On the Efficiency of Dynamic Multicast Mobility Anchor Selection in DMM: Use Cases and Analysis

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***Abstract*—The ever-increasing mobile Internet traffic has led to the development of a new IP mobility management concept in the Internet Engineering Task Force (IETF) - distributed mobility management (DMM). Based on the fact that the mobile Internet traffic will be dominated by the mobile video, the scalability and bandwidth efficiency from multicast routing makes the IP multicast play more important role. In DMM, IP multicast can be enabled by deploying the MLD proxy function at the mobility access router (MAR). The MAR at which the multicast flow is initiated is used as a multicast mobility anchor (MMA) for this flow. In case of mobility, the multicast traffic is tunneled from the anchor to the current MAR. As a result, the movement of the listener causes several issues for the ongoing multicast flow such as service disruption, non-optimal routing (end-to-end delay) and the tunnel convergence problem. In some cases, it is almost impossible to meet the requirements in terms of service disruption and delay (e.g., for the real-time and delay-sensitive services). In this paper, we introduce a dynamic MMA selection mechanism in order to mitigate these issues. The MMA selection takes into account such contexts as the multicast service, the mobile node's mobility and the network. Numerical results show that by selecting the appropriate MMA, these requirements can be satisfied even for services with stringent interruption and delay constraints.**

Keywords*—IP multicast, Distributed mobility management, Multicast listener mobility, Mobility anchor selection, Proxy Mobile IPv6.

I. INTRODUCTION

The increasing penetration of the mobile devices, such as tablets and smart phones is generating a huge number of data traffic over mobile networks. Mobile data traffic is expected to grow to 11.2 exabytes per month by 2017, a 13-fold increase over 2012 [1]. The increasing traffic is mainly driven by mobile video traffic: estimates say that mobile video traffic will account for 66.5% of total mobile data traffic by 2017 [1]. Despite increasing volume of traffic, mobile data revenue per user is falling fast. Thus, mobile network is evolving towards flat network architecture in order to be able to cope with the huge amount of traffic and reduce data transmission costs. Examples of this trend are traffic offloading (e.g., Local IP Access and Selected IP Traffic Offload (LIPA-SIPTO)) and content delivery network (CDN) [2].

In all-IP mobile networks, IP mobility is a crucial concept to meet the demand of ubiquitous Internet connectivity as well as new service requirements such as seamless handover across heterogeneous networks, consistent quality of experience and stringent delay constraints. Considering conventional IP mobility management (e.g., Mobile IPv6, Proxy Mobile IPv6 (PMIPv6) [3]) which leverages on the centralized mobility management approach in a flat architecture, it raises several issues for the network operator like inefficient use of network resources, poor performance, and scalability issues [2].

Altogether, a novel concept, the so-called distributed (and dynamic) mobility management (DMM) [4] has been introduced to overcome the limitations of the centralized mobility management. The key concepts of DMM are: i) the mobility anchors are placed as close as possible to the mobile nodes (MNs); ii) the control and data plane are distributed among the network entities located at the edge of the access network; and iii) the mobility support is provided dynamically to the services/MNs which really need it. While DMM is expected to be an effective solution in terms of IP mobility management to deal with a huge number of devices and traffic, IP multicast can be considered as a valuable solution from service point of view. In some cases, IP multicast can provide significant advantages compared to unicast regarding overall resources consumption (e.g., bandwidth, server load and network load) and deployment cost to deliver the traffic, especially video traffic [5][6].

However, a limited work has been done considering IP multicast in a network-based DMM environment. At this stage, IP multicast can be enabled in DMM by deploying the Multicast Listener Discovery (MLD) proxy function at the mobility access router (MAR) [7]. The multicast traffic is routed directly from the native multicast infrastructure via the current MAR for the new multicast flow. For the flow after handover, the multicast traffic is tunneled from the MAR where the flow is initiated to the current one via the mobility tunnel between them. Thus, the multicast mobility anchor (MMA) is assigned at the initial phase of the multicast flow (identical with the unicast mobility anchor): the MAR where the flow is initiated. The multicast flow will be anchored at the initially assigned MMA during its lifetime. Therefore, even when the MN moves far away from its anchor, the multicast traffic still traverses the anchor. As a result, it causes several issues to the ongoing multicast flow such as service disruption, non-optimal routing, end-to-end delay and tunnel convergence

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problem. These problems become serious when considering the interruption-sensitive and delay-sensitive services. Also, even the mobility anchors are distributed, some anchors are overloaded more than the others [8].

