from home, a MN may wish to rely on a proxy or 'standby'
multicast membership service, optionally provided by a HA or proxy
router. Such functions rely on the ability to restart fast packet
forwarding; it may be desirable for the proxy router to remain part
of the multicast delivery tree, even when transmission of group data
is paused. To enable such proxy control, the authors in [68] propose
an extension to MLD, introducing a Listener Hold message that is
exchanged between the MN and the HA. This idea was developed in [58]
to propose multicast router attendance control, allowing for a
general deployment of group membership proxies. Some currently
deployed IPTV solutions use such a mechanism in combination with a

recent (video) frame buffer, to enable fast channel switching between
several IPTV multicast flows (zapping).

5.3 Solutions for Multicast Source Mobility

5.3.1 Any Source Multicast Mobility Approaches

Solutions for multicast source mobility can be divided in to three
categories:

o Statically Rooted Distribution Trees. These methods follow a
  shared tree approach. Romdhani et al. [69] proposed employing
  the Rendezvous Points of PIM-SM as mobility anchors. Mobile
  senders tunnel their data to these "Mobility-aware Rendezvous
  Points" (MRPs). When restricted to a single domain, this scheme is
  equivalent to bi-directional tunneling. Focusing on interdomain
  mobile multicast, the authors designed a tunnel- or SSM-based
  backbone distribution of packets between MRPs.

o Reconstruction of Distribution Trees. Several authors have
  proposed the construction of a completely new distribution tree
  after the movement of a mobile source and therefore have to
  compensate for the additional routing (tree-building) delay.
  M-HMIPv6 [58] tunnels data into a previously established tree
  rooted at mobility anchor points to compensate for the routing
  delay until a protocol dependent timer expires. The RBMoM
  protocol [70] introduces an additional Multicast Agent (MA) that
  advertises its service range. A mobile source registers with
  the closest MA and tunnels data through it. When moving out of
  the previous service range, it will perform MA discovery, a re-
  registration and continue data tunneling with a newly established
  Multicast Agent in its new current vicinity.

o Tree Modification Schemes. In the case of DVMRP routing,
  Chang and Yen [71] propose an algorithm to extend the root of a
  given delivery tree for incorporating a new source location in
  ASM. The authors rely on a complex additional signaling protocol
  to fix DVMRP forwarding states and heal failures in the reverse
  path forwarding (RPF) checks.

5.3.2 Source Specific Multicast Mobility Approaches

The shared tree approach of [69] has been extended to support SSM
mobility by introducing the HoA address record to the Mobility-aware
Rendezvous Points. The MRPs operate using extended multicast routing
tables that simultaneously hold the HoA and CoA and thus can
logically identify the appropriate distribution tree. Mobility thus
re-introduces the concept of rendezvous points to SSM routing.

Approaches for reconstructing SPTs in SSM rely on a client
notification to establish new router state. It also needs to preserve
address transparency for the client. Thaler [72] proposed introducing
a binding cache and providing source address transparency analogous
to MIPv6 unicast communication. Initial session announcements and
changes of source addresses are distributed periodically to clients
via an additional multicast control tree rooted at the home agent.
Source tree handovers are then activated on listener requests.

Jelger and Noel [73] suggest handover improvements employing anchor
points within the source network, supporting continuous data
reception during client initiated handovers. Client updates are
triggered out of band, e.g. by SDR/SAP [74]. Receiver-oriented tree
construction in SSM thus remains unsynchronized with source
handovers.

To address the synchronization problem at the routing layer, several
proposals have focused on direct modification of the distribution
trees. A recursive scheme may use loose unicast source routes with
branch points, based on a multicast Hop-by-Hop protocol. Vida et al
[75] optimized SPT for a moving source on the path between the source
and first branching point. O'Neill [76] suggested a scheme to
overcome RPF check failures that originate from multicast source
address changes with a rendezvous point scenario by introducing
extended routing information, which accompanies data in a Hop-by-Hop
option "RPF redirect" header. The Tree Morphing approach of Schmidt
and Waehlisch [77] used source routing to extend the root of a
previously established SPT, thereby injecting router state updates in
a Hop-by-Hop option header. Using extended RPF checks the elongated
tree autonomously initiates shortcuts and smoothly reduces to a new
SPT rooted at the relocated source. Lee et al. [78] introduced a
state-update mechanism for re-using major parts of established
multicast trees. The authors start from an initially established
distribution state, centered at the mobile source's home agent. A
mobile leaving its home network will signal a multicast forwarding
state update on the path to its home agent and, subsequently,
distribution states according to the mobile source's new CoA along
the previous distribution tree. Multicast data is then intended to
flow natively using triangular routes via the elongation and an
updated tree centered on the home agent.

