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IP Multicast Mobility Solutions for Video Services

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Abstract

This Deliverable provides an analysis and possible solutions to the issues related to use of IP multicast by both moving sources and receivers. This deliverable considers the different business case relevant for MEDIEVAL with particular focus on Personal Broadcasting, one the most innovative MEDIEVAL use cases.

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Executive Summary

The purpose of this deliverable is to present the MEDIEVAL mobility architecture for IP Multicast Flows. When Video Services do not require multicast support the Unicast Mobility Architecture of MEDIEVAL applies.

Two main scenarios require the use of IP Multicast Mobility: Personal Broadcast (PBS) and Mobile TV Services. PBS corresponds to the live transmission of a mobile user to the network, much like the Mobile TV but with mobility at the sender.

The final architecture is intended to simultaneously be compatible with 3GPP architecture, in particular the *Multicast Broadcast Multimedia Service* (MBMS), and to take advantage of the flat mobility architecture based on the *Distributed Mobility Management* (DMM) proposed by MEDIEVAL.

Moving the Mobility Anchors from Core level to Access level yields to an architecture where *Localized Mobility Domains* (LMDs) are composed of *Mobility Access Routers* (MARs). Multicast Mobility mechanisms are supported within a single LMD since they are network based.

MARs ensure several Multicast related functions: Multicast Routing, Group Management, Multicast Context Transfer and Multicast Mobility Management. All these functions are grouped in an architectural component named MUlticast Mobility Engine (MUME) residing in MARs.

As far as mobility is concerned, two cases have to be distinguished, depending on the Mobile Node (MN) role: Multicast Source Mobility and Multicast Listener Mobility. Multicast Source Mobility applies to the PBS scenario, while Multicast Listeners Mobility applies to both PBS and Mobile TV scenarios.

Both mobility scenarios (source and listener) have been analysed and solutions for the flat mobility architecture have been designed. Each scenario yields to two different schemes: “Local Mobility Anchor (LMA) based” and “Mobile Access Gateway (MAG) based” schemes. This terminology stems from the IETF *Proxy Mobile IPv6* (PMIPv6) terminology, which was the reference for the solution space analysis of the MEDIEVAL DMM approach.

The final choice between the two proposed schemes for each mobility scenario (source and listener) will be done after an evaluation phase.

Due to the dynamic nature of the mobility architecture, multicast mobility mechanisms are only invoked for ongoing sessions when needed, avoiding useless tunnelling, and moving it out of the core network.

Finally, the MUME Component is part of the Mobility subsystem and inherits from its interfaces with other MEDIEVAL subsystems, namely: Video Services Control, Transport Optimization and Wireless Access.

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Abbreviations

3GPP	3rd Generation Partnership Project
A-MAR	Anchor MAR
ASM	Any Source Multicast
BCE	Binding Cache Entry
CoA	Care of Address
CBT	Core Based Tree
CDN	Content Delivery Network
CM	Connection Manager
CN	Correspondent Node
CTD	Context Transfer Data
CT-Req	Context Transfer Request
CTDR	Context Transfer Data Reply
CXTP	Context Transfer Protocol
DAD	Duplicate Address Detection
DR	Designated Router
DMM	Distributed Mobility Management
E2E	End-to-End
eMBMS	evolved MBMS
FM	Flow Manager
HA	Home Agent
HO	Handover
HoA	Home Address
IETF	Internet Engineering Task Force
IGMP	Internet Group Management Protocol
ICMPv6	Internet Control Message Protocol IPv6
IP	Internet Protocol
LMA	Local Mobility Anchor
LMD	Localized Mobility Domain
LTE	Long Term Evolution
MAG	Mobile Access Gateway
MAR	Mobility Access Router
MBMS	Multicast/Broadcast Multimedia Service
MIPv6	Mobile IPv6
MBMS-GW	MBMS Gateway
MEDIEVAL	MultimEDia transport for mobIlE Video AppLications
MIH	Media Independent Handover
MIHF	Media Independent Handover Function

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MIPv6	Mobile IPv6
MLD	Multicast Listener Discovery
MN	Mobile Node
MR	Multicast Router
MUME	MUlticast Mobility Engine
OS	Operating System
PBA	Proxy Binding Acknowledgement
PBS	Personal Broadcast Service
PBU	Proxy Binding Update
PGW	Packet Data Network Gateway
PoA	Point of Attachment
PoS	Point of Service
PIM-SM	Protocol Independent Multicast - Sparse Mode
PIM-SSM	Protocol Independent Multicast – Source Specific Multicast
PMIPv6	Proxy Mobile IPv6
RPF	Reverse Path Forwarding
RP	Rendezvous Point
RPT	Rendezvous Point Tree
QoE	Quality of Experience
SAP	Service Access Point
SGW	Serving Gateway
S-MAR	Serving MAR
SPT	Shortest Path Tree
SSM	Source Specific Multicast
T-MAR	Target MAR
VoD	Video on Demand
WLAN	Wireless Local Area Network

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1 Introduction

The main goal of the MEDIEVAL project is to evolve the Mobile Systems architecture for efficient video traffic support. As a result, IP multicast is one of the key pretensions for achieving efficient network resource usage, and is one of the base mechanisms towards the realization of network-supported mobile video distribution. There have been many obstacles to its deployment, similarly to what happened with IPv6, but there are arguments that may show that its momentum is approaching, in particular the increase in big data transfers. While other transport mechanisms for content delivery have driven more attention from both research and commercial sides (e.g. CDN and P2P techniques), mainly supported by the time-shifted nature of video consumption, IP multicast is seen having its place in the specific business cases of mass and live content delivery, such as a World Cup match or the latest news on a catastrophe, which are mapped to two of the Use Cases considered in MEDIEVAL – Mobile TV and PBS. However, as it will be seen throughout the document, one of the major challenges for future multicast support results from the consideration of mobility itself.

One of the main drawbacks of multicast protocols is that they were designed to support the stationary multicast parties. As such, the movement multicast subscribers between different networks results in severe problems. Nonetheless, the same happens for a user transmitting its content using multicast (at least in better accepted protocols) [24]. The fact is that mobility raises some issues as a result from the interaction of IP multicast and IP mobility protocols, such as packet loss, routing optimization, transparency, packet replication, and group leave latency, etc [11], which is demonstrated in the next sections.

To solve the aforementioned issues, the IETF has worked in different solutions highlighting the difference between source and listener multicast mobility problems. However the proposed solutions remain unable to address at the same time the issues of scalability, resource and route optimization, compatibility with unicast mobility. We propose to address these issues in terms of architecture (edge mobility anchors) and distributed mobility schemes suitable to both source and listener mobility servicing Personal Broadcast and Mobile TV.

Regarding 3GPP scope, mobile networks supported by their proposed architectures shall support IP Multicast distribution in the Core Network (CN) in the evolved MBMS services framework. The new eMBMS architecture as of release 9 of 3GPP LTE specifications [35] requires a functional entity, MBMS Gateway (MBMS-GW), to be present in the Core Network. MBMS-GW is responsible for IP multicast address allocation to downstream nodes and in acting as the head of the multicast distribution tree. In particular the IP multicast distribution of MBMS user data plane goes to eNodeBs. 3GPP IP Multicast distribution mechanisms are based on IETF protocols and Mobility is managed by 3GPP LTE specific control procedures. The novel architecture proposed by the MEDIEVAL project is to design efficient general mechanisms to manage mobility for IP Multicast in the context of 3GPP and non 3GPP networks.

From IP mobility point of view, most of current standardized IP mobility solutions like Mobile IPv6 (MIPv6) and PMIPv6 leverage on a centralized mobility approach. The presence of a centralized mobility anchor (e.g., Home Agent (HA) in MIPv6, LMA in PMIPv6) that is located in the core network allows a mobile device to be reachable when it is not connected to its home domain. Therefore, both MN context and traffic encapsulation need to be maintained at the mobility anchor. However, when hundreds or thousands of MNs are communicating in a given cellular network, a centralized mobility anchoring point causes well-known bottlenecks and single point of failure issues. In addition, current mobility support (based on MIPv6 and PMIPv6) has been designed to be “always on” and to maintain the context for each mobile subscriber whereas the mobile node remains motionless.

In order to address the aforementioned issues, the MEDIEVAL mobility model, based on the DMM concept (currently under study at IETF) [8][9] tries to move the mobility anchors from the core level down to the edge. Moreover, the mobility support will be provided dynamically when it is really needed. The MEDIEVAL mobility model does also help in solving some multicast-related issues present in centralized mobility approaches such as the tunnel overhead (using LMA-MAG tunnel in PMIPv6 at least when the MN starts a multicast session) and route optimization by placing the anchors as close as possible to the mobile nodes.

In this document, we study solutions for both source and listener multicast mobility within a PMIPv6 domain, which are mainly based on those proposed by the IETF MULTIMOB Working Group [33]. Due to the fact that PMIPv6 is a well accepted protocol for intra-domain mobility, being deployed by several standardization bodies, among other reasons, it was selected as the base protocol for intra-domain multicast

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mobility. We then present a study for adapting these solutions to both the DMM approach and MEDIEVAL requirements, in order to provide the suitable solutions for multicast mobility in the context of MEDIEVAL project. Our study is limited to the study of intra-domain multicast mobility. Thus, the support for multicast mobility between different (LMD), naming introduced in [20], is out of scope.

Two possibilities for multicast mobility support are considered for both source and listener: i) using a tunnel between the previous MAR (A-MAR) and the current serving MAR (S-MAR), which play the role of MAG and LMA, respectively (LMA-based scheme), or ii) using a separated multicast infrastructure for sending / receiving the traffic (MAG-based scheme).

Finally, we present and describe the signaling for Personal Broadcast Services (PBS) use case, which will be also subject of the next Deliverable on business case analysis (D1.2).

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2 Key Contributions

This deliverable analyzes the main issues and potential solutions related to the use of IP multicast from both a source and receiver perspective. The following list is a summary of the main contributions of this deliverable, in which we also highlight the related efforts in terms of dissemination and standardization:

- The state of the art of multicast mobility support is analyzed and summarized, focusing on solutions for network-based IP localized mobility – namely for Proxy Mobile IPv6 (PMIPv6) – which is the main mechanism used in the MEDIEVAL unicast mobility solution, as described in more detail in [20].
- An analysis of the mobility requirements in regards of multicast traffic in MEDIEVAL is performed, considering the key use cases scenarios described in [25], and in particular to Personal Broadcasting. Two main scenarios are addressed: listener mobility and source mobility. The former is relevant for Personal Broadcasting and Mobile TV, while the latter is important for Personal Broadcasting.
- Based on the former analysis of the MEDIEVAL requirements, the solution space is explored, analyzing how the different existing solutions could be adopted in the MEDIEVAL architecture. Since the overall mobility architecture designed in MEDIEVAL [20] is heavily based on the Distributed Mobility Management (DMM) concept, we have also performed a first analysis on how the DMM approach applies to existing PMIPv6 multicast solutions.
- A first design of the IP multicast mobility solution in MEDIEVAL is described in this deliverable. This solution will be fully developed and specified in [26]. Preliminary contributions based on the baseline solution for PMIPv6 [1] have been submitted to the IETF [2][13], presented in several IETF meetings and published as a journal paper [29]. A complementary work has also been published as conference paper [27].
- This deliverable does not provide the final design of the multicast mobility solution integrated with the MEDIEVAL unicast framework. Although, the basic building blocks and interfaces are presented, along with most of the necessary primitives. This initial version of the MEDIEVAL mobility architecture has been published in [28].
- Finally, this deliverable analyzes how the initial multicast mobility solutions fit into the MEDIEVAL scenarios and use cases.

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3 Reference Protocols and Challenges

3.1 IP Multicast

The increased need for high throughput per user has made IP multicast an even more useful mechanism for resource efficiency in networks. Most multicast protocols were developed for static users (and networks), which does not align with nowadays needs [10]. Thus, both multicast group discovery and routing, and mobility protocols must be aligned in order to obtain a reliable and scalable solution that seamlessly guarantees users' services during mobility process, particularly for demanding ones such as real-time video. In this section we briefly summarize how the basic IP multicast protocols – namely group management and multicast routing – work.

3.1.1 Group management

Group management protocols are an integral part of the IP multicast specifications, as they are required to make multicast routers aware of interested receivers and manage their subscriptions. The two relevant protocols designed for multicast group management, depending on the IP version, are Internet Group Management Protocol (IGMP) for IPv4, and Multicast Listener Discovery (MLD) for IPv6 [17][18]. The former runs on top of IP, while the latter is an integral part of Internet Control Message Protocol (ICMPv6), being their principles of operation very similar. Throughout this document we focus on IPv6 control plane. Thus, the MLD protocol operation is briefly explained below.

The goal of MLD is to enable multicast routers to learn, for each of their directly attached links, which multicast addresses and which sources have interested listeners on that link. MLD is an asymmetric protocol, as it specifies different behaviors depending on whether the node is a multicast address listener (that might be a host or a router) or a multicast router. The information learnt by the routers using MLD is provided to the multicast routing protocol running on the routers, in order to ensure that multicast packets are delivered to all links where there are listeners interested in such packets. Due to the nature of multicast, a multicast router only needs to know that at least one node attached to one of its links is interested in receiving packets.

A multicast router performs "the router part" of the MLD protocol on each of its attached links, listening to the messages sent by the multicast address listeners. On the other hand, a multicast address listener (host or router) performs the "listener part" of the MLD protocol on all the interfaces where multicast reception is enabled.

The basic operation of MLD (IGMP is quite similar) is the following:

- The multicast router periodically broadcasts MLD Query messages onto the link.
- Hosts attached to the link respond to the Query messages by sending MLD Report messages indicating their group memberships.
- All routers receive the Report messages and note the memberships of hosts on the link.
- If a router does not receive a Report message for a particular group for a period of time, the router assumes there are no more members of the group on the link.

All MLD messages are IP datagrams with a Hop Count of 1. Since IP does not provide reliable transport, some messages are sent multiple times to aid reliability.

3.1.2 Multicast routing

There are different IP multicast routing protocols proposed. Next, we briefly describe two of the most popular protocols nowadays: Protocol Independent Multicast Sparse Mode (PIM-SM) and Protocol Independent Multicast Source Specific Multicast (PIM-SSM).

Protocol Independent Multicast is a family of multicast protocols known for not implementing its own topology discovery mechanism (thus, named protocol independent); instead, it uses information supplied by unicast routing protocols. Additionally, IGMPv3 and MLDv2 are used for multicast listener discovery, allowing the routers to decide to which multicast trees they'll be part of. In PIM-SM [16], the most deployed multicast routing protocol, multicast packets are transmitted through a Shortest Path Tree (SPT) from the source to the Rendezvous Point (RP), and then using a shared RP tree (RPT) from the RP to the receivers.

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Besides the use of a shared-tree, where any source can address its packets to a multicast group, PIM-SM allows the use of channels identified by a destination IP address and a source IP address, respectively, G and S. In these source-specific channels, it is thus important that the RP does not change its address, as this leads to the tree reconstruction, meaning significant overhead, latencies and packet losses [16]. From the listeners' side, mobility means multicast branch modification, also reflecting in delivery delays and packet losses.

A shared media LAN has more than one PIM-SM routers connected to it. The Designated Router (DR) is the (elected) single router which acts on behalf of directly connected hosts with respect to the PIM-SM operations. In PIM-SM default behaviour, when a source wants to deliver multicast traffic, it sends it out to its DR, which encapsulates the data into a PIM Register, and sends it to the RP (possibly being passed between other multicast routers (MR) before arriving to it). The RP is then responsible for decapsulating the PIM Register packets and send the native multicast traffic down the corresponding RPT. After receiving the first PIM Register from the source's DR, the RP will start sending PIM Stop-Register packets, making the source's DR deliver the traffic to RP natively. In certain cases, receiving traffic through the RPT may mean a significant unnecessary latency due to the routing triangulation. A listener's Designated Router (DR) may send a (S, G) PIM Join directly to the source's DR, in order to build a Shortest Path Tree (SPT). When the subscriber's DR gets the first packet through this new tree, it will send a Stop-Register message to the RP, in order to unsubscribe from the RPT, avoiding getting duplicate packets. On the other hand, PIM-SSM builds trees that are rooted in just one source, offering a more secure and scalable model for a limited amount of applications (mostly broadcasting of content). In SSM, an IP datagram is transmitted by a source S to an SSM destination address G, and receivers can receive this datagram by subscribing to channel (S,G) [30].