In this paper, we mainly argue the need for a dynamic multicast mobility anchor selection. From a service point of view, it helps satisfy the requirements in terms of service disruption and delay, especially when considering real-time services. Also, it provides a mechanism to better distribute the load among MARs. The MMA selection takes into account not only the multicast service context (e.g., interruption-sensitive and delay-sensitive services) but also the mobile node's mobility context and the network context (such as current load of MARs and multicast channel policy), thus enabling per-flow multicast support. In other words, depending on the contexts each multicast flow can be treated differently. The MMA selection can be done dynamically when a multicast flow is initiated or when the listener performs a handover thanks to the MLD proxy supporting multiple upstream interfaces [9].

The rest of this paper is organized as follows. Section II presents the DMM concept and the multicast-related issues in a DMM environment. Section III describes the MMA selection regarding different contexts as well as use-case scenarios. The performance evaluation is conducted in Section IV. Section V discusses the tunnel management problem and provides some insights of how MMA selection works. Finally, Section VI concludes the paper and provides perspectives for future work.

II. RELATED WORK

A. *Network-based Distributed Mobility Management*

Due to the lack of DMM standards, this paper follows the concept of the network-based DMM [10] proposed by the IETF DMM Working Group[1]. We consider that a DMM domain consists of mobility access routers (MARs) which implement the functionality of a mobile access gateway (MAG), and a local mobility anchor (LMA) [3] as well as a plain access router. In a DMM domain, the MN gets different prefixes when changing its point of attachment. In case of mobility, the MN's flows are anchored (if necessary) at the MAR in which the MN's prefix in use is allocated (called anchor MAR or aMAR). Hence, the packets can be redirected via the tunnel from the anchor to the current MAR (cMAR).

Fig. 1 represents an example scenario of how DMM works. Once the MN enters a DMM domain (attaches to MAR1), it configures an IPv6 address based on the prefix allocated (Pref1) and can use its address to initiate a flow with the corresponding node (CN) (say flow1). The MN then moves to MAR2 and starts a new flow (say flow2) using the prefix allocated at MAR2 (Pref2). If the flow1 is kept alive, it will be anchored at MAR1. This means that flow1 is redirected through MAR1 using the mobility tunnel MAR1-MAR2. Next, the MN moves to MAR3. At this step, the flow1 and flow2 are anchored at MAR1 and MAR2, respectively. From flow1 point of view, MAR1, MAR2, and MAR3 are the anchor, the previous and the current MAR, respectively. While for flow2, MAR2 is both the anchor and the previous MAR (pMAR).

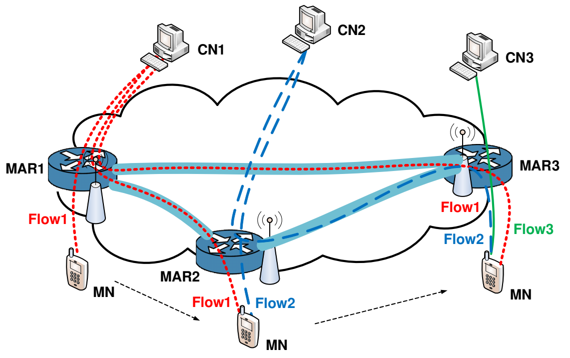

Fig. 1: An example scenario for DMM.

B. *Multicast Listener Mobility in DMM*

Regarding multicast in a DMM environment, there is a limited work for multicast support since the DMM is still in an early stage of standardization. So far, no complete solution has been found for multicast in DMM. To enable multicast in DMM, two basic scenarios are considered regarding the multicast functionality deployed at the MAR: multicast router (MR) or MLD proxy [7]. However, the operators may not want to support the multicast routing function on MAR due to its implementation and operational costs. This is the reason why our paper focuses on the scenario in which the MAR acts as an MLD proxy. Also, only multicast listener mobility in the network-based DMM is further studied.

