Efficient Multicast Content Delivery over a Distributed Mobility Management Environment

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***Abstract*—The growth in mobile devices and mobile traffic in which multimedia is a main type of traffic leads the mobile network to become more flattened. A new mobility management, called distributed mobility management (DMM), has been proposed to cope with the flat IP architecture. While DMM is a potential solution in terms of IP mobility management to deal with a huge number of wireless devices and traffic, IP multicast can be seen as a promising service for enhancing the efficiency of multimedia content delivery. Considering IP multicast listener mobility in a DMM environment, there exist some issues. Several proposals have been introduced to solve these issues, however, mainly for Proxy Mobile IPv6 (PMIPv6) networks. These proposals also remain unable to tackle all the multicast listener-related issues at the same time. Moreover, there are several limitations when these proposals are considered in a DMM environment. In this paper, a complete solution is introduced for all of these issues by taking the different proposals into account in an appropriate way in a DMM environment. This solution can also be applied for multicast source mobility.**

***Keywords*—IP multicast, multicast mobility, distributed mobility management, tunnel convergence problem, handover delay, leave latency, sub-optimal routing**

I. INTRODUCTION

The ever-increasing mobile devices and traffic [1] bring several challenges to the current networks [2]. To overcome these challenges, the mobile network is evolving towards a flat IP architecture in order to lower costs, reduce system latency, and decouple radio access and core network evolution [2] (e.g. Local IP Access and Selected IP Traffic Offload (LIPA/SIPTO) architecture [3]). However, when considering most of the existing IP mobility solutions (e.g. Mobile IPv6 (MIPv6) [4] and PMIPv6 [5]) which leverage on the centralized mobility management approach in a flat architecture, there exist some serious issues such as complex tunnel management, poor performance, and scalability issues, etc. [2] [6].

A novel approach, called distributed (and dynamic) mobility management (DMM) [2] [7], has been proposed to be compatible with the flat IP architecture and overcome the limitations of the centralized mobility management. The main ideas are: i) the mobility anchors are placed as close as possible to the mobile nodes (MNs); ii) the control and the data plane are distributed among the network entities; and iii) the mobility service is provided dynamically to the service that really needs it. Consequently, the DMM concept enables the networks to be scalable with the massive data traffic and a huge number of MNs. In DMM, two approaches are considered namely a host-based and a network-based mobility [7].

In the future, the multimedia will be indeed the main traffic of the mobile data traffic [1]. In this context, IP multicast, which provides an effective way for multimedia content delivery, plays a very important role. Since the multicast protocols are designed for the fixed nodes, the movement of multicast nodes between different networks results in severe problems [8]. However, limited work on multicast mobility in a DMM environment has been developed.

In a DMM environment (network-based approach), multicast mobility support can be enabled by deploying Multicast Listener Discovery (MLD) Proxy function [9] at the mobility access routers (MARs) (called MLD-DMM). The multicast traffic is routed from the native multicast infrastructure for the multicast sessions that are initiated at the current MAR. For the sessions after mobility, the multicast traffic is delivered from the previous MAR via the bi-directional tunnel between the current MAR and the previous one. This behavior resembles the based solution for multicast support in PMIPv6 [10]. This scheme can be applied for both multicast source and listener in a DMM environment. However, in this paper, we mainly focus on the multicast listener support in a network-based DMM.

Nevertheless, this scheme does not address any multicast listener-related issues [8]. A set of proposals has been introduced (mainly for PMIPv6) in which each of them aims at solving a couple of issues, for example: i) the multicast context transfer (CXT) for the service disruption and packet loss issue [11] [12]; ii) the multiple upstream interfaces support for the Internet Group Management Protocol (IGMP) / MLD Proxy for the tunnel convergence problem [13]; iii) the explicit tracking function for leave latency and waste of resources issue [14] [15]; and iv) the channel-manageable solution for both tunnel convergence and sub-optimal routing issue [16]. Yet, they fail to address all these issues at the same time. Moreover, there are several limitations when these proposals are applied in a DMM environment (see Section II.B).

In this paper, we will briefly look at the proposals for

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different multicast listener mobility-related issues. A complete solution then will be proposed to solve these issues in a DMM environment in an appropriate way. The proposed solution takes all of the above-mentioned proposals into consideration. Also, we describe how to implement the multiple upstream interfaces support for the IGMP/MLD Proxy (referred as MLD Proxy in this paper).