3.2 IP Multicast Mobility

3.2.1 Introduction

By the time multicast was introduced, typical utilization of Internet was a quite different and static process than as of today. As such, most multicast protocols were not designed considering peers mobility neither its consequences. The impact of mobility (e.g. the change of globally reachable IP address) has different consequences, depending on factors such as the role of the node in the multicast session (source or listener), and or the considered multicast model (any-source or source-specific). The importance for enabling multicast to be present in mobile environments, though, is even more clamant, as users usually share frequency bands of limited capacity. Adding to that, it is not easy to modify multicast protocols according to mobility requirements. [24] states the problems involved in MIPv6-supported multicast and enlists some possible solutions. Though, the base protocol considered in MEDIEVAL for multicast support is PMIPv6, which will be used as a platform for researching a fully multicast-compliant DMM-based architecture. While some problems described in the previously referred document are shared with PMIPv6, there are also significant differences due to the network-based nature of this protocol.

This section provides an in-depth description of the relevant problems that may result from the mobility of a multicast node within a PMIPv6 domain. Firstly, an overview of the impact of wireless in multicast is presented in the following.

3.2.2 Problems due to wireless medium

Mobility is a logical result of the availability of wireless access technologies. In [14], a comparison between multicast in wireless and wired media is done, listing the problems that result from wireless usage. As multicast was not designed considering wireless networks, challenges such as dynamic group membership and update of delivery path due to node movement arise. Additionally, wireless is typically an unreliable media, meaning variable bandwidth or packet losses, and overall wireless communications are more costly (both in power and processing overhead). Also, the longer the distance between the source and the listeners, the bigger are the packet losses (from 1% up to 30%, again, depending on the link characteristics). The same document lists some requirements for IGMP/MLDv2 behaviour in wireless:

- Adaptive to different link characteristics;
- Minimal Join and Leave latency;
- Robustness to packet loss;
- Minimum packet transmission;
- Packet burst avoidance.

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As such, the tuning of MLDv2 parameters must be considered for obtaining improved multicast service stability and for a better behaviour during handovers.

3.2.3 Problem statement for multicast mobility in PMIPv6

Proxy Mobile IPv6 is a network-based mobility protocol. As such, the MN is not aware of any mobility signaling while moving inside a PMIPv6 domain. Similarly to MIPv6, a bi-directional tunnel is used to forward traffic from and to the MN, being the end point of the tunnel a Mobile Access Gateway (MAG) instead of the MN itself. When a MN wants to send traffic to a CN, the MAG will encapsulate that data, and forward it to the MN's Local Mobility Anchor (LMA), which then decapsulates and routes it as necessary to the CN. When a CN wants to send traffic to the MN, LMA intercepts the packet (which was sent to the MN's Home Address (HoA), checks the corresponding Binding Cache Entry (BCE), and forwards the data to the right MAG, which is responsible for decapsulating and delivering the traffic to the MN. The key difference between MIPv6 and PMIPv6 lies in the MAG, which is the entity responsible for emulating a constant L3 network. This process is achieved by sending a proper router advertisement (RA) after the proxy tunnel is configured.

The fact that multicast and mobility protocols are designed independently from each other, leads to the existence of hazards in their interaction. Regarding PIM and PMIPv6, the result is no different, with the headers of one another completely maladapted to each other, with cumulative encapsulations (and thus more overhead) and also inappropriate multicast queries timings for mobility scenarios. Besides, problems resulting from mobility can be independently broken into the listener and the source, [10].

3.2.3.1 Problems at the listener

In network-based mobility protocols, as the mobile node is not aware of the mobility process, it cannot take multicast-related decisions due to mobility. It is therefore the network which is responsible maintaining the multicast session in a seamless way, by being constantly aware of the MNs connectivity status, besides their multicast subscription interests.

From the multicast listener point of view, different challenges arise when handling mobility in PMIPv6. When an MN changes its access router, the target MAG somehow has to know about the MN's interest in multicast data. As the MN is mobility-unaware, it won't restart the tunnel as soon as it changes its MAG, preventing a smooth multicast session resume. In other words, some entity in the network needs to have multicast discovery capabilities and act in one of 2 ways:

- Query the MN for multicast needs (MLDv2 Queries) as soon as it arrives: this implies changing the behaviour of the MLD protocol at the new MAG, using as input the detection of a new MN at the link-layer.
- Transfer the MN's multicast profile to the target access router: this solution implies context transfer from the previous MAG to the new one, and the definition of extensions for the Proxy Binding Update / Acknowledge (PBU/PBA) messages in order to contain multicast-specific information.

Another problem of deploying multicast protocols such as PIM-SM is the activation of localized routing optimization. In scenarios where multiple listeners use the same MAG as the source, the traffic will travel all the way to the source's LMA (RP), and down the RPT back to the MAG, and only then will be delivered to the listeners. Although that represents a worst case scenario, in general multicast packets will not travel through an optimal route, at least considering base PMIPv6 support.

Last but not least, the tunnel convergence problem must be considered, driven from the tunnel utilization. When multicast listeners registered at distinct LMAs (e.g., 3 MNs associated with 3 different LMAs) access the same MAG, the traffic sent by the LMAs will "converge" at the MAG. If those MNs subscribe to the same multicast group, the basic multicast principle of "only one copy per packet" is corrupted, because the MAG will receive and transmit the traffic from each LMA it receives data from, thus replicating the multicast packets (in this example, 3 times).

3.2.3.2 Problems at the source

As seen in the previous section, the address of the source is critical for the correct multicast traffic delivery

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in source-specific multicast, because if the address of the source changes (e.g., due to mobility), a distinct SPT to the RP will be triggered, corresponding to the channel (S’, G). That global reachability is an important advantage of centralized mobility protocols like MIPv6 or PMIPv6. In PMIPv6, the LMA has one or more Home Network Prefixes for each MN, which defines the address range that the MN may use as Proxy-CoA when associated to a MAG.

A deployment option in PMIPv6 is to set all MAGs with the same link-scope address, this way avoiding demanding processing due to routing tables update (MN’s gateway change), interface address configuration and Duplicate Address Detection (DAD) processes. Although the referred address transparency issues related to the multicast session (RPF check and source header verification at the listener side, as described below) are avoided in PMIPv6, this comes at a price of non-optimal routing, due to the use of the fixed mobility tunnel. This problem may be seen when activating the SPT route optimization between the source and the listeners. The activation of this theoretically shortest path in PMIPv6, besides requiring that all MAGs have multicast capabilities, doesn’t bring any practical advantage towards the RPT utilization. Due to the referred mobility tunnel, the traffic must always go through the LMA, and the most significant route distance of the whole path might be between the MAG and the LMA. On the other hand, by using the RPT, and as long as the RP maps to a static node, a more robust solution is obtained, having a not-much less-optimal route. Regarding the RP, its optimal selection must be considered, because all traffic from the MN will go through the LMA, its mobility anchor.

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4 State of the Art on IP Multicast Mobility

The previous sections presented some background on multicast support in mobile environments, as well as its associated problems. As referred, the scope of this study is on intra-domain multicast mobility, leaving inter-domain issues aside, contrarily to the architecture proposed for unicast [20]. That consideration has significant impact, being one of the reasons for considering PMIPv6 as the reference mobility protocol for multicast mobility support, besides the fact it is a protocol adopted by several system architectures (3GPP, 3GPP2, WiMAX) as well as in IEEE WLAN.

This section, similarly to the previous one, considers both source and listener multicast mobility, reflecting what was done so far regarding multicast support in PMIPv6. As can be concluded from the considered bibliography, most research done so far came from IETF itself. Besides, the support for multicast source mobility has not been target of extensive study yet, although it has clearly been identified as a key issue for personal broadcasting and similar services.

4.1 IP Multicast Mobility in PMIPv6

We address multicast mobility support in PMIPv6 by splitting possible solutions in two main branches, like [3] described, and this organization can also be viewed from both source and listener's roles:

i) LMA-based solutions: multicast traffic must go through the MN's LMA, either in uplink (source role) or downlink (listener role) direction.

ii) MAG-based solutions: multicast traffic is treated differently from unicast, by not having to be processed by the MN's LMA. This means multicast uses a completely separated infrastructure from unicast mobility anchor, and can also occur for the two multicast roles, listener or source. For both schemes, either a Rendezvous Point Tree (RPT) or Shortest Path Tree (SPT) can be selected, being reflected in different ways.

4.1.1 LMA-based solutions

In the LMA-based solutions, the multicast traffic is always routed via the terminal's LMA. Therefore, all multicast traffic passes through the MAG-LMA tunnel, just like unicast traffic. The main disadvantage of this approach is the derouting, particularly in cases where the listeners are associated to the source's MAG, where a loop started at the MAG is formed. As the main advantages, this scheme is the simplest deployment technique, not requiring extensions to PMIPv6 or to PIM-SM protocols. Below, the state of the art for LMA-based schemes is reviewed, and studied from the listener and source's point of view. Notice that the multicast tree from the RP to the LMA or MAG of the listener is omitted for a simpler analysis.

4.1.1.1 Source Mobility

When the considered MN has the role of a multicast source, the impact of using the SPT is similar to that of the RPT scheme. If the source's LMA acts as the RP of the multicast group, the route travelled by packets is the same in both SPT and RPT. The actual multicast service routing distance and latency depends on the way multicast is supported at the listener's side (LMA/MAG-based, RPT or SPT), and vice-versa. When switching from the RPT to the SPT, the join message towards the source's home address (HoA) is captured by the LMA and sent through the mobility tunnel. Thus, in both RPT and SPT, the traffic must go through the source's LMA, meaning that the SPT does not significantly improve the route (this would only happen in theory when the RP is far from both the source's LMA and the RP, which doesn't practically apply), contrarily to static multicast scenarios where the mobility tunnel is not used.

Although, if we consider the permanent use of the RPT, one significant advantage results, which is the fact that all the listeners will retrieve the content from a fixed address, making the source's mobility totally transparent to the listeners. Using the SPT, though, results in the service disruption and possible packet replication during the HoA-CoA binding update time.

Figure 1 depicts possible network topologies that the listeners might use when the source is using a LMA-based scheme, where two main variations may occur. On the first, the listener uses also a LMA-based scheme, and consequently, the route may vary from a longer one, where the RP is distant from both the source's and listener's LMAs, and a smaller one, where the RP is either the source's LMA (LMA1) or listener's LMA (LMA2), or even if the SPT is used (no RP). On the second variation, the listener uses a

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MAG-based scheme, which results in less overhead due to the lack of the listener's mobility tunnel. More on this scheme is described in section 5.2.2. Other possible topological combinations would be having the source and listeners registered to the same LMA, as well as to the same MAG, which will also result in more or less optimal paths. In general, the LMA-based scheme is easier to implement, since no extra extensions for the PMIPv6 protocol and the multicast routing protocols are necessary.

The description for source mobility support and corresponding network signalling is presented in [5], applying the base deployment solution proposed by IETF for multicast listener mobility support [1]. Simply put, the multicast data transmission is independent of the mobility procedures, being the only requirements having all MAGs acting as MLDv2 proxies (for learning and proxying group membership information and forwarding multicast packets based on such information) and the LMA's with multicast router capabilities (MLDv2 and PIM-SSM protocols), allowing LMA's to act as RPs (and providing them with full multicast capabilities).The handover process of the multicast source when using a LMA-based scheme and a RPT where the LMA is the tree's RP can be resumed in the following steps:

- When the new MAG detects the MN presence, the standard PMIPv6 handoff occurs. The MAG will verify its policies records, obtaining whether or not the MN may be associated to it; the MAG then sends a PBU, and after receiving the corresponding PBA from the LMA, it establishes the bidirectional tunnel;
- The source continues the multicast session, and the MAG captures its packets. The tunnelled packet's header will have as source the Proxy-CoA and as destination the LMA.
- LMA receives the tunnelled packet, decapsulates the multicast packet, which has as source the same global scope address used for this multicast session, and as destination the IP multicast group.
- As the destination is a multicast address for which the LMA was already acting as RP, it forwards it down the RPT tree. Alternatively to the use of the LMA as the RP, another strategy could be to set a Content Delivery (CDN) node as the RP, allowing for the content to be simultaneously available using IP multicast and unicast.

In [3], extensions for PBU/PBA messages are introduced: a S bit for identifying the MN as a source, and another bit J is for activating the MAG-based scheme (LMA-based scheme is used by default), in order to provide an environment where a decision point can select one of the two schemes, according to the scenario's characteristics.

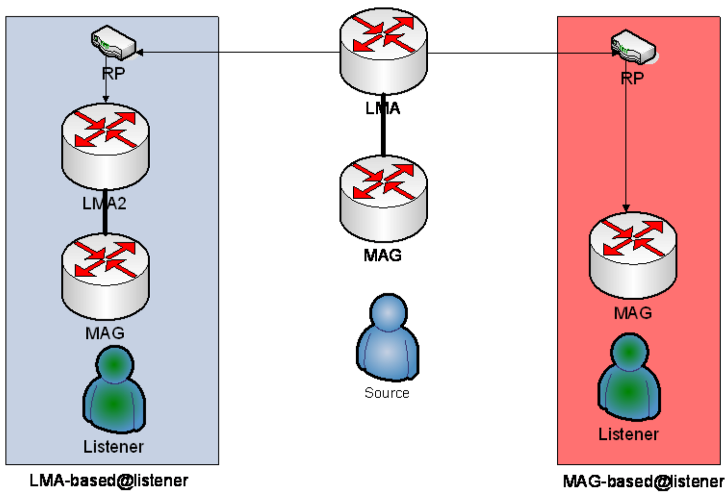

Figure 1. Topologies using LMA-based scheme at the multicast source

4.1.1.2 Listener Mobility

When the MN has a multicast listening role, using a LMA-based scheme means that the MN's LMA serves as a multicast subscription anchor point, either using RPT or SPT. Also for the listener, this solution typically does not require modifications to mobility and multicast protocols standards. Figure 2 presents some of the possible paths the traffic may travel from the source to the listener. It can be seen that the shortest path possible that a multicast session may traverse is achieved when the LMA is the same for the source and the listener, and when it acts as the RP for the multicast group. Note that for some services such as Mobile TV, the content doesn't flow from a mobile source, but from the Internet.

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Within IETF, most of the proposals currently being developed for tackling the problems referred in Section 4, fit in the LMA-based scheme. For instance, [2] proposes the use of a dedicated multicast LMA, acting as a mobility anchor for multicast, solving the tunnel convergence problem, but centralizing all multicast traffic in few centralized points. Not inserted in any specific scheme, [11] proposes improvements for tuning IGMPv3 and MLDv2 for both mobile hosts and routers, optimizing those protocols taking into account the nature of wireless media and the dynamicity of such scenarios, in order to solve problems such as "leave latency" in dynamic IP multicast trees – the time between the moment the last user requesting a multicast group leaves the router and the moment the router deletes the corresponding entry. [13] tackles explicitly the problem of handover latency in time-sensitive applications, and proposed an extension for PMIPv6 for including multicast subscription information in the PBU/PBA messages. As such, the multicast context exchange is intermediated by the LMA.

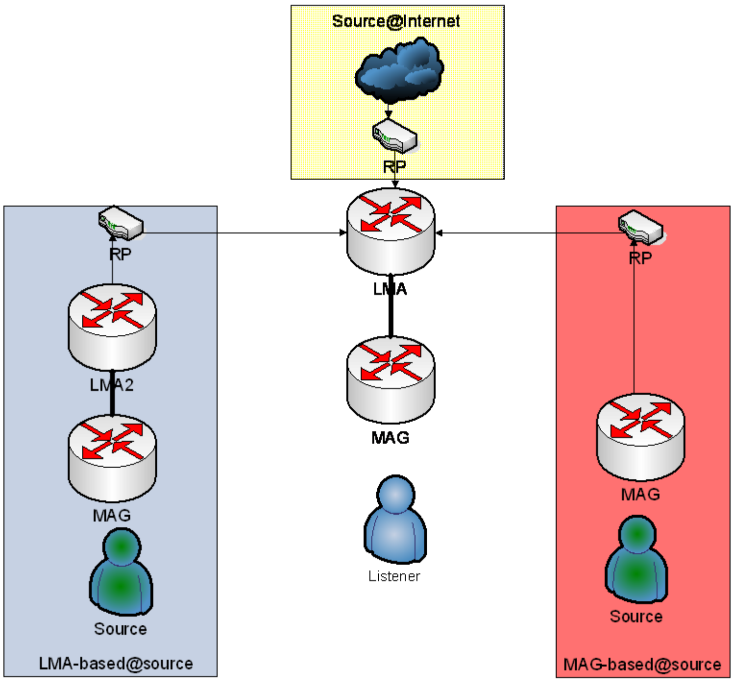

Figure 2. Topologies using LMA-based scheme at the multicast listener

4.1.2 MAG-based solutions

Similar to the LMA-based scheme, the MAG-based scheme can be applied in both of two scenarios: the any source multicast (ASM) and the source specific multicast (SSM). This scheme can be applied for both multicast source and multicast listener mobility.