Considering the MLD proxy deployment at the MAR, when a multicast flow is initiated, the multicast traffic is received directly from the native multicast infrastructure via the cMAR. After handover, the traffic is routed from the anchor to the current MAR via the tunnel between them (like unicast traffic). In this paper, it is called the default multicast mode in DMM. However, this mode does not address any multicast-related issues arising from the movement of listener. These issues are discussed in the following subsections.

1) Service disruption (and packet loss): When a multicast listener moves from the pMAR to the cMAR, several multicast-related procedures [11] need to be executed in order to allow the listener to continue receiving the ongoing multicast flows. Consequently, it may cause a noticeable service disruption. By using the multicast context transfer and the explicit tracking function, the service disruption time could be greatly reduced [11]. However, it is still far from the values required by specific services (e.g, interruption-sensitive services). For instance, in [12][13], the authors show that the multicast service disruption time strongly depends on the tunnel delay between the aMAR and cMAR. Hence, by reducing the tunnel delay, the service disruption time can be reduced.

2) Non-optimal routing and end-to-end delay: Since the multicast traffic always traverses the aMAR, it often results in a longer route (e.g., when the source and the listener are close to each other but far from the listener's aMAR). In particular, when considering a significant large domain, it can cause high end-to-end delay. Therefore, avoiding utilization of the mobility tunnel or shortening the tunnel could help.

3) Tunnel convergence problem: In case of mobility, the utilization of the mobility tunnel for the multicast flow may result in the tunnel convergence problem. This issue occurs

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[1] http://datatracker.ietf.org/wg/dmm/

when multiple instances of the same multicast traffic converge to an MAR, leading to redundant traffic. It is because multiple MLD proxy instances are installed at MAR with their upstream interfaces configured to different aMARs. Since the purpose 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 will be much more than that in a PMIPv6 domain. As a consequence, the tunnel convergence problem is supposed to be much more severe than that in PMIPv6, especially in highly mobile regimes. As stated in the DMM requirements [4], the multicast solutions in DMM should take this issue into consideration. By using an extension to MLD proxy to support multiple upstream interfaces [9], the tunnel convergence problem can be avoided. In this case, only one proxy instance will be installed at MAR with its upstream interfaces being configured towards different aMARs and its upstream MR. As a result, the MAR will receive only one instance of the multicast packet.

III. DYNAMIC MULTICAST MOBILITY ANCHOR SELECTION

In order to mitigate the issues caused by the movement of a listener following the muticast default mode, this paper proposes a mechanism which allows dynamically selecting and using the appropriate MMA among the candidates. This idea follows the assumption of the DMM protocol specified by the IETF [14]. The MMA selection can be done whenever the listener performs a handover or a multicast flow is initiated due to the MLD proxy supporting multiple upstream interfaces. As a result, the tunnel convergence problem is completely avoided. It is noted that if the ongoing multicast flow is present at the new MAR (or cMAR), the MN will get this channel directly from this MAR. Thereafter we only consider the case where the cMAR is not receiving the ongoing multicast channel.

To dynamically select the appropriate MMA, different contexts should be taken into account. This paper considers such contexts as the multicast service context (e.g., interruption-sensitive, delay-sensitive, and long-lived/short-lived flow), the MN's mobility context (high/low mobility), and the network context (like load of MARs, geographical proximity, and multicast channel policy). Each context can be assigned with a priority number. For example, a lower value indicates more important context. Based on the considered contexts, different use-case scenarios of MMA selection are then presented.

At this stage, similar to the default mode, when a listener initiates a multicast flow, the cMAR will act as the MMA for this flow (the multicast traffic will be received directly from the native multicast infrastructure). This means that the MMA selection in the initial phase will be left for future works. For a handover flow, the multicast traffic can be received from the aMAR, the pMAR, the cMAR, or even an MAR in which multicast flow is already available, or a less loaded MAR so as to achieve service disruption and end-to-end delay requirements. In addition, the everyday mobile users spend up to 62% of their time at home and work (in general, typical location) [15]. Thus, in some cases, the typical location would also be a good candidate. In the scope of this paper, four main candidates for multicast anchor, namely, the aMAR, the pMAR, the cMAR and the typical location (tMAR) will be considered corresponding to four approaches MMA_aMAR, MMA_pMAR, MMA_cMAR, and MMA_tMAR, respectively. The MMA candidates based on the network context (e.g., proximity or less loaded MAR) will be left for future works.