The remainder of this paper is organized as follows. Section II highlights the different existing proposals for separate issues. Section III describes the proposed solution. Section IV provides some considerations regarding multicast source mobility and tunnel management. Finally, Section V concludes the paper and provides perspectives for the future work.

II. RELATED WORK

A. Network-based Distributed Mobility Management

Due to the lack of DMM standard, in this paper, a generic approach considers that a DMM domain consists of the mobility access routers (MAR). Basically, the MAR implements the functionality of a plain access router, a mobile access gateway (MAG), and a local mobility anchor (LMA) [2] [17]. In a DMM domain, the MN gets a different set of IP addresses when changing its point of attachment. In case of mobility, the MN's flows are anchored (if necessary) at the previous MAR in which the using MN's prefix is allocated. Hence, the packets can be redirected via the tunnel from the previous to the new MAR. Mobility management may be fully distributed where both the data and the control planes are distributed; or partially distributed where the central mobility anchor is still present, but for the control plane only.

B. Multicast Listener Mobility-related Issues and Solutions

Regarding multicast in DMM environments, there is a limited work for multicast support since the DMM is still in its infancy. In [18], the authors provide different use cases for IP multicast support as well as mention about the issues when IP multicast is applied in DMM paradigm. Two scenarios are considered regarding the multicast functionality deployed in the MAR: multicast router (MR) or MLD Proxy. In the first scenario (MR function on MAR), the tunnel convergence problem and sub-optimal routing are avoided. It is because the MAR (acting as an MR) can select the upstream MR based on the multicast routing information and/or network management criteria. However, smooth handover cannot be assured [18]. Also, the operators may not want to support the multicast routing function on MAR due to its implementation and operational costs. For these reasons, this paper focuses on the second scenario in which the MAR acts as an MLD Proxy.

In the second scenario (MLD Proxy function on MAR), when a multicast session is started at the current MAR, the multicast traffic is received directly from the native multicast infrastructure. In case of mobility, the multicast traffic is routed from the previous to the new MAR via the bi-directional tunnel between them. However, this scheme does not address any specific optimizations and performances issues which are discussed in the following subsections.

1) Service Disruption and Packet Loss during Handover: Since the MN (listener) in the network-based mobility management is not aware of the mobility process, it cannot make the multicast-related decisions. When a multicast listener moves to a new MAR, it has to wait to express its interest in subscribing to the multicast channels until it receives an MLD Query (from the new MAR). Thus, it experiences a certain delay in obtaining multicast content due to the extra time related to the multicast service activation and MLD Query/Report transmission. In [12], different solutions for this issue have been introduced. The authors showed that by incorporating between the multicast context transfer and the explicit tracking function, the service disruption time could be significantly reduced without increasing the multicast-related signaling and modification of PMIPv6 protocol. Hence, the seamless handover can be achieved. Although this solution is for PMIPv6, the similar idea can also be applied in a DMM environment.

2) Tunnel Convergence Problem and Sub-optimal Routing: In case of mobility, the utilization of mobility tunnel for the multicast session may result in the tunnel convergence problem. This problem happens when the multiple instances of the same multicast traffic converge to a MAR, leading to the redundant traffic. It is because multiple MLD Proxy instances are installed at the MAR with their upstream interfaces configured to different tunnels towards different MARs (acting as the LMA). Since the objective of DMM is moving the mobility anchors from the core to the edge of the networks, the number of mobility anchors in a DMM domain (anchoring MAR - in the network edge) will be much more than that in a PMIPv6 domain (LMA - in the core network). Thus, the tunnel convergence problem may become much more severe than that in PMIPv6 especially in highly mobile regimes.

Several solutions have been proposed to solve the tunnel convergence problem. In [16], the authors introduce a framework managing all multicast channels and controlling which channel should be local or remote. In other words, the MAR will decide to get a multicast channel from the multicast infrastructure (for local content) or from the previous MAR (for remote content) to minimize the multicast traffic duplication. This solution also helps to route the multicast traffic in a better way, since the multicast traffic does not have to pass the previous MAR in case of local content availability. However, as only one upstream interface is configured at a time, it may cause the tunnel convergence problem again when an aggregated MLD Report is sent to the upstream interface. Thus, the tunnel convergence problem cannot be completely avoided.