One of the most important advantages of this approach is that multicasting functions are totally separated from mobility anchor by using a native multicasting infrastructure. As the result, the complexity of LMA is reduced since it does not have to deal with multicast traffic processing. In addition, with native multicasting infrastructure, the MAG-based scheme does not make any packet overhead (tunnelling overhead) because the multicast traffic is not transferred via the tunnel between LMA and MAG.

4.1.2.1 Source Mobility

The MAG-based scheme for source mobility support is presented in [3]. The multicast traffic originated by source can be directly transmitted from the MAG to the receivers via multicasting infrastructure. For supporting the MAG-based scheme, it requires some modifications of MAG's behaviour. Firstly, when the MAG receives the multicast packets, it should not encapsulate them in LMA-MAG tunnel but directly to RP (in case of RPT scheme) or directly to native multicasting infrastructure (in case of SPT scheme). It should also ignore all the join messages sent by the Listeners to the MN-HoA of the Source.

The MAG-based approach can also be applied for multicast listener mobility. In this case, the MAG simply sends join message to RP (or DR) on behalf of mobile nodes that want to subscribe to a multicast group.

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Therefore, the multicast traffic is routed directly from native multicasting infrastructure to the MAG. And then, the MAG forwards the multicast traffic to receivers.

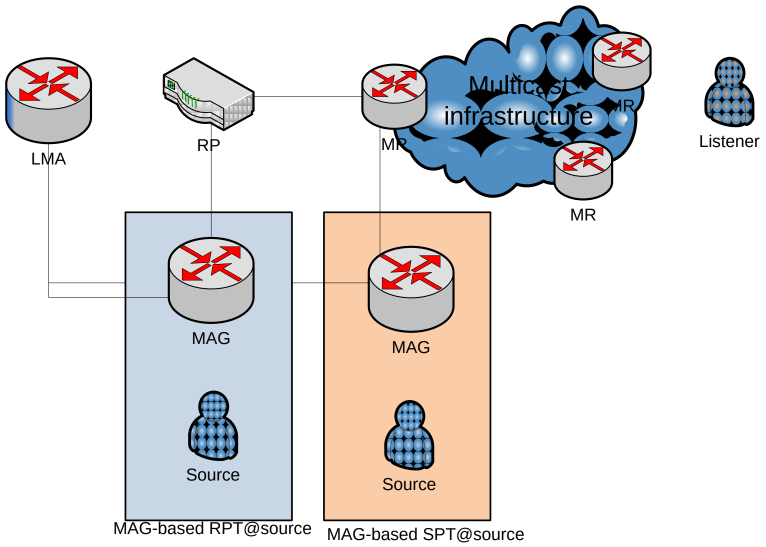

Figure 3. Topologies using MAG-based scheme at the multicast source

In MAG-based RPT scheme, the RPT-based multicast tree can be established after receiving join message to multicast group by RP. The MAG sends the multicast traffic originated by source to the RP. Afterwards, the multicast traffic is routed natively from RP to receivers according to the multicast routing protocol. In this case, the multicast path is better than the LMA-based RPT scheme. The multicast delivery tree is relatively stable because the address of RP is fixed. When the source moves to another MAG (or another LMA), the SPT path from the RP to listeners is fixed while the SPT path from source to the RP can be changed. But this change is insignificant and does not influence much on the multicast service. But it also raises the problem of route optimization. One of the solutions proposed is to relocate RP to optimize the RPT-based tree. Yet, the relocation algorithms are being studied.

While in MAG-based SPT scheme, the source-based tree is the best path for multicast traffic from source to receivers. In some case, the listener's DR in RPT-based scheme can decide to switch over to the SPT-based scheme to optimize the multicast path. Yet, this solution proposed is being studied.

In MAG-based SPT scheme, all multicast listeners are forced to know the address of the MAG corresponding to the multicast service. Normally, as the anchor point of the MN, the LMA receives the subscription messages. Then the subscribe messages are transmitted to the source through the LMA-MAG tunnel. That means the LMA/MAG must have the mechanisms to notify the DRs re-subscribe the multicast group. The new subscribe message should be sent directly to the MAG. Should a DR wish to subscribe a multicast group, it can query for the topological location of multicast source first. After receiving the query, the LMA (or a centralized control element) notices the DR about the current MAG's address. The DR sends subscription message to MAG and the SPT tree is established. When source moves to another MAG, the multicast delivery tree has to be reconstructed. As a result, it requires some extra mechanisms to inform all the multicast listeners (or DRs) of the new MAG's address.

Still, the problem of Reverse Path Forwarding (RPF) check failure is raised due to MAG address change. That means the multicast routing states should be modified to reflect the new IP address and to avoid dropping packets due to RPF failure. The seamless handover and packet loss are also very important issues. Therefore, it requires some mechanisms to make sure that multicast transmission continues immediately after source attached to the new MAG and minimize the overhead in reconstructing multicast trees due to a source movement. Some algorithms shall be considered to minimize routing update cost and to reduce reconstruction time such as re-using the intersection path of the new multicast delivery tree and the old one.

In spite of many efforts to propose the multicast tree reconstruction, mobility support for SSM (SPT scheme) is known to be a major open problem. It is suggested that the MAG-based SPT scheme should not be considered for its difficult implementation. Vice versa, the MAG-based RPT scheme also can be used as a

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solution for both multicast source and multicast receiver mobility. In this case, the MAG has to act as a MLD-proxy or a multicast router. Due to its implementation or operational costs, operators may not want to support multicast routing on MAG, but for support flexible scenarios, the MAG should act as a multicast router.

In order to support multicast source mobility, the basic PMIPv6 signalling (PBU/PBA) are required to be extended. [3] proposes using a one bit “S” to indicate that the MN is a multicast source while a one bit “J” is added to indicate whether the MAG has the ability to adopt the MAG-based scheme.

4.1.2.2 Listener Mobility

The MAG-based scheme can also be applied for multicast listener mobility. One approach is to use exactly the same solution as the direct routing solution that is proposed in [4]. In this case, the MAG can act as a MLD-proxy or a multicast router. When MAG acts as a MLD-proxy, a single proxy instance at MAG with up-link to the multicast infrastructure, for instance, could serve group communication purposes.

For listener mobility, the MAG simply sends join messages to DR on behalf of mobile nodes that want to subscribe to a multicast group. Therefore, the multicast traffic is routed directly from native multicasting infrastructure to the MAG. And then, the MAG forwards the multicast traffic to attached receivers. As the result, the tunnel convergence problem in which a MAG may receive the same multicast packets from several LMAs also will be solved.

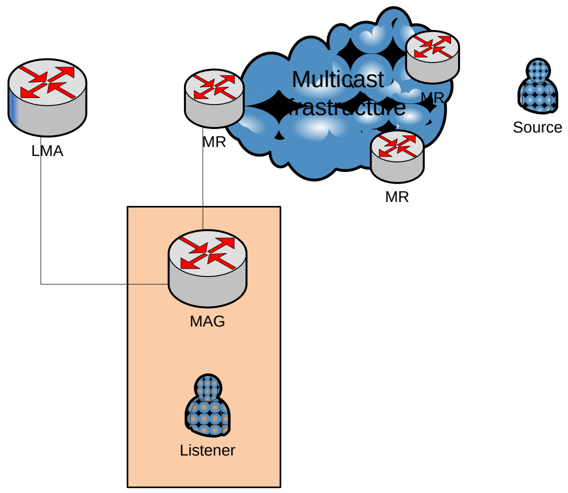

Figure 4. MAG-based scheme for multicast listener

When an MN moves from one MAG to another, the need to communicate efficiently on the move and to minimize the packet loss caused by a handover is becoming increasingly important because the handover latency is unacceptable for real-time IP services and throughput sensitive applications. Normally, as an MLD proxy, the new MAG utilizes MLD Queries to get MN’s multicast subscription. In addition, Context Transfer also can be used to the new MAG get MN’s multicast subscription. It helps a new MAG to quickly get MN’s multicast subscription information. In [12] a solution for speeding the HO process through context transfer is proposed by using a Multicast Mobility Option in PBU/PBA messages directly between the previous and new MAG. The latter work also proposed two distinct modes: predictive (where MAG binding and context transfer occur prior to the MN HO) and reactive (where the mentioned operations occur after the MN has attached to the new MAG). Forwarding packets from the previous MAG to the new MAG can be required to reduce the packet loss, but it can also raise the tunnel convergence problem. In order to make the multicast service continue quickly after listener attached to the new MAG, [14] proposed IGMP/MLD protocol extensions while in [11] the tuning IGMP/MLD behaviour is considered. In conclusion, the MAG-based scheme for multicast listener mobility may be simple and easy to deploy, not requiring any extensions of PMIPv6 entities (LMA and MAG), but it may also require extensions to the mobility protocol if context transfer is needed for speeding the process.

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5 IP Multicast Mobility in MEDIEVAL

5.1 Analysis for MEDIEVAL requirements

D1.1 [25] analyzes in more detail the general challenges that MEDIEVAL aims at addressing. In this section, we focus on describing the particular requirements of the IP multicast mobility solution designed by the project, not only in regards of the problems it should solve, but also considering the constraints imposed by the general mobility architecture, which is described in [20]. Take into consideration that these requirements are mostly associated with multicast support at first and last hop, thus the separation between source and listener mobility, with little or no reference to the core network. These will be included at a later stage, and in [36]:

- R1: A multicast receiver SHALL be able to move and change its layer-3 point of attachment, while keeping the reception of the multicast traffic, with minimal (if any) packet disruption.
- R2: A multicast source SHALL be able to move and change its layer-3 point of attachment, while sending multicast traffic, and minimizing the impact on the subscribed receivers.
- R3: The multicast mobility solution SHALL minimize as much as possible the amount of replicated copies of the multicast traffic due to the mobility management.
- R4: The multicast mobility solution SHALL optimize the routes followed by multicast traffic, by placing the anchors/RPs as close as possible to the mobile nodes. This is in line with the Distributed Mobility Management general design principle followed by the unicast mobility solution, as described in section 5.2 (“Distributed and Dynamic Mobility Management Concept”) in [20].
- R5: The multicast mobility solution SHALL support both mobile listeners and sources. The solution SHALL allow the use of different anchors for mobile nodes, acting as sources, listeners, or both.
- R6: The multicast mobility solution SHALL allow mobile nodes to benefit from multicast mobility management while roaming within the same LMD. If the mobile node changes LMD, multicast traffic will be disrupted, as the mobile would need to subscribe again to the content (for the case of listener mobility) or use a different source address (for source mobility). The solution will, therefore, be based on PMIPv6, adapted to the DMM approach. The project MAY investigate the use of client-based mobility solutions to tackle the inter-LMD (this also includes inter-domain scenario) case.
- R7: The multicast mobility solution MAY assume that the access network is multicast-enabled, meaning that MARs run multicast protocols, and the use of tunnels to deliver multicast traffic can be avoided in some situations.
- R8: The multicast mobility solution SHALL allow for dynamically changing the anchor for multicast traffic (Multicast Router function) upon mobile node movement (by recalculating the multicast tree), or keeping it and using tunnels between the anchor/RP and the current point of attachment of the mobile node (DMM-based solution). The decision should be based, among other factors, on the number of multicast receivers, the latency associated to recalculate the tree, etc.
- R9: The multicast mobility solution SHALL benefit from the cross-layer approach followed in MEDIEVAL, to optimize multicast handover decisions.
- R10: The multicast mobility solution SHALL be compatible with the MEDIEVAL unicast mobility solution and avoid adding unnecessary additional complexity.
- Additionally, the multicast mobility solution SHALL consider general mobility requirements R4, R6, R7, R8, R9 described in [20].

5.2 Analysis of the solution space

As identified in previous section, multiple considerations exist for supporting multicast mobility. First of all, the multicast role (source or listener) impacts the nature of the solution to be applied. For multicast source mobility, the key considerations lie in the source address and in the RP selection. For listener mobility the most meaningful aspect is to make the multicast content available at the S-MAR as soon as possible. Besides, the mobility profile of a user should be taken into account, as there is a more-or-less clear trade-off

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between the route optimality (e.g. in LMA-based solutions) and the dynamicity of the multicast tree (present in MAG-based schemes), which also translate in different levels of complexity.
The problems resulting from centralized mobility approaches are well identified in [31]: non-optimal routes; non-optimality for evolved network architectures; low scalability of both centralized route and mobility context maintenance; wasteful maintenance of mobility state for nodes which don't need it; mobility signalling overhead in P2P communications; and single-point-of-failure. Most of these problems are present in multicast communications. As such, in this section we present different options for multicast mobility support and by following MEDIEVAL's distributed mobility architecture.

Differently from centralized mobility management protocols, in MEDIEVAL a user starting a multicast session in any particular MAR will send / receive that traffic natively, i.e. without the need for establishing mobility tunnels (MN-HA in MIP, or MAG-LMA in PMIPv6), just like would happen for a static machine accessing the service. In the mobility activation process for multicast sessions, there are two options: to support mobility similarly to previously referred protocols, using a tunnel between the previous mobility access router (A-MAR) and the current one (S-MAR) – LMA-based scheme – or to send / receive the traffic using a separated multicast infrastructure – MAG-based scheme. The process for the first method is similar to the one used in PMIPv6, with some considerations to be made due to the distributed and dynamic mobility approach, for example regarding the tunnel convergence problem. As for the second method, it should be better suited for applications with less strict delay or jitter requirements. Although, seamless service may be obtained as well for listeners by the use of multicast context transfer, as a replacement for IP address continuity activation.

Herein, the goal is to, considering the distributed nature of the mobility anchors, determine which alternatives are worth evaluating in the future through means of simulation or prototyping, by discarding those with a larger range of disadvantages (in terms of efficiency, complexity, packet replication and / or signalling overhead).

5.2.1 Multicast source mobility

A high level description of the different alternatives for multicast source mobility support, which can be depicted in Figure 5, is herein provided. Once again, the core design option relates to the way multicast operation interacts with mobility-related ones. While in LMA-based scheme multicast mobility support is handled similarly to unicast mobility support, in MAG-based scheme multicast traffic is operated in its own way, reliant of multicast native infrastructure. The way the multicast traffic flows for the considered solutions space are numbered from 1 to 4, where "Multicast tree" represents the RPT if using a RP, or SPT otherwise, and are as follows:

1) **Source is supported by LMA-based scheme and RPT**

Similarly to PMIPv6, this method is the simplest to achieve, but, depending on the domain's size and the distance the MN moves from the A-MAR, it may lead to non-optimal routes. It is expected, though, that this routing distance does not have great impact, being LMDs not too large. This issue is to be evaluated in future work, but this solution seems to present advantages in terms of efficiency and simplicity when compared to others. The use of a DMM-based solution deriving from PMIPv6 allows the RPT to be kept intact, and the global source address to be kept constant during the mobility of the MN, due to the HoA. Comparatively to PMIPv6, the tunnel's concentration per mobility manager device (MAR) is decreased, just like in unicast mobility support, avoiding the identified single-point-of-failure and overhead problems.

When the A-MAR starts receiving the multicast content, it should build a (S,G) source-specific entry for that content, not going through the (*,G) PIM Register and PIM Stop phases which would happen when sending the content through a Designated Router (DR) before arriving to the RP. After the MN starts moving, the S-MAR, which has MLD-proxy functionality, determines whether MN can receive multicast services, and adds a new downstream link with up-link to the A-MAR, similarly to the process using base PMIPv6 solution [1].

2) **Source is supported by LMA-based scheme and SPT**

Just like in PMIPv6, and in method 1), the traffic flows through a common point, the A-MAR. This means that the theoretically main advantage relatively to the use of RPT, the forwarding path optimization, is neutralized. This happens because each (S, G) Join message arrives to the RP, the first router having the (S,G) state, resulting in the same end-to-end path as with the RPT. Not only is this advantage eliminated, but

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it would also bring unnecessary signaling proportionally to the amount of listener's DR, corresponding to the PIM-Register / Stops they would need to send.