A. Considered Contexts

1) Multicast service context: When services are sensitive to interruption or packet loss, the service disruption time should be minimized. For instance, the interruption time should be less than 300ms for a real-time service, while 500ms for a normal one [16]. For the end-to-end delay-sensitive service, the long mobility tunnel which can result in high end-to-end delay should be avoided. ITU-T Recommendation G.114 [17] suggests that if one-way transmission time for connection delays can be kept below 150ms, most applications will experience a transparent interactivity. Moreover, the long-lived flows may perform many handovers while the short-lived ones seem to be initiated and terminated at the same MAR without performing any handover. Even if a short-lived flow performs a handover, it is expected that the flow does not last long after the handover.

2) Mobile node context: A mobile node with high mobility performs frequent handovers. In this case, almost all ongoing multicast flows are the handover ones which may cause the longer tunnel. If the multicast traffic is always routed through the aMAR, the longer dwell time is, the more serious the impact will be. Also, the number of anchors and tunnels may be increased. On the contrary, for the low mobility node, the MN is expected to stay at one or several MARs most of the time. Since the users spend most internet usage times at their typical locations (tMAR), in some cases, the tMAR can be a good candidate.

3) Network context: The MMA selection can also be based on several network contexts such as current load of the MARs, geographical proximity of the MAR to the MN as well as the multicast channel policy[2]. For example, when the load of cMAR or aMAR is high, it can cause long delays and packet losses by selecting them as the multicast anchor. In this case, the least loaded MAR (among the MARs having the multicast forwarding state for this channel) can be a potential candidate. The reason lies in the fact that if the channel is already available at the selected MAR, the service disruption time can be minimized (no need extra time to join the multicast channel). Also, with a negligible increase of load, this MAR can forward the traffic to the cMAR [23], [5].

B. Use-case Scenarios

1) Interruption-sensitive service: Since the service disruption time should be minimized, the aMAR and cMAR may not be good candidates. It comes from the fact that in the MMA_aMAR approach the tunnel delay between the aMAR and cMAR can result in a significant handover delay. In the MMA_cMAR approach, the cMAR may need time to join the multicast channel. As the multicast traffic is already available at the pMAR as well as the delay between pMAR and cMAR is supposed to not be large, the pMAR would be a good choice. Two examples for the interruption-sensitive service are live video streaming and real time gaming.

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[2] The network operator can define the channel policy in which some channels should be received directly from the native multicast infrastructure (to gain benefit from local content) while the others from their anchor MAR [18]

2) (End-to-end) Delay-sensitive service: The aMAR may not be a good candidate since the long tunnel between the aMAR and cMAR should be avoided to prevent a high end-to-end delay. Note that if the pMAR is selected, an additional delay can be added each time the MN performs a handover. Some examples of this type of service are real time gaming, live video streaming, and conversational VoIP/Video.

3) Long-lived flow and high mobility node: In this scenario, during the flow lifetime there are many handovers. In case of MMA_aMAR, the tunnel delay between the aMAR and cMAR is supposed to be long (also increasing tunneling overhead), thus the aMAR may not be suitable in terms of end-to-end delay as well as service disruption time. On the contrary, the cMAR and pMAR can be potential candidates. Yet, if the cMAR is selected, it can cause the service disruption problem. At this stage, the pMAR which can be considered as a compromise solution between the service disruption and the end-to-end delay may be suitable. Video streaming in vehicles is one typical example.

4) Long-lived flow and low mobility node: Since the flow is long-lived and the MN is of low mobility, the delay between the aMAR and cMAR is supposed to be small. Thus, the impact of the mobility tunnel can be ignored. The aMAR and pMAR would be better compared to cMAR regarding service disruption. Additionally, if the MN has a typical location, it may be most of the time in the typical location. Hence, tMAR can be a potential anchor. Software/firmware updates are one example for this case.

5) Short-lived flow: Since the flow is short-lived, the delay aMAR-cMAR is supposed to be small. Thus, the cMAR, pMAR and aMAR would be good candidates. News, weather and sport updates are some examples for this type of flow.