Another solution for this issue is an extension to MLD Proxy to support multiple upstream interfaces [13] [19]. In this case, only one MLD Proxy instance is installed on a MAR with the multiple upstream interfaces in which each interface is configured towards another MAR (LMA). Thus, the MAR will receive only one instance of multicast traffic from a MAR or from the native multicast infrastructure. However, the upstream interfaces must be manually configured [11]. In a DMM environment, it is impossible to manually configure the upstream interface for all MARs particularly in high mobility regimes. This is because each MAR can be the mobility anchored (playing the role of the LMA) for MNs which still use a prefix allocated by this MAR. In [19], different usage scenarios for multiple upstream interfaces as well as their requirements have been introduced. Yet, how to apply this extension in a DMM paradigm is still an open question.

3) Leave Latency and Waste of Resources: In DMM, due to the mobility, the last member of a multicast group may move to the new MAR without explicitly leaving the group in the previous one. As a result, the previous MAR will continue forwarding multicast traffic during certain duration (leave latency). Thus, it causes a waste of resources and network congestion [8] [20]. There are two strategies to reduce the leave latency. The first one is tuning the behavior of the MLD for routers [14]. However, it may cause an increasing of multicast-related signaling which could influence the wireless link condition between the MAR and the MN. Especially, the problem will be more severe with a large number of multicast listeners [12]. Another strategy is a combination of the explicit tracking function for routers [15] and the multicast context transfer. It helps to shorten the leave latency and reduce resources waste by reminding the previous MAR to stop forwarding the multicast traffic.

III. DESCRIPTION OF THE SOLUTION FOR MULTICAST LISTENER MOBILITY IN DMM

As discussed in the previous section, several proposals have been introduced (mainly for PMIPv6) to tackle the multicast listener-related issues. However, they have some limitations when applying in a DMM environment. In this context, our solution which takes into consideration these proposals can offer several benefits while keeping the advantages of those different proposals. The benefits are detailed as below:

- *All-in-one*: One solution for all the multicast listener mobility-related issues (service disruption and packet loss during handover; tunnel convergence problem; leave latency and network resource waste; and sub-optimal routing).
- *Dynamic utilization of mobility tunnel*: The utilization of mobility tunnel for the ongoing multicast sessions is enabled in appropriate cases e.g. for remote content, or for a channel with strict delay requirements.
- *Tunnel convergence problem avoidance*: This solution can fully resolve the tunnel convergence problem.
- *Possibility to be applied with multicast source mobility.*
- *Centralized channel management (in case of partially distributed scheme)*: The central entity (Multicast Channel Control) manages the multicast channels and defines the scope of each channel (local or remote, or both of them).

Moreover, this paper also discusses the practical aspect of how to implement the MLD Proxy with multiple upstream interfaces capability.

A. Description of the Solution

In this section, the solution will be presented following two different DMM schemes: partially and fully distributed.

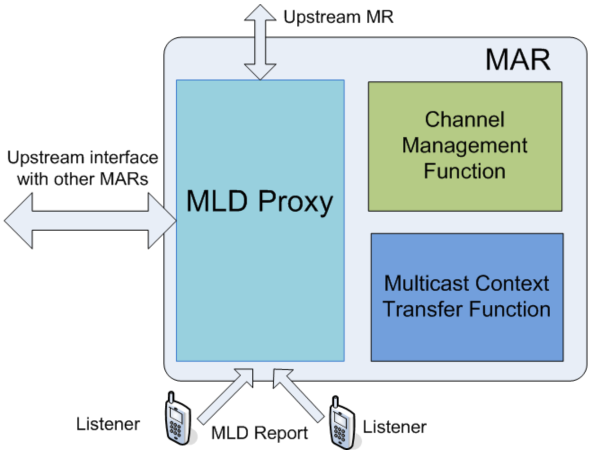

Fig. 1: Multicast mobility management module on MAR.

1) Partially Distributed Scheme: The solution leverages on a central entity and a multicast mobility management module to deal with the multicast issues. The central entity - Multicast Channel Control (MCC) manages all the multicast channels in order to decide which channel should be locally or remotely supported. The decision is made based on the channel setting which is configured manually/statically by the network operator. It can also be relied upon several criteria e.g. scope of the multicast channel, delay requirement, and the mobility behavior of the listener (e.g. its mobility rate). However, the decision in details is out of scope of this document. It is noted that the MCC can be co-located with the central mobility anchor [17], or resided in a separate entity.