3) Source is supported by MAG-based scheme

This method allows the use of optimal routes (in case the RP is not A-MAR), and avoids unnecessary replication independently of the mobility support scheme at the listeners.

Although, it imposes rapid discovery and routing to RP, so that the arrival time of the first message from the current access router (which might still be called S-MAR, although no tunnel is used for multicast packets) to the RP does not result in session discontinuity.

4) Source is supported by MAG-based scheme and SPT

This scheme causes severe problem to the multicast session, particularly due to the constant SPT reconstruction for high-mobility source multicast nodes as the source IP address changes with the MN address reconfiguration. This happens because no mobility operation occurs, meaning that a new HNP is used when sending traffic at the (new) S-MAR. This would also imply that the listeners must subscribe to the new channel. It may therefore be stated that both MAG-based schemes are better aimed for applications without IP address continuity requirements.

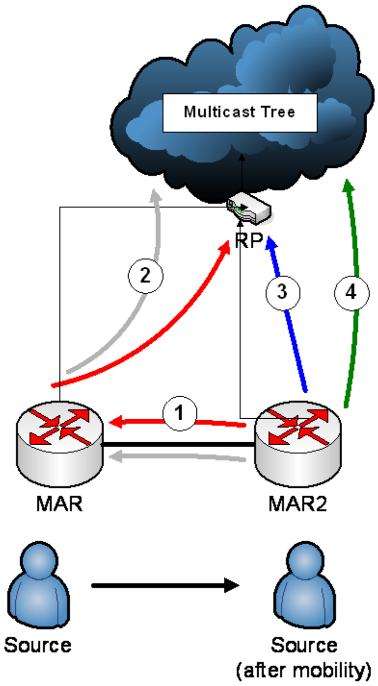

Figure 5. Multicast source mobility in DMM

5.2.2 Multicast listener mobility

A high level description of the different alternatives for multicast listener mobility support is herein provided. As described in Figure 5, unlike LMA-based scheme, when MAG-based scheme is considered, multicast traffic is not transferred via the mobility tunnel between two MARs. The way the multicast traffic flows for the considered solutions space are numbered from 1 to 4, are as follows:

1) Listener is supported by LMA-based scheme (A-MAR = RP)

The utilization of a LMA-based scheme implies encapsulation of multicast packets in unicast, and is the equivalent to the Multicast Encapsulation procedure as referred in [10], and its equivalent in PMIPv6 may be seen in [13]. A similar approach may be obtained by merging some of the functionality of LMA in the previous MAR.

The most significant problem in both LMA-based schemes is this same tunnel, which, besides representing more processing overhead, raises the previously referred tunnel convergence problem. This problem has a different impact than in PMIPv6. The level of replication is amplified by the increase of the number of nodes with a mobile context which are receiving the same content in a common S-MAR and initiated their session

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at different A-MARs. For example, for N mobile nodes starting their session in different access routers, if they all move to S-MAR1, there will be N tunnels, therefore N-1 replications. This might bring severe overhead in highly mobile environments.

2) Listener is supported by LMA-based scheme and SPT

The tunnel convergence problem still holds, although there is an increase in the quality of the forwarding path, as each A-MAR receives content through a SPT and not from the RP. For this and the previous method, the design of a solution incorporating multicast context transfer is a good one for solving the time between the mobility process and the actual service resume. The proposal in [13] is a good starting point that may be applied in DMM, due to its mobility-management protocol-independent nature.

3) Listener is supported by MAG-based scheme (multicast anchor point = S-MAR)

When the MN handover is detected (triggered by the appropriate MIH Event or due to network congestion, the process could follow two approaches. The first approach is based on a native multicast infrastructure [4], with the S-MAR sending a MLD Query to the MN, and receiving the correspondent MLD Report. The MR in the S-MAR will then join the necessary multicast trees. As the S-MAR will send itself the (S,G) Join message towards the RP, and avoids the use of the mobility tunnel, the tunnel convergence problem is solved. The issue is the time it may take to receive the MLD Report from the Listener, which may be enough to lead to a noticeable service disruption. As such, the other approach is to follow an optimized solution similar to the one in [12], where the MLD states of the MN are transferred from the A-MAR to the S-MAR, providing a fast multicast context transfer. Comparatively to the referred standard, only the predictive mode would be considered, as 802.21 protocol's intention is precisely the avoidance of any reactivity due to mobility. Also, the previous MAG functionality is copied to the A-MAR, while the S-MAR operates with the new MAG role.

In both MAG-based solutions, the high level of mobility of some listeners results in frequent SPT update, and in problems such as leave latency.

4) Listener is supported MAG-based scheme and SPT

The main advantage of this solution is the improvement in the path between the source and the S-MAR. Although, it amplifies multicast tree reconstruction and leave latencies, if we consider multiple listeners with a dedicated SPT from their MAR towards the source's DR/MAR.

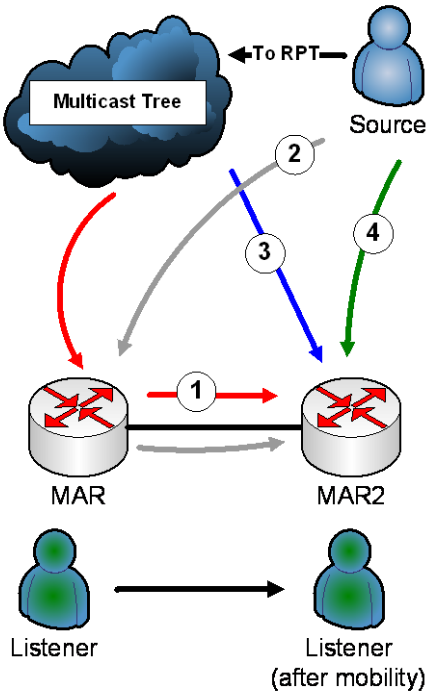

Figure 6. Multicast listener mobility in DMM

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5.3 Solution operations for MAR and MN

The mobility architecture leverages on the concept of DMM for network-based mobility scenarios. Hence, only the mobility in a same LMD will be considered. In DMM, a new architectural element is introduced: MAR that plays the role of LMA, MAG in PMIPv6 or Serving Gateway (SGW)/ Packet Data Network Gateway (PGW) in LTE.

The MUlticast Mobility Engine (MUME) is the Module of the Mobility Engine Component responsible for multicast mobility operations. It is located at the MAR to make sure that the mobility process is transparent to the mobile terminal. This mobility architecture supports both multicast source and multicast listener mobility. Therefore, the MUME executes different operations for multicast source and listener. In addition, the considered multicast routing protocols are PIM-SM and PIM-SSM. Thus, these operations are different for these multicast routing protocols.

In MEDIEVAL, the multicast mobility support is provided dynamically when it is really needed. For example, when a listener moves from one MAR to another (from A-MAR to T-MAR), the multicast mobility support is only required for the current flow that was initially created at the A-MAR before handover. It means that Context Transfer (and packet forwarding) between two MARs could be required. When LMA-based is used and multicast source mobility is considered, for the current flow which was initially created at A-MAR before handover, the multicast traffic is routed from T-MAR (now the S-MAR) to A-MAR. For the multicast flow that is created after handover, the multicast traffic originated by the source can be transmitted directly to multicast infrastructure via T-MAR. Therefore, the MUME interacts with Flow Manager (FM) of the same MAR in order to execute multicast mobility decisions.

As above-mentioned, MUME executes different operations for multicast source and listener. In addition, these operations also depend on the role of MAR (A-MAR or S-MAR) and on the considered scheme (LMA-based scheme, MAG-based scheme). In order to clarify the operations of MAR, Table 1 provides the necessary function/operation of MAR for multicast support. Following subsections are devoted to the detailed description of the operations.

		LMA-based	**MAG-based**
Multicast Source	A-MAR	1, 4, [2](*)	1, [2]
	S-MAR/T-MAR	3, 5	1
Multicast Listener	A-MAR	1, 4, 6	[1], 3, 6
	S-MAR/T-MAR	3, 5, 6	[1], 3, 6

Table 1. MAR operations

The functions/operations are listed in the table above:

- Multicast routing function
  - (1) Multicast router (**)
  - (2) RP
- Group management function
  - (3) MLD proxy
- Mobility management function (based on PMIPv6)
  - (4) LMA function
  - (5) MAG function
- (6) Context transfer function

(*)[]: optional function

(**) When a MAR acts as a multicast router, it performs the PIM-SM/SSM function and router part of MLDv2 function.

5.3.1 Multicast Source

5.3.1.1 MAR operations

If an LMA-based scheme (SPT and RPT) is used, when a source moves to another MAR, the MAR (A-MAR) where the flow was initially created plays the role of LMA while the T-MAR (now the S-MAR) acts as a MAG. In this case, the T-MAG can act as a MLD proxy while the A-MAR acts as a MR. If a MAG-

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based scheme is used, both MAR simply play the role of source's DR. In LMA-based RPT scheme and MAG-based RPT scheme, it is possible to choose the A-MAR as a RP. Therefore, depending on MAR's role, MAR executes the corresponding operations: source's DR operations (for current attached source), RP operations, the LMA's operation and the MAG's operation (when source is away from home). As a multicast router, MAR performs the source's DR operations described in section 3.1.2 such as receiving Join/Prune messages, processing Hello messages, etc. In addition, MAR (A-MAR) can play the role of RP when an LMA-based RPT scheme or a MAG-based RPT scheme is used. In this case, the RP operations (see section 3.1.2) should be considered.As an MLD proxy, T-MAR performs the MLD proxy operations (see section 3.1.1) such as sending MLD queries, receiving MLD reports, managing multicast subscription, etc.

When LMA-based scheme is considered, MAR also performs the operations based on the operation of the LMA and the MAG in PMIPv6 [16]. As a MAG, the current serving MAR (S-MAR) sends a modified PBU message (as described in section 4.1) to the Previous-MAR (A-MAR) that plays a role of a LMA. After receiving PBU message, as an LMA, the A-MAR replies to S-MAG by sending a PBA message. In addition, when MN attaches to a link connected to the MAR, MAR performs the basic operations of PMIPv6 such as authentication, authorization operations (like what happens in MAG) and prefix allocation operations (executed by a LMA) as described in section 5.6.1 ("Mobility Access Router Operation") of [20].

An important issue for all the schemes is the method through which the T-MAR obtains the A-MAR address. For this, the communication between the Flow Managers (as MIH Users) of both A-MAR and T-MAR during the Handover preparation comes into place, by means of the MIH 802.21 protocol. It is only necessary to provide the Flow Manager of the T-MAR with the capability for using the IP address from the triggering Flow Manager (at the A-MAR) as a parameter for triggering the Multicast Mobility Engine. More on this is described in section 5.4.

5.3.1.2 MN operations

When an MN attaches to a MAR, the MN acquires an IPv6 address from the prefix announced by the MAR. Therefore, the MN can start new communications with that address. When the MN moves to another MAR, the mobility support should be enabled with the flow which was initially created in the previous MAR. For this flow, the previous MAR plays the role of LMA while the current serving MAR plays the role of MAG. Hence, the MN performs the operations as described in section 5.6.2 ("Mobility Access Router Operation") of [20].

5.3.2 Multicast Listener

5.3.2.1 MAR operations

When LMA-based scheme is considered, the T-MAR (now the S-MAR) plays the role as MAG while the A-MAR plays the role as LMA. The multicast traffic is routed to listener via the tunnel between S-MAR and A-MAR. Therefore, S-MAR performs MAG's role while A-MAR performs LMA's operations described in [16]. In this case, the A-MAR and S-MAR can act as a multicast router and an MLD proxy respectively. When MAG-based scheme is considered, the S-MAR can also act as a multicast router. In addition, to reduce packet loss and delay due to handover, forwarding mechanism and Context Transfer [19] could be enabled between two MARs. As an MLD proxy, MAR executes the MLD proxy operations as described in section 3.1.1 like sending MLD queries, receiving MLD reports, multicast subscription management, etc.

While a MAR acts as a PIM router (PIM-SM/SSM), the MAR performs listener's DR operations described in section 3.1.2 and the router part of multicast group membership protocols (MLD and IGMP) such as sending Join/Prune messages, state management (multicast router operations), sending MLD queries, receiving MLD reports (MLD operations), etc.

Normally, when handover occurs, as an MLD proxy or a multicast router, the new MAR relays on the standard MLD (IGMP) procedures to get the knowledge of MN multicast subscription after handover. In order to reduce packet loss and handover delay, Context Transfer could be required especially for real-time IP services and throughput sensitive applications. It helps the new MAR to quickly get MN's multicast subscription information. In this case, MAR executes the operations described in [19] such as receiving Context Transfer Request (CT-Req), transmitting Context Transfer Data (CTD), receiving Context Transfer Data Reply (CTDR). In addition, when MN attaches to a link connected to the MAR, MAR performs the

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basic operations of PMIPv6 such as authentication, authorization operations (like what happens in MAG) and prefix allocation operations (executed by a LMA) as described in section 5.6.1 of [24].

5.3.2.2 MN operations

When the considered MN has the role of being a multicast listener, it performs the host part of multicast group membership protocols (IGMP for IPv4 and MLD for IPv6) such as sending MLD reports, receiving MLD queries, etc. The MN also performs the operations as described in section 5.6.2 ("Node Operation") of [20].

5.4 Architectural Components

Regarding the architecture, the Multicast Mobility Engine (at the MAR) is the Module of the Mobility Engine Component responsible for executing multicast and multicast mobility operations. Only intra-LMD mobility is considered, which maps to network-based mobility scenarios. As such, the Flow Manager, being the MIH User possessing the mobility decision, triggers Multicast Mobility Engine for multicast flow mobility due to a set of possible triggers, which results in different operations for nodes acting as multicast sources or listeners. For instance, the handoff of a listener may trigger a Context Transfer by the MUME, while the handoff of a source could lead to a (source-aware) modified PBU being sent to a MAR. It is therefore necessary to make a distinction during the mobility signaling in order to trigger the correct process. Thus, the MUME acts on behalf of the Flow Manager, which accesses information about multicast flows properties, such as IP multicast group addresses and corresponding sources (in PIM-SSM) and multicast trees Rendezvous Points (RPs). The operation of MUME and of the MN is as follows.

5.4.1 Multicast Mobility Engine

The Multicast Mobility Engine module (depicted in Figure 7) can be split into four main functions: i) a multicast group management function, ii) a multicast routing function, iii) a mobility management function and iv) a context transfer function. The multicast group manager function refers to the multicast group management operations and information storage, and maps to the MLD capabilities (either full MLDv2 or MLDv2 proxy, depending on the considered node). The multicast routing function corresponds to the multicast routing protocol stack of the node, which in the considered scenarios will be PIM family protocols. As for the mobility management function, it is summarized as the mobility protocol stack, which will be a distributed mobility management protocol based on PMIPv6. Finally, the context transfer function handles the multicast context transfer exchange, in order to preemptively prepare the multicast tree for the user's needs.

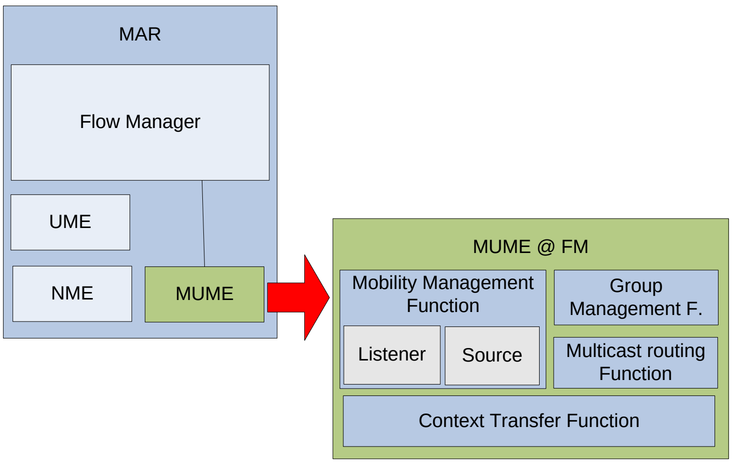

Figure 7. Multicast Mobility Engine representation

5.4.2 Mobile Node

In MEDIEVAL, unlike MARs, there is no component at Mobile Nodes responsible for executing multicast operations. As described in [34], when an IPv6 Node needs to join multicast groups, it SHOULD implement "the listener part of Multicast Group Membership protocols (MLDv2 for IPv6)". Currently, MLDv2 support

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is included in almost Operating Systems. Therefore, in MEDIEVAL, when IPv6 support is considered, we assume that MLDv2 is supported by default.