6. Security Considerations

This document discusses multicast extensions to mobility. It does not
define new methods or procedures. Security issues arise from source
address binding updates, specifically in the case of source specific
multicast. Threats of hijacking unicast sessions will result from any

solution jointly operating binding updates for unicast and multicast
sessions.

Admission control issues may arise with new CoA source addresses
being introduced to SSM channels (cf. [79] for a comprehensive
discussion). Due to lack of feedback, the admission [80] and binding
updates [81] of mobile multicast sources require self-consistent
authentication as achievable by Cryptographically Generated Addresses
(CGAs).

Modification to IETF protocols (e.g. routing, membership, session
announcement and control) can introduce security vulnerabilities and
require consideration of issues such as authentication of network
entities, methods to mitigate denial of service (in terms of unwanted
network traffic, unnecessary consumption of router/host resources and
router/host state/buffers). Future solutions must therefore analyze
and address the security implications of supporting mobile multicast.

7.Summary and Future Steps

   This document is intended to provide a basis for the future design of
   mobile IPv6 multicast methods and protocols by:

        o providing a structured overview of the problem space that
          multicast and mobility jointly generate at the IPv6 layer;

        o referencing the implications and constraints arising from
          lower and upper layers, and from deployment;

        o briefly surveying conceptual ideas of currently available
          solutions;

        o including a comprehensive bibliographic reference base.

   It is recommended that future steps towards extending mobility
   services to multicast proceed to first solve the following problems:

     1. Ensure seamless multicast reception during handovers,
        meeting the requirements of mobile IPv6 nodes and networks.
        Thereby address the problems of home subscription without
        n-tunnels, as well as native multicast reception in those
        visited networks, which offer a group communication service.

     2. Integrate multicast listener support into unicast mobility
        management schemes and architectural entities to define a
        consistent mobility service architecture, providing equal
        supporting for unicast and multicast communication.

   3. Provide basic multicast source mobility by designing
      address duality management at end nodes.

8. IANA Considerations

   There are no IANA considerations introduced by this draft.

Appendix A. Implicit Source Notification Options

   An IP multicast source transmits data to a group of receivers without
   requiring any explicit feedback from the group. Sources therefore are
   unaware at the network-layer of whether any receivers have subscribed
   to the group, and unconditionally send multicats packets which
   propagate in the network to the first-hop router (often known in PIM
   as the designated router). There have been attempts to implicitly
   obtain information about the listening group members, e.g. extending
   an IGMP/MLD querier to inform the source of the existence of
   subscribed receivers. Multicast Source Notification of Interest
   Protocol (MSNIP) [82] was such a suggested method that allowed a
   multicast source to querying the upstream designated router. However,
   this work did not progress within the IETF mboned working group and
   was terminated by IETF.

   Multicast sources may also be controlled at the session or transport
   layer using end-to-end control protocols. A majority of real-time
   applications employ the Realtime Transport Protocol (RTP) [83]. The
   accompanying control protocol RTCP [81] allows receivers to report
   information about multicast group membership and associated
   performance data. In multicast, the RTCP reports are submitted to the
   same group and thus may be monitored by the source to monitor, manage
   and control multicast group operations. The Real Time Streaming
   Protocol (RTSP), (RFC 2326) provides session layer control that may
   be used to control a multicast source. However, RTCP and RTSP
   information is intended for end-to-end control and is not necessarily
   visble at the network layer. Application designers may chose to
   implement any appropriate control plane for their multicast
   applications (e.g. reliable multicast transport protocols_), and
   therefore a network-layer mobility mechanism must not assume the
   presence of a specific transport or session protocols.

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