Residing in the MAR, the multicast mobility management module takes responsibility for all actions related to the multicast mobility. The structure of this module is depicted in Fig. 1 and briefly described as follows:

- The MLD Proxy module performs the operation of the MLD Proxy [9] which is able to configure multiple upstream interfaces. This module also supports the multicast explicit tracking function in order to keep per-host multicast membership state [15].
- The channel management function (CMF) communicates with the MCC to retrieve the channel information (local or remote).
- The multicast context transfer function (MCTF) is responsible for the multicast context transfer exchanging between MARs to reduce the service disruption time.

The multiple upstream interfaces capable of the MLD Proxy can be enabled by extending the membership state information (which is available thanks to the explicit tracking function) with the information related to the upstream interface identifier (ID) and the list of the local sources associated with this interface. Thus, each entry of the membership state consists of the following information: upstream interface ID, multicast source address (S), group address (G), number of listeners, listener records, and local sources belong to this upstream interface [15]. Hence, the membership state can be served as an upstream interface selection policy. By doing so, it can completely resolve the tunnel convergence problem.

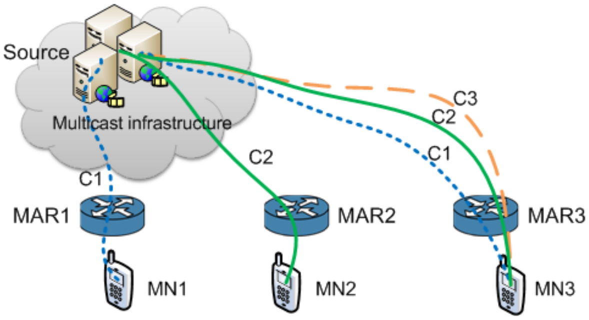

Fig. 2: Multicast sessions at the initial stage.

2) Fully Distributed Scheme: In this case, the MCC is removed from the architecture. The CMF will perform the logical function of the MCC in a distributed way to decide which channel should be locally or remotely supported. The decision criterion can also consider several criteria similar to that of MCC. However, how to implement the CMF function in a distributed way is out of scope of this document.

B. Operation of the Solution

In order to describe the operation of the solution, we suppose that at the beginning three MNi (i=1,2,3) are originally attached to three MARi (i=1,2,3), respectively (see Fig. 2). About the MN1, it at first acquires an IPv6 address issued from the prefix (Pref1) which is allocated by the MAR1. It then can use this IP address to initiate a new multicast session (for example, subscribing to the channel C1 (S1, G1)). After adding the MN1 to a downstream interface, the MAR1 updates its membership state and sends an aggregated MLD Report to its upstream MR to receive the multicast session. At this stage, the membership state information at MAR1 is updated with the following information (MR_ID, S1, G1, 1, {MN1}, {}), where MR_ID is the upstream interface identifier towards the multicast infrastructure. Similarly, the MN2 subscribes to the channel C2 (S2, G2) at MAR2 while MN3 subscribes to the channel C1 (S1, G1), C2 (*, G2) and C3 (S3, G3) at MAR3. Thus, the membership state at MAR2 is (MR_ID, S2, G2, 1, {MN2}, {}), while at MAR3 is as (MR_ID, S1, G1, 1, {MN3}, {}), (MR_ID, *, G2, 1, {MN3}, {}), (MR_ID, S3, G3, 1, {MN3}, {}).