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6 Interactions and Interfaces

6.1 Scenarios and Validation

This section confronts innovation item 5 from [20]: "Design of novel mechanisms to optimize Video transmission over heterogeneous air interfaces addressing cellular technologies and IEEE 802.11 technologies (including multicast/broadcast audio video streams)", and corresponding requirements: "the Mobility platform SHALL support both unicast and multicast schemes for destination node mobility and "the Mobility platform SHALL support both unicast and multicast schemes for source node mobility".

Herein, the requirements cited above are tackled, namely by the intensive study of multicast source and listener mobility support. For unicast mobility operations refer to [20].

Before going through the use case, a short description of video types and their relationship with the e2e transport is provided. Video delivery services can be split into two main types: progressive download and real-time streaming. The latter can be divided into live (PBS or Mobile TV) or on-demand, and into interactive or non-interactive. While static IP multicast trees, currently deployed in most IPTV services, have a high network cost (number_of_channels multiplied by the number of DSLAMs), the utilization of dynamic IP multicast trees is the all-time most economical design [21]. Following these and other facts, there clear interest in making multicast available in specific use cases. On the other hand, some services explored as well in MEDIEVAL, such as VoD, are not considered as having multicast support.

In the project context, IP multicast is considered to be used by default in Personal Broadcasting Service and Mobile TV. Although, this e2e support may be affected by a set of parameters, namely:

- Access network capabilities: multicast access and transmission at radio level is assumed to be available for the two considered radio technologies: 802.11aa and LTE.
- Core network capabilities: in the present deliverable, the networks are assumed to have full multicast support. In MEDIEVAL scope though, scenarios where no multicast routing is available are also explored [25].
- Terminal capabilities (computers latest OS's come with MLD, while for mobile terminals OS's this support is expected to be added soon),
- Considered service (e.g. asynchronous nature VoD vs real-time nature of PBS),
- Content popularity (e.g. unpopular channels are delivered using well designed topology-aware P2P architectures supported by ALTO or IEEE 802.21 protocol).

Thus, considering the aforementioned parameters are all verified, the relevant use case is the Use Case 3 [25], which demonstrates the potential of multicast utilization at both the source and listener sides, and their mobility process. The Use Case description is as follows:

<u>Step 1</u>

A small group of friends from Cannes decides to establish an e-club for disseminating news since their town does not offer anything matching their interest (i.e. web page, TV channel, blog, etc.). They share several hobbies (e.g. music, movies) but each of them is specialised in a particular aspect.

Fred is specialised in politics, Mike in cinema and Anne likes more to be in contact with people and discuss gossip about celebrities. To this end, they set up a sort of social network, allowing each of them to broadcast video information from their own mobile.

<u>Step 2</u> This step is not relevant here since it concerns only Networks not provisioned with IP Multicast.

A typical activity for Fred is to accompany politicians around the town and visitors that come to the city.

Today he is following the mayor and other politics that visit certain places in town and make short interviews. There is also the important opening ceremony of a new shopping centre and Fred is the one assigned to cover it.

At the shopping centre, Fred connects to his mobile operator network using LTE and starts recording the ceremony, transmitting the content to the e-club friends. The LTE network covering the new shopping centre

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is not yet fully operational and does not yet provide full multicast capability. However, since most of the e-club friends are located on the same campus, they are still able to receive the ceremony using their mobile phones in group reception mode, which ensures better quality on the new LTE MEDIEVAL network, either directly through the LTE or through the campus hotspot.

Step 3

A few days later, both Anne and Mike are assigned to cover the Cannes Film Festival. Anne is doing interviews at the red carpet, asking the protocol questions to all the celebrities that come by. Still she is doing spicy questions and pushing some of the celebrities' life in the interviews. Mike is covering the arrival of the limousines and does some small talk about the Film festival history, past winners and the movies that are candidates to this year's awards. Anne and Mike share a state-of-the-art mobile, which ensures that the live broadcast transmissions from Cannes are reliable and in high-definition.

Using Wi-Fi hotspots that have been setup especially on the stairs and in the Festival area for journalists, they relay using the mobile, Anne taking the broadcast whenever someone arrives and Mike taking the opportunity to talk between the interviews. They often have to move to a different location and change the hotspot to catch a few words from the well-known artists as and when they arrive.

The video that Anne and Mike are recording is being provided to all the news e-club subscribers by using an advanced multicast session distributed over the whole area and across the MEDIEVAL operator network.

In order for the reader to better comprehend the order in which the different stages (session setup, mobility preparation and execution, etc) take place, *Table 2* is provided.

Table 2. Multicast mobility process order

Mobility stage	**Initiation**	**Preparation**	**Generic Mobility Process**	**Mobility execution**	**Mobility Completion**
Source Mobility Process	Figure 8	Figure 10	Figure 11	Figure 12 or Figure 13	Figure 14
Listener Mobility Process	Figure 9	Figure 10	Figure 15	Figure 16 or Figure 17	Figure 18

6.2 Multicast Mobility Flows

6.2.1 Session initiation

There is a clear difference between the session setup from the receiving party and from the content sender.

When the source intends to send the traffic, the network behaves according to Figure 8. The MEDIEVAL application starts an APP_SP_ServiceRegistration with the Video Services Portal, explicating the need for broadcasting using PBS. This immediately triggers the uplink provisioning by WP2 side, which is out of the context from this document. In common with other MEDIEVAL services, as can be consulted in [25], the Application contacts the CM through an APP_CM_GetTerminalInfo.request, which triggers the information collection regarding available networks, by means of MIIS. Thus, while the uplink provisioning occurs, the Video Service Portal sends a DM_VSP_SetStream.request towards WP5 Decision Module, which follows by contacting FM and making it aware of the need of a uplink multicast service. FM is then responsible for setting the flow ID based on the flow information, and collecting all these parameters in the response to the Decision Module. This module then forwards the session information to the Video Service Portal, while the uplink provisioning is complete and the terminal is acknowledged (not represented in the figure).

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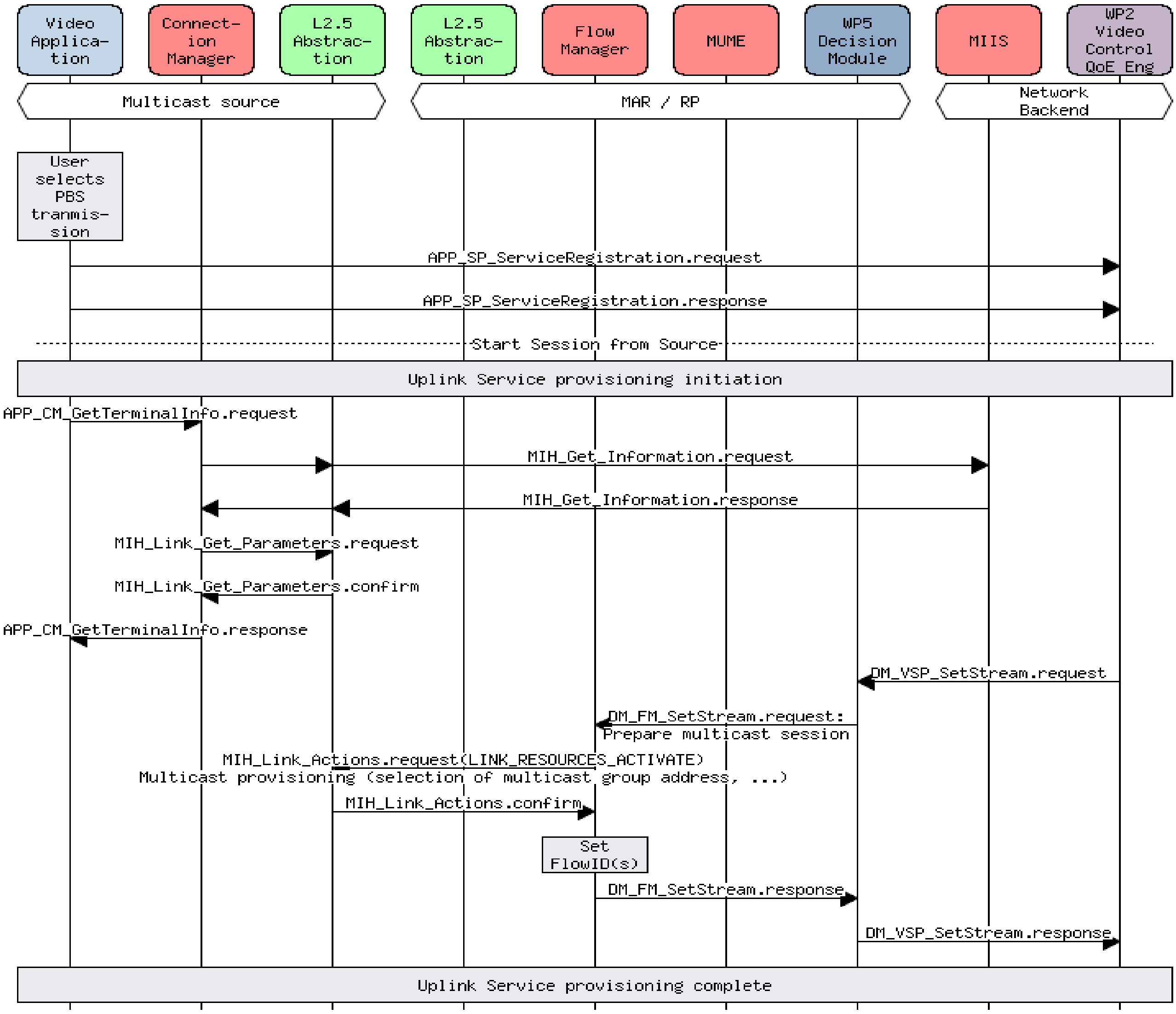

Figure 8. Source service initiation

Regarding the video receiver side (Figure 9), the process is similar to the unicast session initiation procedure, with the following main differences:

- DM_VSP_SetStream.request: VSP sends this message for preparing the network for a uplink connection.
- DM_FM_SetStream.request: this message provides the FM with the awareness that the terminal requires the reception of a multicast connection.
- FM_MUME_TriggerMLDReport: based on the previous message, FM will trigger a MLD Report towards the MUME of the MAR to which the terminal is going to connect, in order to accelerate the process for receiving the first multicast packet.

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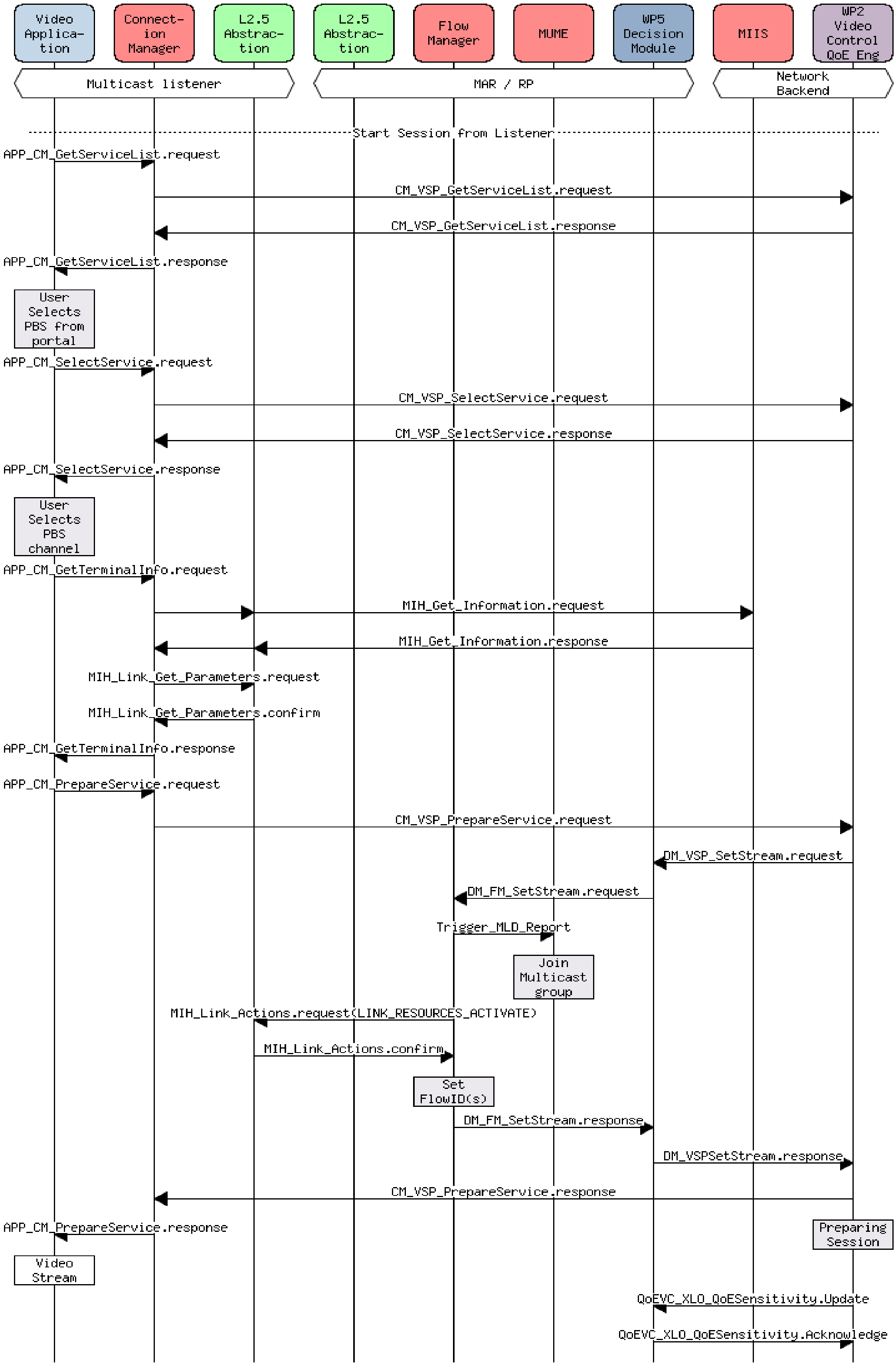

Figure 9. Listener service initiation

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6.2.2 Handover Preparation

The handover preparation for the multicast node (either as listener or as source) is represented in Figure 10, and the process mainly includes MIH operations. The MARs of interest are the ones which have activated in its MIH_N2N_HO_Query_Resources.response(s) the multicast capability.

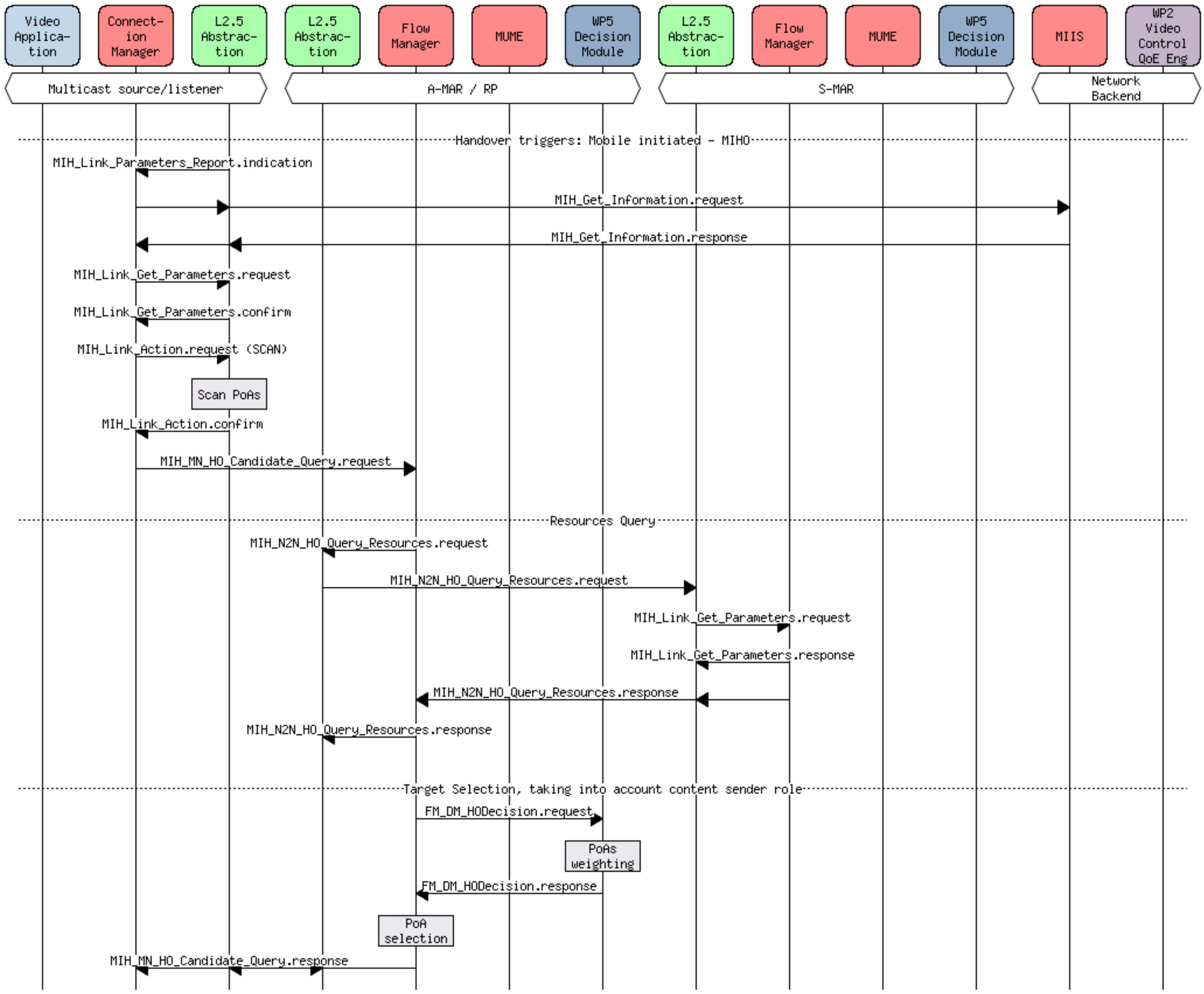

Figure 10. Handover preparation for multicast terminal (source or listener)

6.2.3 Source Mobility

Step 3 of the presented use case considers that a user (Anne or Fred) moves between different networks while live streaming video content via multicast. Figure 11 depicts the generic source multicast mobility process. The DM_FM_SetStream.request triggers the preparation of the (LTE or WiFi) wireless channels for sending multicast traffic. This is done thanks to the verification by FM that multicast capabilities are available over the network and terminal.