Table I and Table II summarize the possible MMA candidates regarding different scenarios in terms of service disruption and end-to-end delay, respectively. Note that the candidate marked with "(√)" is considered as a potential one.

TABLE I: MMA selection in terms of service disruption.

Scenario \ MMA Candidate	**aMAR**	**pMAR**	**cMAR**	**tMAR**
Interruption-sensitive service	-	√	-	-
Long-lived and high mobility	-	√	-	-
Long-lived and low mobility	√	√	(√)	(√)
Short-lived	√	√	√	-

TABLE II: MMA selection in terms of end-to-end delay.

Scenario \ MMA Candidate	**aMAR**	**pMAR**	**cMAR**	**tMAR**
Delay-sensitive service	-	(√)	√	-
Long-lived and high mobility	-	(√)	√	-
Long-lived and low mobility	√	√	√	(√)
Short-lived	√	√	√	-

IV. PERFORMANCE ANALYSIS

This section presents the performance analysis from the multicast service perspective regarding two metrics: multicast service disruption and end-to-end delay. The network issues (e.g., load balancing) will be left for future works. At this step, only three different approaches MMA_aMAR, MMA_pMAR and MMA_cMAR will be considered.

As described in Section II.B, the multicast context transfer (MCXT) is required to avoid a large delay (about 5s in the normal case, and 2.5s in the best case) caused by the multicast-related procedures (e.g., MLD response delay) [11]. This delay is much longer than the maximum tolerant interruption time, which as specified in [16] is 500ms. Thus, we suppose that the multicast context transfer is used, and the MLD proxy supporting multiple upstream interfaces is deployed at the MAR (see Fig. 2).

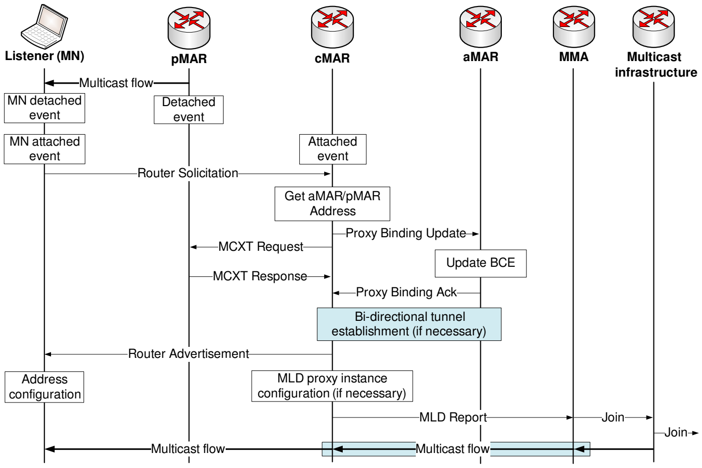

Fig. 2: Multicast-related handover signaling with context transfer.

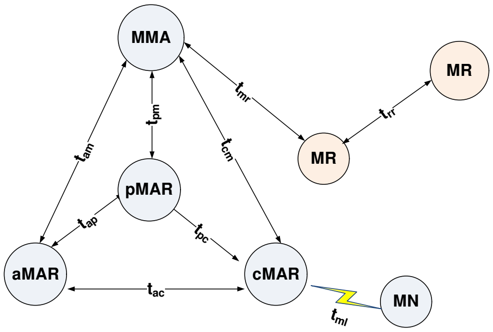

Fig. 3: Reference network topology.

A. Reference model

Fig. 3 shows a reference topology for performance analysis. The delay factors consisting of total delay are defined as follows:

- t_{ac}: the delay between aMAR and cMAR.
- t_{ap}: the delay between aMAR and pMAR.
- t_{pc}: the delay between pMAR and cMAR.
- t_{am}: the delay between aMAR and MMA.
- t_{pm}: the delay between pMAR and MMA.
- t_{cm}: the delay between cMAR and MMA.
- t_{mr}: the delay between MMA and its upstream MR.
- t_{rr}: the delay between two MRs.
- t_{ml}: the delay between MAR and listener (MN).
- t_{join}: the delay time an MR needs to join a multicast channel (including processing time and PIM Join transmission time).