When the MN1 moves from the MAR1 (previous MAR, or pMAR) to the MAR2 (new MAR, or nMAR) (see Fig. 3), it configures a new IPv6 address from the new prefix allocated (Pref2). A bi-directional tunnel is then established between the MAR2 and the MAR1 to carry the unicast traffic from/to the MN1 using Pref1. The multicast context transfer between MAR1 and MAR2 is executed in parallel, allowing MAR2 to get the MN1's active multicast subscriptions (channel C1) in advance. It can be done by extending the Proxy Binding Update (PBU) / Proxy Binding Acknowledgment (PBA) message or using the CXT Request / CXT Response message as described in [12]. In case of partially distributed scheme, the MAR2 then contacts with the MCC to decide whether the channel C1 should be local or remote. In fully distributed scheme, the decision is made by the CMF module. In addition, if the MN1 is the last member of the channel C1 at the MAR1 and if the channel C1 is defined as a local channel (L), the MAR1 will be indicated (by the MAR2) to immediately stop forwarding this channel. Thus, it shortens leave latency and reduces waste of resources. Assuming that the channel C1 is defined as a remote channel (R), the MLD Proxy instance at MAR2 will configure an upstream interface towards the tunnel MAR1-MAR2. It then sends an MLD Report to MAR1 to subscribe to this channel. Consequently, the multicast traffic will be routed from MAR1 to MAR2 via the tunnel MAR1-MAR2 and reaches the MN1. The membership state at MAR2 will be updated with the following records: (MAR1_MAR2_ID, S1, G1, 1, {MN1}, {}), (MR_ID, S2, G2, 1, {MN2}, {}), where MAR1_MAR2_ID is the interface ID of the tunnel MAR1-MAR2.

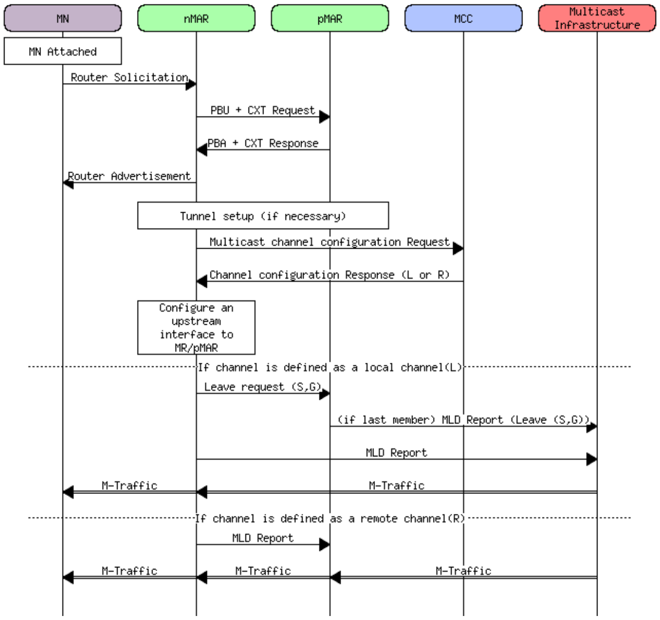

Fig. 3: Handover signaling (partially distributed scheme).

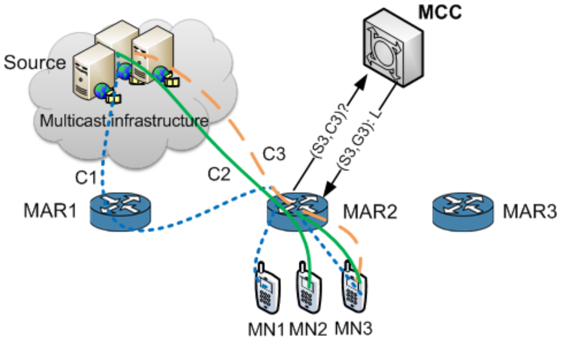

Fig. 4: After mobility, the channel C1 is received via the tunnel MAR1-MAR2 (remote), while the channel C2 and channel C3 from the native multicast infrastructure (local) (partially distributed scheme).

Similarly, up on an IP handover, the MN3 is attached to the MAR2. Since the multicast state for the channel C1 and C2 is available at MAR2, the MN3 can immediately get the traffic for these channels. The channel C3, defined as a local channel, is routed from the native multicast infrastructure to the MAR2 and reaches the MN3. Afterward, the membership state at MAR2 is as follows: (MAR1_MAR2_ID, S1, G1, 2, {MN1, MN3} {}); (MR_ID, *, G2, 2, {MN2, MN3}, {}); (MR_ID, S3, G3, 1, {MN3}, {}).