As Anne is moving, the radio link status goes below a threshold level and there is need to change network. The generic mobility process can be seen in Figure 11. The role of DM in the target network selection is slightly different for multicast services, and particularly for uplink operations. The mobility process can be split in two possibilities: either the multicast traffic is anchored at the initial MAR (S-MAR) and tunnelled towards A-MAR, similarly to the unicast mobility support solution; or the content is sent natively from the source to the current MAR, towards the RP, implying a fast transmission of the RP address to the target MAR, as well as a few modifications to the multicast routing protocol (namely, the use of link-scope address as the Source identifier in order to keep address transparency at the application layer). For both cases, CM_QoEVC_ContentAdaptation primitives family is necessary for preparing the up link before

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(CM_QoEVC_ContentAdaptationCommit) and after (CM_QoEVC_ContentAdaptationComplete) the handover.

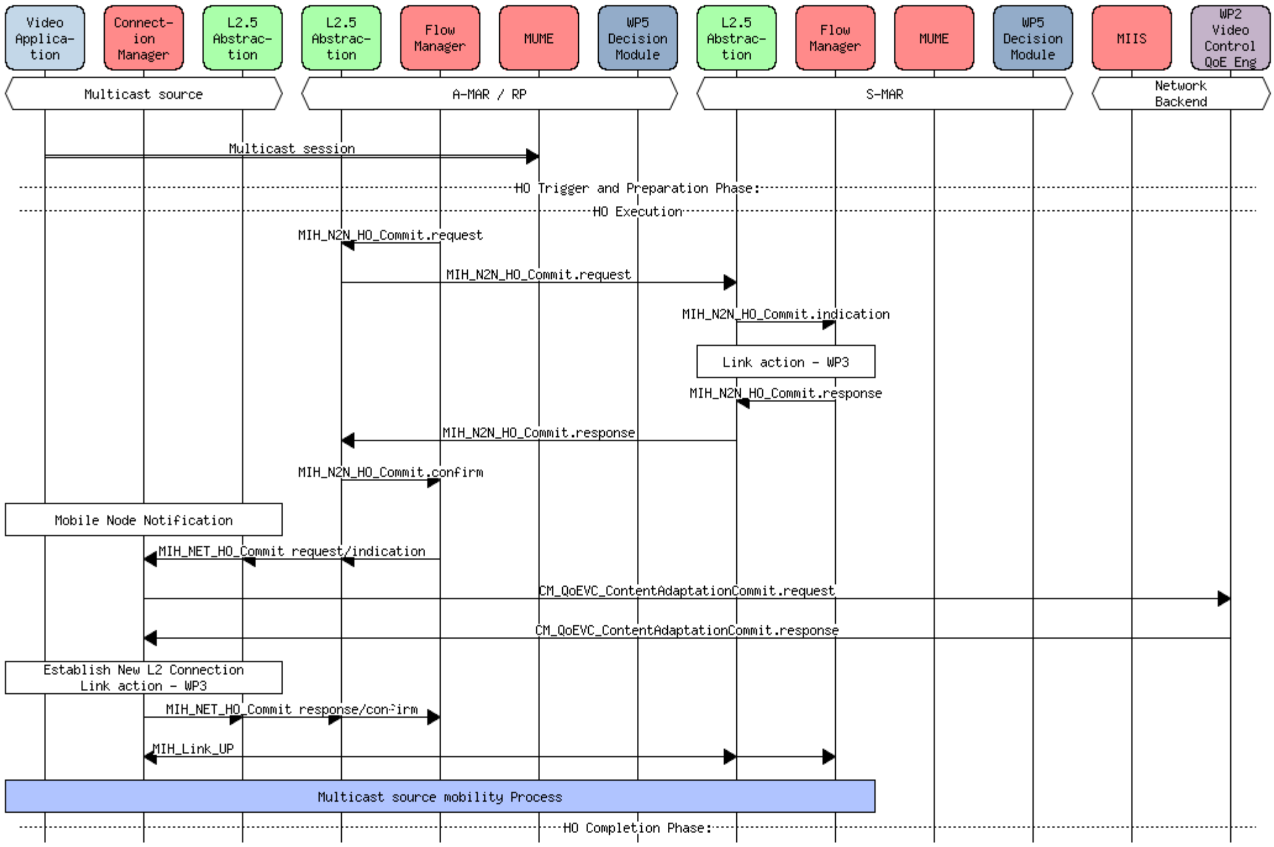

Figure 11. Multicast source mobility generic signalling

Figure 12 and Figure 13 present the signalling involving MEDIEVAL blocks for the two different possibilities, mostly from a WP4 view. For simplification, radio conditions variation is considered as the trigger for the mobility process, translating into a mobile-initiated HO.

The first possibility regarding the mobility management process is to follow the unicast mobility solution as proposed in the present architecture [9], corresponding to a LMA-based scheme, where the multicast traffic is sent through the mobility tunnel. Thus, this process is the simplest solution among the different studied possibilities, mainly due to the issues identified when studying the MAG-based scheme for multicast source mobility in PMIPv6. Overall, LMA-based scheme is more costly in terms of signalling overhead, due to the need to send all traffic encapsulated. Although, it facilitates the multicast tree preservation, and almost implies the use of A-MAR as the RP. As observed in previous sections, the activation of SPTs using this scheme doesn’t provide any advantage, as the traffic would follow a similar route towards the listeners, passing by A-MAR.

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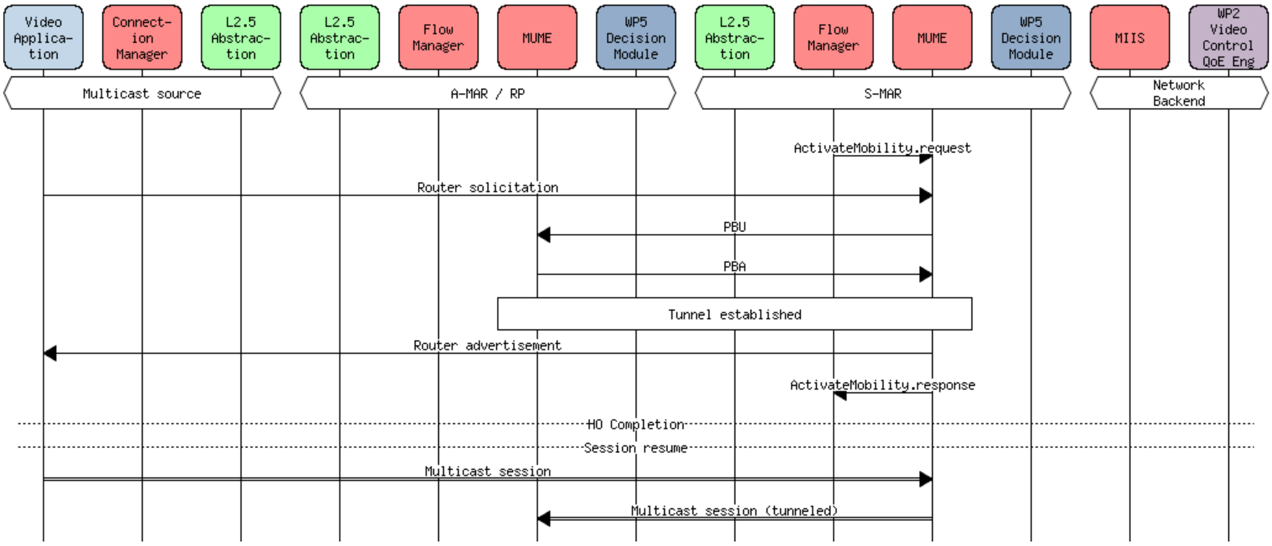

Figure 12. Multicast source mobility signalling – LMA-based scheme

The second option considered avoids the mobility tunnel, and anchors the multicast traffic at the initial A-MAR (not as mobility anchor though), implying modifications to the PIM-SSM protocol (Figure 13). First, it is required that the RPT is used for the duration of the session, in order to make the multicast tree morphology independent of multicast source mobility. For that, the listener's MARs shouldn't initiate SPTs towards the (S,G) channel. Adding to that, the multicast traffic should be sent natively from the current MAR (source's DR) to the starting MAR (RP), similarly to the LMA-based scheme, and not by means of PIM Register unicast packets. This implies the RP to send a PIM Join towards the source's current MAR. In order to avoid service disruption, the rapid notification of the new MAR address should be provided to the RP, possibly by MIH signaling.

In order to comply with the MN address change, the (S,G) channel should be defined with S being the MN's IPv6 link-scope address. This is a relevant difference to standard PIM-SSM behaviour, being mapped within MUME.

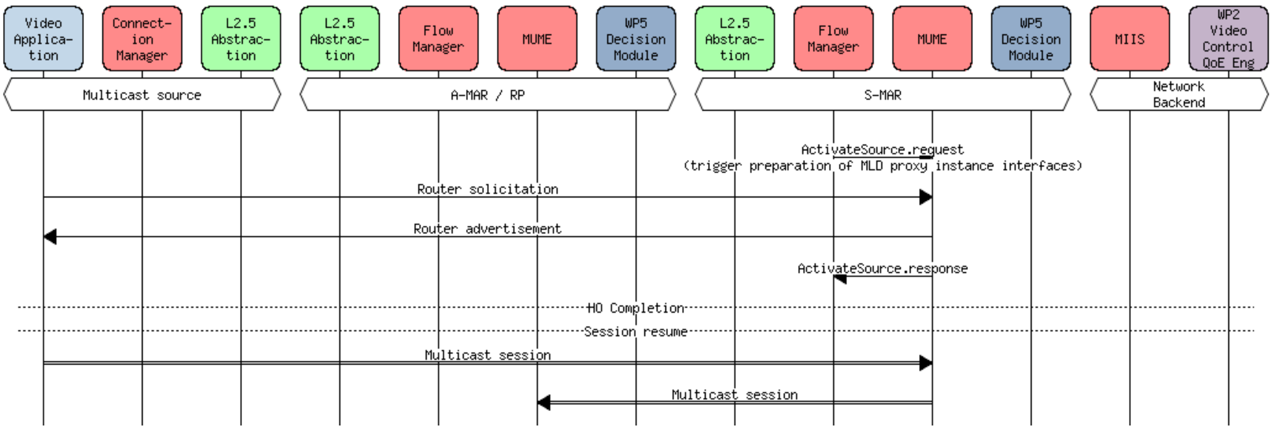

Figure 13. Multicast source mobility signalling – MAG-based scheme

The mobility process is concluded by releasing the resources of the previous network and through MIH_HO_Commit and MIH_HO_Complete requests (Figure 14). As referred, the CM_QoEVC_ContentAdaptationComplete primitive takes place after the HO execution, in order to adapt the video for the bandwidth intensive nature of the uplink transmission.

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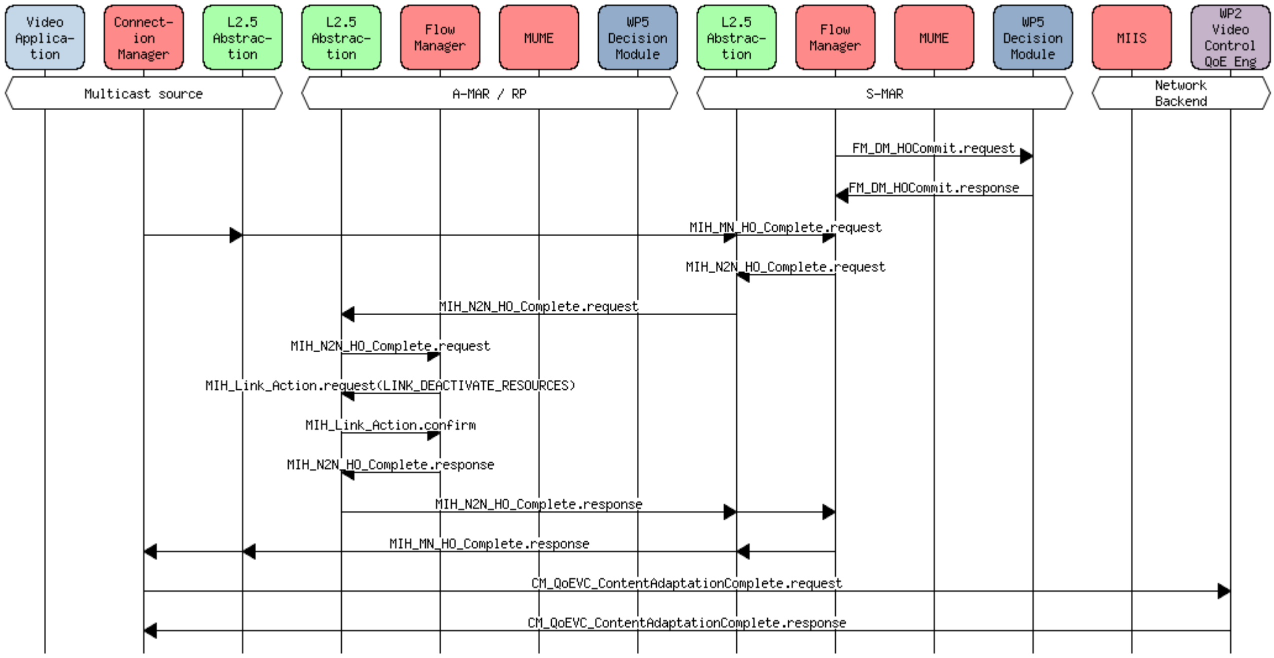

Figure 14. Handover completion for multicast source

6.2.4 Listener Mobility

In Step 3 of the use case, it is also considered the content receivers have mobility needs. This section presents the signalling for mobility from the listeners' side.

As seen in the previous sections, multiple alternatives are possible for multicast listener support. While a solution deriving from IETF's base multicast mobility solution in PMIPv6 assures multicast support, it doesn't assure that the strict requirements of real-time applications like HD live video are fulfilled. Thus, for such requirements, the utilization of fast mobility mechanisms makes sense. The following describes the network signalling for a scenario where a multicast receiver moves. In the first approach considered, an alternative LMA-based solution is represented, where the A-MAR encapsulates multicast traffic in a tunnel towards S-MAR. Thus, the distributed mobility process used for unicast traffic is considered.

The aim is to analyze the requirements of the user, service and network, and proceed with the most efficient mechanism. A trivial scenario that may occur in the current use case is having a listener moving to a MAR which is already delivering the same multicast group(s). In such case, the replication resulting from the use of a tunnel to the new router should be avoided, meaning that the standard mobility approach is in fact avoided.