Besides, h_{sc}, h_{sa}, and h_{sp} are the hop-count distances between the multicast source S and the upstream MR of the cMAR, aMAR and pMAR, respectively.

B. *Multicast Service Disruption Time Analysis*

The multicast service disruption time ($SD(.)$) is defined as a period when a multicast listener cannot receive the multicast packets. Therefore, it can be split into three main parts:

- Layer 2 handover latency (t_{L2}) due to the reattachment process from the previous wireless access point to the new one.
- Layer 3 handover duration (t_{L3}) caused by IP-related procedures. In DMM, it includes the time for mobility management procedures (movement detection, address acquisition, and location update procedures).
- The delay due to the multicast-related procedures, called $t_M(.)$. It is defined as the total time taken to complete all the multicast-related procedures including the multicast knowledge gain, multicast subscription and transmission time for the first packet from the multicast router to the listener after handover.

Let $t_{X,Y}$ denote the delay between node X and node Y. Assuming that the delay associated with the processing of the messages in the network entities (e.g., time for proxy binding update (PBU)/proxy binding acknowledgment (PBA) processing and updating binding cache entry (BCE) in MAR) as well as propagation time are included in the total value of each variable. Then the service disruption time is

$$SD(.) = t_{L2} + t_{L3} + t_M(.), \tag{1}$$

where t_{L3} and $t_M(.)$ are given by

$$t_{L3} = 2t_{ml} + t_{addr} + 2t_{ac}, \tag{2}$$

$$t_M(.) = 2t_{pc} + 2t_{cm} + d_{join} + d_{delivery} + t_{ml}. \tag{3}$$

t_{addr} is the time needed to get aMAR/pMAR address.

In Eq. (3), d_{join} and $d_{delivery}$ are the time needed for the MMA to join and get the first multicast packet (from a multicast router which already has a multicast forwarding state for this group, namely intersection MR or IMR), respectively. In case of MMA_pMAR, they can be ignored. We assume that n_{mr} is the average number of hops between the MMA's upstream MR and the IMR. We therefore obtain:

$$d_{join} = t_{mr} + n_{mr} t_{join}, \tag{4}$$

$$d_{delivery} = t_{mr} + n_{mr} t_{rr}. \tag{5}$$

It is noted that in the worst case (wc) the aMAR needs to join the multicast channel (for example, in case the multicast traffic was received from the multicast infrastructure in the pMAR), leading to an additional delay. On the contrary, the multicast traffic is already available at the aMAR (the best case, bc). This case corresponds to the multicast default mode. Also, the layer 3 signaling and multicast-related signaling can be executed in parallel as described in Fig.2, thus, we obtain the service disruption time in case of MMA_cMAR ($SD(cMAR)$), MMA_aMAR ($SD(aMAR(wc))$ and $SD(aMAR(bc))$), MMA_pMAR ($SD(pMAR)$) approach as follows:

$$\begin{aligned} SD(cMAR) = t_{L2} + 2t_{ml} + t_{addr} + 2t_{ac} + 2t_{mr} + n_{mr} t_{rr} \\ + n_{mr} t_{join}, \end{aligned} \tag{6}$$

$$\begin{aligned} SD(aMAR(wc)) = t_{L2} + 2t_{ml} + t_{addr} + 2max\{t_{ac}, t_{pc}\} + 2t_{ac} \\ + 2t_{mr} + n_{mr} t_{rr} + n_{mr} t_{join}, \end{aligned} \tag{7}$$

$$SD(aMAR(bc)) = t_{L2} + 2t_{ml} + t_{addr} + 2max\{t_{ac}, t_{pc}\} + 2t_{ac}, \tag{8}$$

$$SD(pMAR) = t_{L2} + 2t_{ml} + t_{addr} + 2max\{t_{ac}, t_{pc}\} + 2t_{pc}. \tag{9}$$