As a result, for a specific channel, the MAR will receive

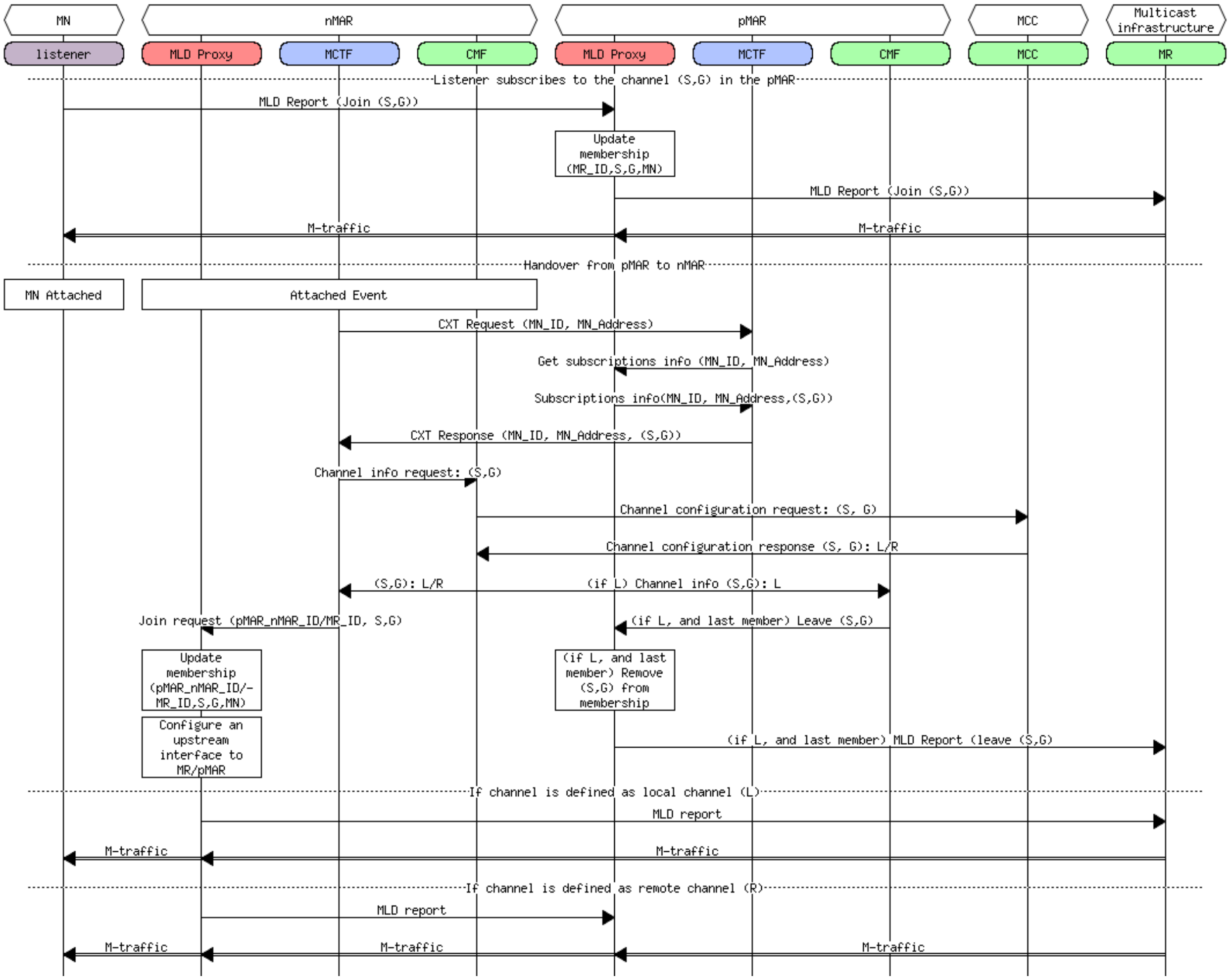

Fig. 5: Signaling of the solution in details (regarding multicast-related operations).

the traffic from only one entity (previous MAR or its upstream MR, see Fig. 4) which helps avoid the tunnel convergence problem. Also, by receiving the multicast traffic from the local sources via the local MR and from the remote sources via the tunnel with the previous MAR, the multicast traffic is routed in a near-optimal way.

As a normal MLD proxy operation, the aggregated MLD Report including the appropriate multicast subscriptions will be sent to the corresponding upstream interface. For example, the MAR2 will send an aggregated MLD Report including the information of the channel C2 (*, G2), and the channel C3 (S3, G3) to its default upstream MR. Similarly, an aggregated MLD Report will be sent to MAR1 (via MAR1-MAR2 tunnel) consisting of the information of the channel C1 (S1, G1).