The procedure for the generic multicast listener mobility is represented in Figure 15. Again, the considered mobility trigger may be radio link degradation or network needs (e.g. congestion, critical QoE), which is translated into a media independent event, or another primitive, reaching the FM of the A-MAR. The detailed message description regarding the HO trigger phase, HO preparation, and HO completion, in terms of MIH 802.21, is once again represented as well. For the current purpose, the relevant part is the HO execution phase, where the mobility protocol execution takes place.

As can be seen, the MIH_Link_UP event is the trigger that the FM awaits before contacting the MUME for effective multicast listener mobility execution.

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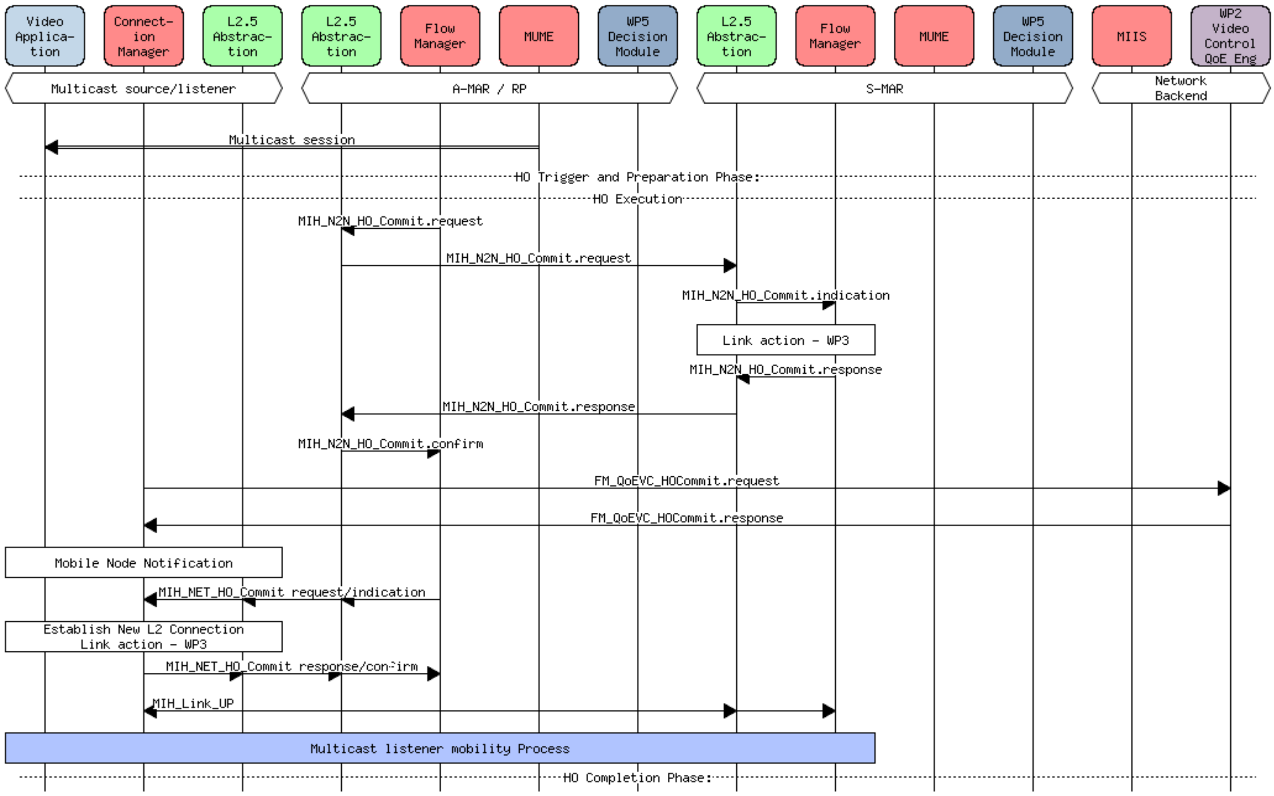

Figure 15. Multicast listener mobility generic signalling

Following a LMA-based solution (Figure 16), by knowing the MN characteristics, the MUME sends a PBU towards the A-MAR MUME, which replies with a PBA.

In order to apply multicast context transfer, MUME has to run differently, triggering a MUME_MUME_ExtendedBindingUpdate towards S-MAR. The receiving MUME will then check MLD state regarding the corresponding MN, and reply with a MUME_MUME_ExtendedBindingAcknowledge, establishing the tunnel. The MUME at the S-MAR, acting through it's MLD Proxy functionality, will immediately send a MLD Report towards the RP in case it doe not receive the multicast group of interest.

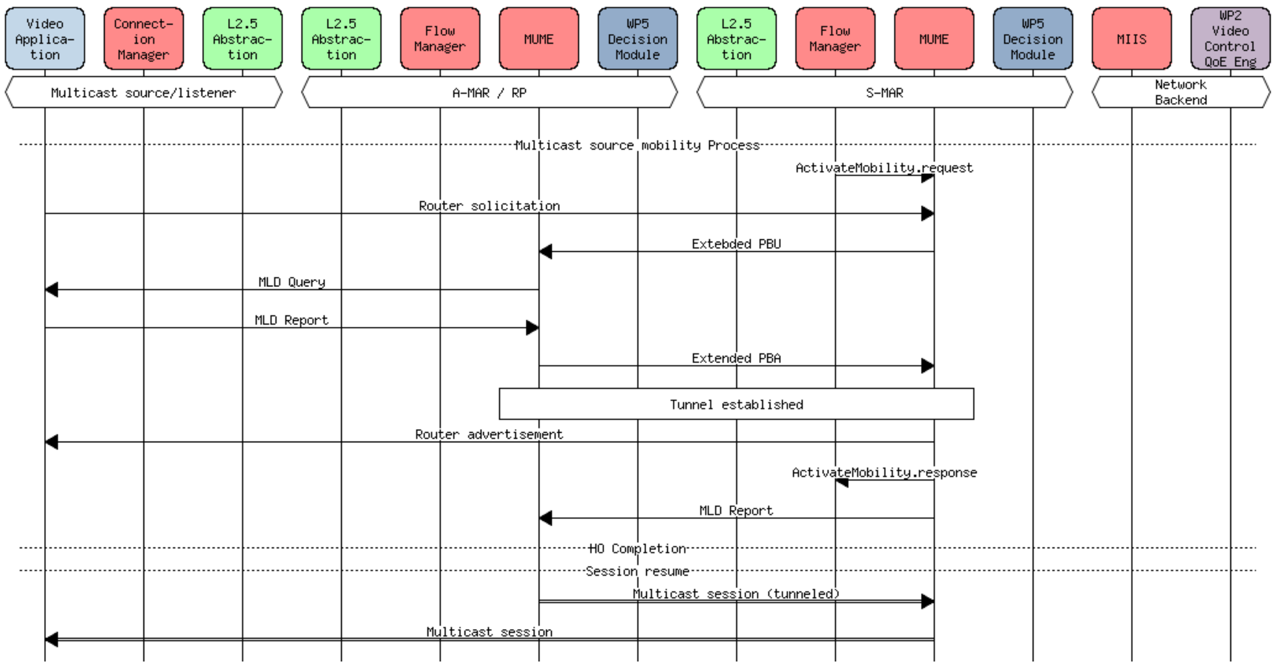

Figure 16. Fast multicast listener mobility signalling - LMA-based scheme

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The second approach uses the MAG-scheme (Figure 17). Considering the requirements of the referred applications, its utilization is only advantageous if Context Transfer is also used. The process has as main difference the non-creation of the mobility tunnel, simply transferring the multicast context from the A-MAR.

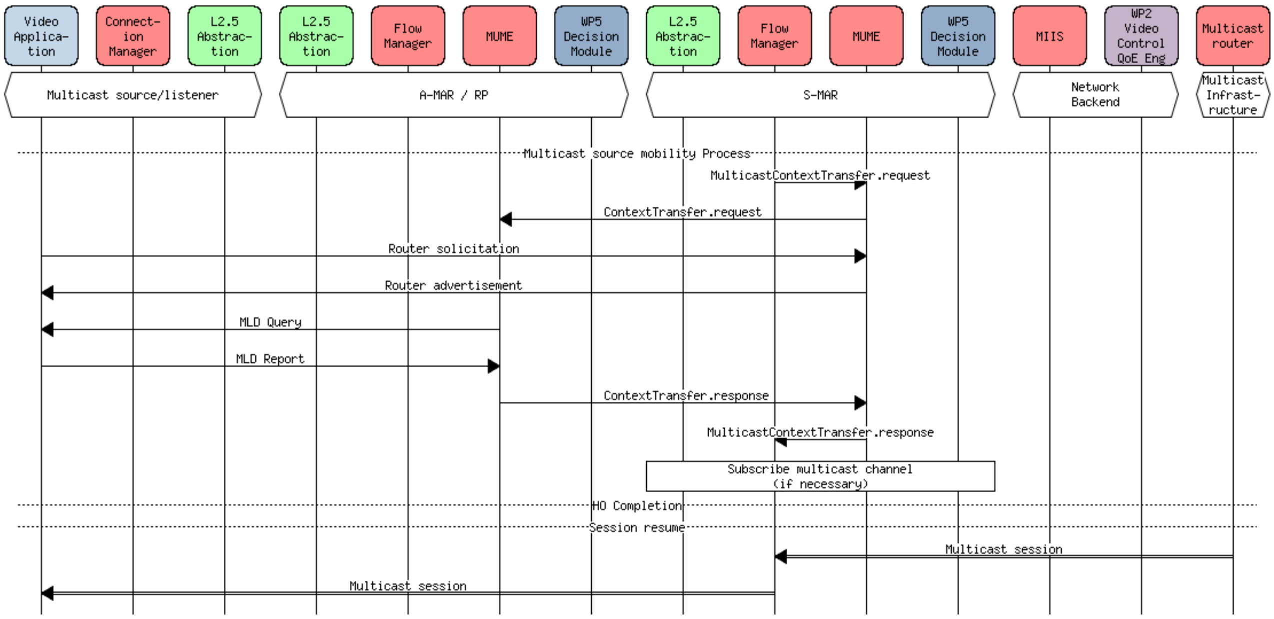

Figure 17. Fast multicast listener mobility signalling – MAG-based scheme

The mobility completion (Figure 18) is similar to the source, with the difference that a FM_QoEVC_HOComplete process replaces the CM_QoEVC_ContentAdaptationComplete, as in this case we require the adaptation of the downlink channel.

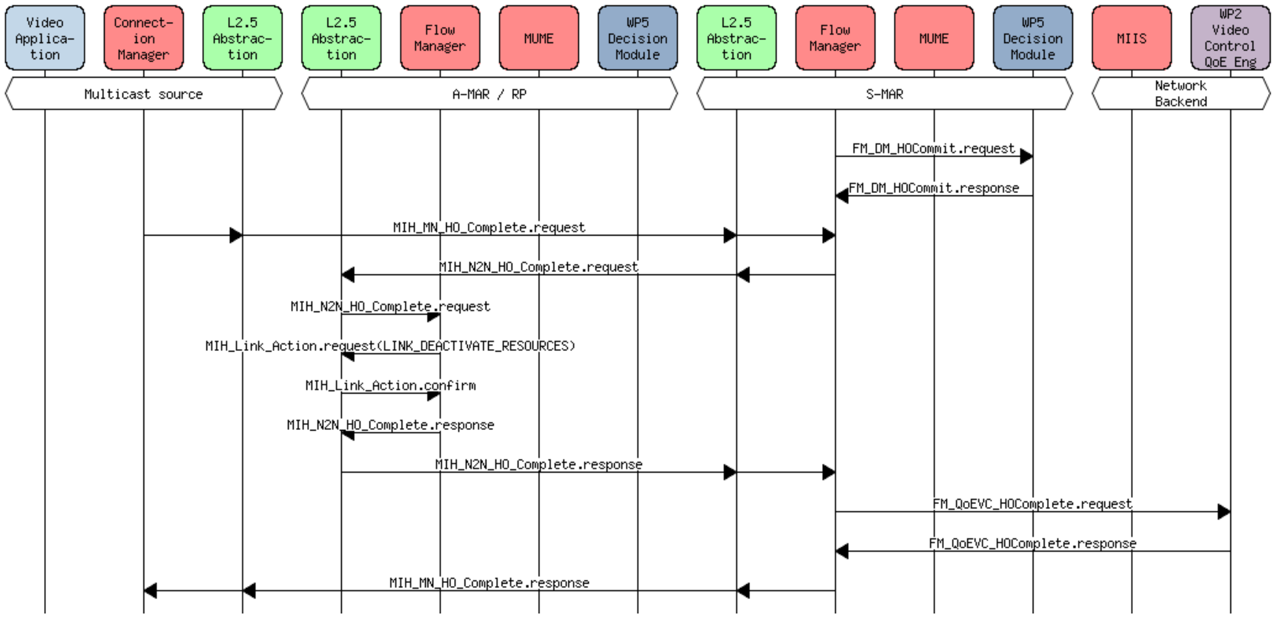

Figure 18. Handover completion for multicast listener

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6.3 Internal Interfaces

As explained in previous section, there is still no single solution for multicast mobility support. As such, the signalling for both schemes is represented, and the features required for supporting those schemes are considered in a single framework. These features are represented by different primitives, meaning that only a set of them will reach the final architecture and implementation stage.

6.3.1 FM_MUME_ If

6.3.1.1 FM_MUME_ActivateMobility

6.3.1.1.1 FM_MUME_ActivateMobility.request

This message is used to notify the MUlticast Mobility Engine (MUME) to trigger the mobility protocol for a multicast source/listener. As such, this message corresponds to multicast mobility operations using the LMA-based scheme.

Semantics of the service primitive

```
FM_MUME_ActivateMobility.request (
    Mobile_Terminal_ID,
    Interface_ID,
    Multicast_Role
)
```

Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal (usually a Network Address Identifier (NAI))
Interface_ID	STRING	The identifier of the interface where to activate mobility.
Multicast_Role	SHORT_INT	The role the MN has in multicast operations

Table 3. FM_MUME_ActivateMobility.request parameter list

When generated

The message is generated by the Flow Manager, knowing that a multicast source or listener node requiring IP address continuity has / is going to attach.

Effect on receipt

After receiving this message the MUME should start the (multicast-aware) mobility protocol for the mentioned node. If the Multicast_Role parameter is set to 0, the MN has a multicast listener function, and the MUME should initiate the mobility process extended with multicast context (MLD state) transfer, that is, relative to the ExtendedPBU.request message. If the Multicast_Role parameter is set to 1, the MN acts as a multicast source, the MUME block assumes the RP to have the A-MAR address, and triggers a standard PBU message as defined in [20].

6.3.1.1.2 FM_MUME_ActivateMobility.response

Function

This message is used to notify the FM that the mobility protocol has finished the tunnel setup for the mobile terminal.

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Semantics of the service primitive

```
FM_MUME_ActivateMobility.response(
    Mobile_Terminal_ID,
    Interface_ID,
    Multicast_Role,
    ResultCode
)
```

Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal (usually a NAI)
Interface_ID	STRING	The identifier of the interface where to activate mobility.
Multicast_Role	SHORT_INT	The role the MN has in multicast operations
ResultCode	UINT_8	The result of the protocol setup. (0 on OK otherwise return an error code)

Table 4. FM_MUME_ActivateMobility.response parameter list

When generated

The message is generated by the MUME when the mobility procedure of the protocol is over. It contains the result of this process.

Effect on receipt

After receiving this message, the FM should either complete the handover, if it receives an affirmative result, or take appropriate action otherwise.

6.3.1.1 FM_MUME_ActivateSource

6.3.1.1.1 FM_MUME_ActivateSource.request

Function

This message is used to setup the local MAR as the incoming end point of the multicast content, sending the content directly to the RP natively.

Semantics of the service primitive

```
FM_MUME_ActivateSource.request (
    Mobile_Terminal_ID,
    Interface_ID,
    RP_address
)
```

Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal (usually an NAI)
Interface_ID	STRING	The identifier of the interface where to receive multicast traffic.
RP_address	IN6_ADDR	The IP address of the MAR where session was initialized

Table 5. FM_MUME_ActivateSource.request parameter list

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When generated

The message is generated when the FM is notified that a MN acting as a multicast source is going to associate to the corresponding MAR.

Effect on receipt

The MUME configures its MLD proxy instance uplink interface towards the RP, and one of its downstream interfaces as the multicast content entrance point. The multicast channel is based on the IP multicast group address and on the link-scope address of the MN. The RP should be obtained similarly to the way A-MAR address is obtained for mobility activation procedures, e.g. by extended `N2N_HO_Query_Resources` to provide the RP address.