C. *End-to-End Delay*

It is worth to note that in case of MMA_pMAR, the pMAR can receive the multicast traffic from its upstream MR (case 1) or from the aMAR (case 2, corresponding to the default mode). Therefore, the end-to-end delay in case of MMA_cMAR ($E2E(cMAR)$), MMA_aMAR ($E2E(aMAR)$), MMA_pMAR ($E2E(pMAR(case1))$ and ($E2E(pMAR(case2))$)) approach are given as follows:

$$E2E(cMAR) = h_{sc} t_{rr} + t_{mr} + t_{ml}, \tag{10}$$

$$E2E(aMAR) = h_{sa} t_{rr} + t_{mr} + t_{ac} + t_{ml}, \tag{11}$$

$$E2E(pMAR(case1)) = h_{sp} t_{rr} + t_{mr} + t_{ml}, \tag{12}$$

$$E2E(pMAR(case2)) = h_{sa} t_{rr} + t_{ap} + t_{pc} + t_{ml}. \tag{13}$$

V. NUMERICAL RESULTS

In this paper, we consider the case where the MN always moves from MAR to MAR as if they were linearly deployed (the user is moving further away from the first attached MAR and never attaches back to a previously visited MAR). It represents the worst case scenario. Thus, $t_{ac} = t_{ap} + t_{pc}$.

TABLE III: Parameters for Performance Analysis.

Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
t_{L2}	50ms	t_{addr}	40ms	t_{ml}	15ms
t_{pc}	10ms	t_{ac}	50ms	t_{rr}	10ms
t_{mr}	10ms	t_{join}	13.5ms	h_{sa}	7 hops
h_{sp}	7 hops	h_{sc}	7 hops	n_{mr}	3 hops

This section presents the numerical results based on the analysis given in the previous one. The default parameter values for the analysis are introduced in Table III, in which some parameters are taken from [20][21]. It is worth noting that the MMA_aMAR (best case) and MMA_pMAR (case 2) approaches correspond to the default mode in case of service disruption and end-to-end delay analysis, respectively.

The multicast service disruption time when the value of t_{ac} is varied is depicted in Fig. 4. For a real-time service, the service disruption time should be less than the maximum tolerant interruption time, which as specified in [16] is 300ms.

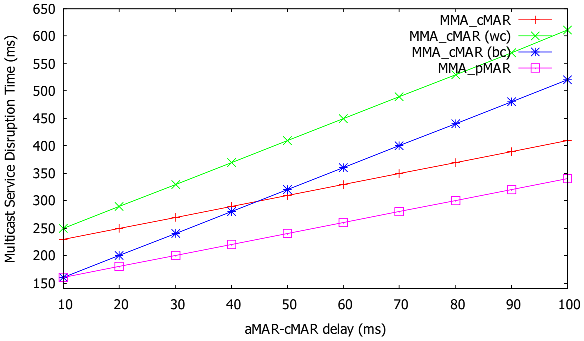

Fig. 4: Multicast service disruption time versus aMAR-cMAR delay.

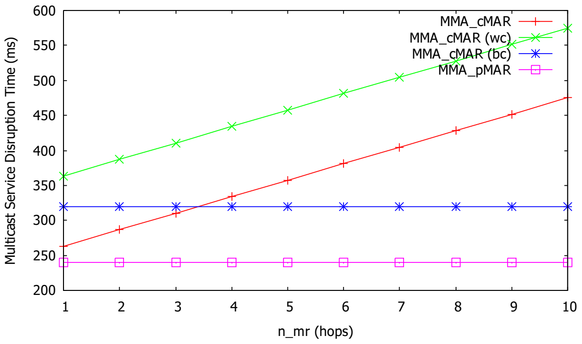

Fig. 5: Multicast service disruption time versus n_{mr}.

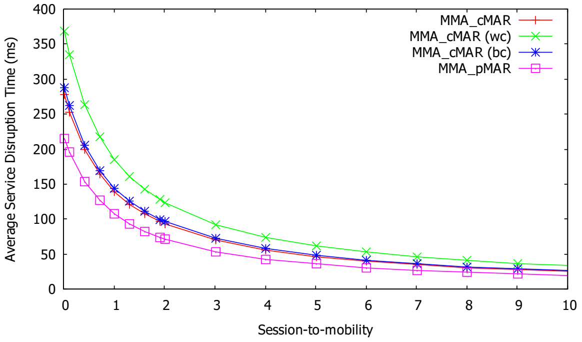

Fig. 6: Average multicast service disruption time as a function of ρ.