The details of the interaction between the internal modules inside a MAR as well as between different entities during a handover process are shown in Fig. 5.

IV. DISCUSSION

A. *Multicast Source Consideration*

The proposed solution can also be applied for the multicast source mobility over a DMM environment. In this case, the local source will be put on the local source list of the corresponding membership record.

This solution provides a possibility to diffuse the multicast traffic from a source via a local MR (for local listeners), or via the tunnel (for remote listeners), or both of them at the same time. The decision is made by the MCC/CMF similar to the case of listener mobility support. For example, when the source S3 of the ongoing channel (S3, G3) moves from the MAR4 to the MAR2, the source S3 can continue to diffuse the channel (S3, G3) by using the previous address (obtained at MAR4) as a source address. In this case, the membership state is updated depending on the type of the multicast channel.

- Local channel: (MR_ID, S3, G3, 1, {MN3}, {S3}) (the multicast traffic from the source is diffused via the MAR2's default upstream MR).
- Remote channel: (MAR2_MAR4_ID, S3, G3, 1, {MN3}, {S3}) (the multicast traffic is routed via the bi-directional tunnel MAR2-MAR4).
- Both local and remote channel: (MR_ID, S3, G3, 1, {MN3}, {S3}), (MAR2_MAR4_ID, S3, G3, 1, {MN3}, {S3}) (the multicast traffic is delivered via

both the MAR2's upstream MR and the tunnel MAR2-MAR4).

It is worth noting that if the channel is defined as a local channel, the reconstruction of the multicast delivery tree may be required after each handover. As a consequence, it may result in significant service disruption and delay, particularly in case of source-specific multicast [8].

Thanks to the multiple upstream interfaces capability, the solution helps to address the sub-optimal routing issue which happens in MLD-DMM when a source and a listener are attached to the same MAR but associated to different MARs. For instance, the traffic is routed in a non-optimal way from the current MAR to the source's previous MAR, then passing through the listener's previous MAR, returning to the current MAR, and finally reaching the listener [21].

B. Tunnel Management Consideration

In PMIPv6, the bi-directional tunnel MAG-LMA can be pre-established or dynamically created [5]. However, in a DMM environment, it is difficult to pre-establish all the tunnels since each MAR can establish one tunnel with each other (especially with a large number of MARs). Thus, by separating the multicast and unicast, the mobility tunnel should be carefully managed to avoid the management complexity and the waste of resources (e.g. maintenance of the tunnel, and keep alive signaling, etc. [6]).

To illustrate the issue, we suppose that the MN1 is the only one mobile node that moves from the MAR1 to the MAR2 with the ongoing multicast session (subscribing to the channel C1). As the normal DMM operations, the bi-directional tunnel between the MAR1 and the MAR2 is established to route the unicast traffic from/to the MN1 using the prefix allocated at MAR1. Also, the MN1 gets the multicast traffic channel C1 from the MAR1 via the tunnel MAR1-MAR2. Then, a new MN (namely MN4) is attached to the MAR2 and expresses its interest in receiving the multicast channel C1. Since this channel is already available at MAR2, the multicast traffic is simply forwarded to the MN4. When the MN1 moves to another MAR, the tunnel between MAR1 and MAR2 should not be removed since it is still used for the multicast channel C1 for the MN4. Thus, the mobility tunnel management should also consider the multicast membership state.

V. CONCLUSION AND FUTURE WORK

In this paper, a complete solution for the multicast listener-related issues in a DMM environment has been presented. This solution takes different proposals for separated issues (mainly for PMIPv6) into account in an appropriate way to keep their advantages while eliminating their limitations for enhancing the efficiency of multicast delivery in a DMM environment. The solution also helps to fully solve the tunnel convergence problem. Moreover, it can also be applied in case of multicast source mobility.

In the next step, the experimentation aiming at justifying the effectiveness of the solution will be made based on a DMM extension of an existing PMIPv6 testbed [12] for the multicast listener/source mobility. The testbed was developed from the open source OAI PMIP [22], User-mode Linux [23] and Network Simulator NS-3 [24]. The explicit tracking and the multicast context transfer function were also implemented in the testbed.

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