6.3.1.1.2 FM_MUME_ActivateSource.response

Function

This message is used to acknowledge the preparation of the MUME for sending the content for the requested multicast channel.

Semantics of the service primitive

```
FM_MUME_ActivateSource.response (
    Mobile_Terminal_ID,
    Interface_ID,
    ResultCode
)
```

Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal (usually an NAI)
Interface_ID	STRING	The identifier of the interface where to send multicast traffic.
ResultCode	UINT_8	The result of the attachment process (0 on OK otherwise return an error code)

Table 6. FM_MUME_ActivateSource.response parameter list

When generated

This message is generated by the MUME after a source attaches to the corresponding MAR.

Effect on receipt

After receiving this message, the FM should either complete the attachment process, if it receives an affirmative result, or take appropriate action otherwise.

6.3.1.2 FM_MUME_MulticastContextTransfer

6.3.1.2.1 FM_MUME_ MulticastContextTransfer.request

Function

Prepares MUME for a multicast context transfer process.

Semantics of the service primitive

```
FM_MUME_MulticastContextTransfer.request (
    A_MAR_address,
    Mobile_Terminal_ID,
    Interface ID
)
```

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Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal (usually an NAI)
Interface_ID	STRING	The identifier of the interface where to send subsequent MLD Queries
A_MAR_address	IN6_ADDR	The IP address

Table 7. FM_MUME_MulticastContextTransfer.requrest parameter list

When generated

This primitive is triggered when a MAG-based scheme is best suited for the multicast listener's application needs.

Effect on receipt

MUME triggers a multicast context transfer process, without mobility tunnel setup.

6.3.1.2.2 FM_MUME_MulticastContextTransfer.response

Function

This message is used by MUME to acknowledge the conclusion of the multicast context transfer process.

Semantics of the service primitive

```
FM_MUME_MulticastContextTransfer.response (
    Mobile_Terminal_ID,
    Interface_ID,
    ResultCode
)
```

Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal (usually an NAI)
Interface_ID	STRING	The identifier of the interface where to send subsequent MLD Queries
ResultCode	UINT_8	The result of the protocol setup. (0 on OK otherwise return an error code)

Table 8. FM_MUME_MulticastContextTransfer.response parameter list

When generated

The message is generated by the MUME when the context transfer process with the previous router (A-MAR) is over.

Effect on receipt

After receiving this message, the FM should either complete the handover, if it receives an affirmative result, or take appropriate action otherwise.

6.3.1.3 FM_MUME_Trigger_MLD_Report

Function

This message is used by FM for triggering a MLD Report message from local MUME.

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Semantics of the service primitive

```
FM_MUME_Trigger_MLD_Report (
    Mobile_Terminal_ID,
    Multicast_Group_address,
    Source_address,
    MN_Link_scope_address,
    Filter_mode
)
```

Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal (usually an NAI)
Multicast_Group_address	IN6_ADDR	The IP address of the considered multicast group
Source_address	IN6_ADDR	The IP address of the multicast source. Associated with a multicast group
MN_Link_scope_address	STRING	The link-scope IP address of the MN
Filter_mode	SHORT_INT	The filter mode (INCLUDE or EXCLUDE) of the multicast channel

Table 9. FM_MUME_Trigger_MLD_Report parameter list

When generated

The message is generated when the FM has decided that it is necessary to make the local MAR part of a certain multicast tree when a MN is not physically present. A typical case where this trigger is used is at session initiation.

Effect on receipt

After receiving this message, the MUME should trigger a MLD Report, so that the multicast functionality of the MAR (PIM-SM protocol) updates its subscription state and joins the multicast tree if needed.

6.3.2 MUME_MUME_If

This interface is necessary for exchanging either multicast or mobility-related information between two MARs, depending on the used scheme and on the multicast node role.

6.3.2.1 MUME_MUME_ExtendedProxyBinding

6.3.2.1.1 MUME_MUME_ExtendedProxyBinding.update

Function

This message is sent by the S-MAR to the A-MAR to request the MN's multicast group state information and the establishment of a tunnel between them.

Semantics of the service primitive

```
MUME_MUME_ExtendedProxyBinding.update (
    Mobile_Terminal_ID,
    Interface_ID,
    S_MAR_address
)
```

Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal
Interface_ID	STRING	The identifier of the interface where to

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		receive multicast traffic.
S_MAR_address	IN6_ADDR	S-MAR address, one of 2 tunnel endpoints

Table 10. MUME_MUME_ExtendedProxyBinding.update parameter list

When generated

The message is generated by the S-MAR when it wants to request the MN's multicast group state and to establish the tunnel for multicast traffic from the A-MAR (after receiving the FM_MUME_ActivateMobility.request from the FM with the MulticastRole parameter set to 0).

Effect on receipt

The A-MAR sends MLD Query(s) to get the MN's MLD state. After receiving the MN's MLD Report, it will reply to the S-MAR with a MUME_MUME_ExtendedProxyBinding.acknowledge with corresponding MN's MLD state. The A-MAR also sets up its endpoint of the bi-directional tunnel to the S-MAR.

6.3.2.1.2 MUME_MUME_ExtendedProxyBinding.acknowledge

Function

This message is used to transfer the multicast state relative to the MN and indicate the S-MAR to complete the tunnel establishment.

Semantics of the service primitive

```
MUME_MUME_ExtendedProxyBinding.acknowledge (
    Mobile_Terminal_ID,
    Interface_ID,
    Number_of_Records (N),
    Multicast_Addr_Record [1],
    ...
    Multicast_Addr_Record [N]
    ResultCode
)
```

Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal
Interface_ID	STRING	The identifier of the interface where to receive multicast traffic.
Number_of_Records	UINT_8	Number of Multicast Address Records

Multicast_Addr_Record{
 	
Multicast_address
Filter_mode
 	
Number_of_Multicast_Sources
Multicast_Source_List{
Multicast_Source_address
}
}
	TLV_List {
	
	IN6_ADDR
	SHORT_INT
	UINT_8
	TLV_List {
	IN6_ADDR
	}
	}
		Multicast record for specified multicast address
		
		Multicast group address
		Filter mode (INCLUDE or EXCLUDE)
		
		Number of Multicast Sources
		The list of Multicast Source addresses
		Address of Multicast Source

ResultCode	UINT_8	The result of the protocol setup. (0 on OK otherwise return an error code)

Table 11. MUME_MUME_ExtendedProxyBinding.acknowledge parameter list

When generated

The message is generated by A-MAR after setting up its endpoint of bi-directional tunnel.

Effect on receipt

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After receiving this message, S-MAR will set up the multicast status of the point-to-point link between the S-MAR and the MN as well as join the content identified by Multicast Address Records on behalf of the MN (in case the S-MAR is not receiving already the multicast traffic). It also sets up its endpoint of the bi-directional tunnel to the A-MAR.

6.3.2.2 MUME_MUME_Context_Transfer

The primitives supported by this interface are used for exchanging multicast group state information between MARs.

6.3.2.2.1 MUME_MUME_ContextTransfer.request

Function

Context transfer is used between the previous and current access routers for multicast flows involved in the video delivery, providing a fast multicast tree reconstruction and allowing an uninterrupted service.

Semantics of the service primitive

```
MUME_MUME_Context_Transfer.request (
    Mobile_Terminal_ID,
    Interface_ID
)
```

Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal
Interface_ID	STRING	The identifier of the interface where to receive multicast traffic.

Table 12. MUME_MUME_ContextTransfer.request parameter list

When generated

When a MAG-based scheme is used for supporting a multicast listener, such as no mobility is actually activated, the S-MAR communicates with A-MAR through means of context transfer protocol for exchanging the multicast profile information.

Effect on receipt

The receiving MUME sends MLD Query to get the MN's MLD state entries, and embeds it in a message to be sent to the requesting MUME.

6.3.2.2.2 MUME_MUME_ContextTransfer.response

Function

This message is used to transfer the multicast state relative to the MN.

Semantics of the service primitive

```
MUME_MUME_Context_Transfer.response (
    Mobile_Terminal_ID,
    Interface_ID,
    Number_of_Records (N),
    Multicast_Addr_Record [1],
    ...
    Multicast_Addr_Record [N]
    ResultCode
)
```

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Parameter	Type	Description
Mobile_Terminal_ID	STRING	The identifier of the Mobile Terminal
Interface_ID	STRING	The identifier of the interface where to receive multicast traffic.
Number_of_Records	UINT_8	Number of Multicast Address Records

Multicast_Addr_Record{
Multicast_address
Filter_mode
Number_of_Multicast_Sources
Multicast_Source_List{
Multicast_Source_address
}
}
	TLV_List {
	
	IN6_ADDR
	SHORT_INT
	UINT_8
	TLV_List {
	IN6_ADDR
	}
	}
		Multicast record for specified multicast address
		Multicast group address
		Filter mode (INCLUDE or EXCLUDE)
		Number of Multicast Sources
		The list of multicast source addresses
		Address of Multicast Source

ResultCode	UINT_8	The result of Context Transfer. (0 on OK otherwise return an error code)

Table 13. MUME_MUME_ContextTransfer.response parameter list

When generated

After receiving the MN's MLD Report, the MUME at the A-MAR embeds MN's MLD state entries in this message and sends it to the S-MAR.

Effect on receipt

The receiving MUME joins the content identified by Multicast Address Records on behalf of the MNs (in case the S-MAR is not receiving already the multicast traffic).

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7 Conclusion

This document was mostly focused on the support of multicast in the first and last hops of future mobile networks, targeted at the upcoming exasperating adversities operators will face as a result of the increase in video content distribution in cellular networks. The operation and advantages of multicast were presented, along with the problems that result when considering both mobile source or listeners nodes. Therefore, it was seen how the IP address continuity is a key aspect in multicast operation, both at the source and as the listener.

One of the key concepts in MEDIEVAL project is the search for an alternative to centralized mobility solutions. The problems these present are reflected in both unicast and multicast communications, although in different terms. Furthermore, the impact of distributing network capabilities and flattening mobile architectures in multicast protocols was analyzed, consequently coming up with a few possible solutions, with distinct advantages and issues, e.g. in terms of scalability, implementation complexity or signaling overhead.

Thus, two main driving lines for multicast mobility were identified, and can be applied at the source or listener multicast role. The first one follows the base solution proposed in [20], by establishing a mobility tunnel between the access router where the session demanding IP conservation was initialized (A-MAR), and the current access router (S-MAR). The alternative approach is based in [4], and takes advantage of native multicast infrastructure for delivering this traffic, avoiding the tunneling overhead (as well as IP address continuity) from the aforementioned mobility solution. The utilization of this solution at the source side implies some modifications to the multicast protocol itself (PIM-SSM).

A more precise view on the implementation issues, as well as the evaluation of a solid solution supporting both sources and listeners' mobility is expected to be done in the next deliverable, D4.3. This may also aid in identifying the characteristics of the scenarios where different multicast mobility supports make sense, e.g. regarding the number and profile of users, network and service characteristics, and others.

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Annex I: Relevant contributions to dissemination

This annex provides a selected list of the dissemination work on technological topics considered within WP4 (IP multicast related topic) in the first year of the MEDIEVAL project. Both published papers for conferences and contributions to standardization are presented.

I.1 Papers for Conferences

Title: **A Hybrid MIPv6 and PMIPv6 Distributed Mobility Management: the MEDIEVAL approach**

Authors: Fabio Giust, Carlos J. Bernardos, Sergio Figueiredo, Pedro Neves

Conference: MediaWiN 2011

In MEDIEVAL both network and host based mobility solutions are considered as possible deployment solutions of DMM architecture. This paper presents the MEDIEVAL proposed hybrid solution where the two schemes are extended and merged into a hybrid network.

Abstract

Video is a major challenge for the future mobile Internet as it is foreseen to account for close to 64% percent of consumer mobile traffic by 2013. However, the current Internet, and in particular the mobile Internet, was not designed with video requirements in mind and, as a consequence, its architecture is very inefficient when handling this type of traffic. This paper presents a novel mobility architecture inspired by the Distributed Mobility Management paradigm, capable of coping with the future video traffic demands, in a distributed and more scalable way. In the proposed solution, mobility support services are spread among several nodes at the edge of the network, thus realizing a flatter architecture and pushing services closer to the terminals. Our approach overcomes some of the major limitations of centralized IP mobility management solutions, by extending existing standard protocols.

Title: **Media-Independent Multicast Signaling for Enhanced Video Performance in the MEDIEVAL Project**

Authors: Daniel Corujo, Sérgio Figueiredo, Rui L. Aguiar

Conference: Future Network and Mobile Summit 2011

MEDIEVAL explores 802.21 beyond its original goals and considered scenarios. This paper innovates by proposing multicast signalling in 802.21, as a means to achieve better resource efficiency.

Abstract

With the foreseen major increase in video traffic over the coming years, the current Internet's design is being perceived as inefficient for handling the demanding flow of video over wireless access networks, populated by an ever increasing number of mobile terminals. The MEDIEVAL project aims to evolve the current Internet architecture to provide an optimized video support in all layers of the protocol stack. With its cross-layer approach, abstraction mechanisms such as IEEE802.21 will work as enablers between the different architecture modules. With the widespread diffusion of video being realized over multicast and broadcast channels for resource optimization, using 802.21 signalling to optimize handovers affecting groups of users will generate multiple messages to each individual terminal. In this article, we extend 802.21 to support multicast transport of its signalling, enabling more efficient group handover scenarios.

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Title: **Supporting Multimedia Services in the Future Network with QoS-routing**

Authors: Leandro Alexandre, Augusto Neto, Eduardo Cerqueira, Sérgio Figueiredo, Rui Aguiar

Conference: MONAMI 2011

This paper explores a possibility for backhaul support of multimedia services. based on over-provisioning and per-class load balancing. The solution is aided by the creation of multiple multicast trees between which QoS-routing is occurs.

Abstract

The increasing demand for real-time multimedia applications targeting groups of users, together with the need for assuring high quality support for end-to-end content distribution, is motivating the scientific community and industry to develop novel control, management and optimization mechanisms with Quality of Service (QoS) and Quality of Experience (QoE) support. In this context, this paper introduces Q-OSys (QoS-routing with Systematic Access), a distributed QoS-routing approach for enhancing future networks with autonomous mechanisms orchestrating admission control, per-class overprovisioning, IP Multicast and load-balancing to efficiently support multi-user multimedia sessions. Simulation experiments were carried to show the efficiency and impact of Q-OSys on network resources (bandwidth utilization and packet delay). Q-OSys is also evaluated from a user point-of-view, by measuring well-known objective and subjective QoE metrics, namely Peak Signal to Noise Ratio (PSNR), Structural Similarity (SSM) Video Quality Metric (VQM) and Mean Opinion Score (MOS).

I.2 Contributions to Standardization

Title: **Rapid acquisition of the MN multicast subscription after handover**

Authors: Carlos J. Bernardos, Luis M. Contreras, Ignacio Soto

IETF MULTIMOB WG

The MEDIEVAL mobile architecture aims at providing support not only to unicast flows, but also to multicast transmissions, for which a dedicated effort was put in the investigation in order to integrate the two functionalities into the same framework. The following paper is part of the solution for PMIPv6.

Abstract

A new proposal is presented for speeding up the acquisition by the MAG of the MN's active multicast subscription information, in order to accelerate the multicast delivery to the MN during handover. To do that, an extension of the current PMIPv6 protocol is required. The solution described in this memo is not only applicable to the base multicast solution, but also it can be applied to other solutions envisioned as possible architectural evolutions of it. Furthermore, it is also independent of the role played by the MAG within the multicast network (either acting as MLD proxy or multicast router).

Title: **Support Multicast Services Using Proxy Mobile IPv6**

Authors: J.C. Zuniga, A. Rahman, L.M. Contreras, C.J. Bernardos, I. Soto

IETF MULTIMOB WG

The MEDIEVAL mobile architecture aims at providing support not only to unicast flows, but also to multicast transmissions, for which a dedicated effort was put in the investigation in order to integrate the two functionalities into the same framework. The following paper is part of the solution for PMIPv6.

Abstract

The MULTIMOB group has specified a base solution to support IP multicasting in a PMIPv6 domain [RFC6224]. In this document, an enhancement is proposed to the base solution to use a multicast tree mobility anchor as the topological anchor point for multicast traffic, while the MAG remains as an IGMP/MLD proxy. This enhancement provides benefits such as reducing multicast traffic replication and supporting different PMIPv6 deployments scenarios.

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