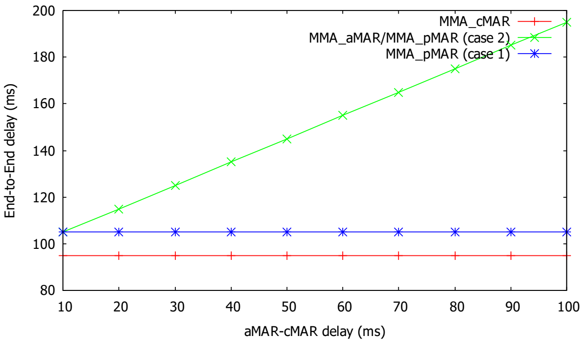

Fig. 7: End-to-end delay as a function of aMAR-cMAR delay.

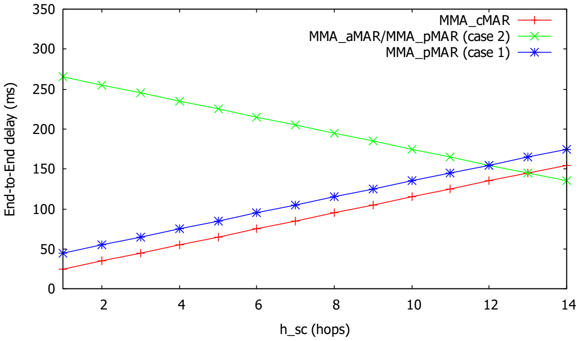

Fig. 8: End-to-end delay as a function of h_{sc}.

As observed in Fig. 4, when the value of t_{ac} is small enough (less than 22.37ms), all approaches meet this requirement. When the value of t_{ac} is quite large (about 45.0ms), only the MMA_pMAR approach satisfies the requirement. In the context described in this paper, a high value of t_{ac} (long tunnel delay) corresponds to the long-lived and high mobility scenario, while a low value of t_{ac} to short-lived or low mobility scenarios.

Fig. 5 shows the multicast service disruption time as a function of the average number of hops between the MMA's MR and the IMR (n_{mr}). From this point, the value of t_{ac} is considered to be 50ms. From this figure, as the n_{mr} is increased, the service disruption time is increased in case of MMA_cMAR and MMA_aMAR (worst-case) while is kept constant in case of MMA_aMAR (best-case) and MMA_pMAR. The reason is that, in the latter case, the multicast traffic is already available at the aMAR/pMAR.

Now we investigate the average multicast service disruption time as a function of the session-to-mobility ratio (ρ) which represents the relative ratio of the session arrival rate to the user mobility rate. According to [19], the handover probability is defined as $\rho_{HO} = \frac{1}{1+\rho}$. Thus, the average multicast service disruption time is calculated as $T = SD(.)\rho_{HO}$. Fig. 6 shows the average service disruption time when ρ is varied over a range from 0.01 to 10. It appears clearly that the MMA_pMAR approach gives a better performance than the others (lower is better). The difference between the approaches becomes more clearly when ρ decreases (especially in highly mobile regimes $\rho \ll 1$).

Regarding the multicast service disruption time, the MMA_pMAR approach always gives a better performance than the others. In addition, in this approach the service disruption time requirements in almost cases can be guaranteed. As a result, the pMAR is a good choice, especially for the interruption-sensitive service.

Considering the end-to-end delay, Fig. 7 illustrates that when t_{ac} is varied, the MMA_cMAR approach gives a better performance compared to the others (lower is better). The delay in case of MMA_pMAR can be fixed (case 1) or increased as the MMA_aMAR approach (case 2). We can observe that when t_{ac} is less than 50ms, all approaches give the end-to-end delay below the value of 150ms (satisfying the delay requirement specified by the ITU-T Recommendation G.114 [17]). Therefore, for a low mobility node or a short-lived flow, all approaches can be selected in terms of end-to-end delay. However, when the value of t_{ac} is large (e.g., 100ms), only the MMA_cMAR approach can guarantee the end-to-end delay (the MMA_pMAR can also meet the delay requirement, yet, only in case 1). As a result, for the long-lived and high mobility scenario as well as delay-sensitive service, the cMAR is a good anchor.

Then, t_{ac} is set as 100ms (corresponding to the long-lived and high mobility scenario) while the value of h_{sc} is varied. At this stage, we suppose that h_{sa} + h_{sc} is a fixed value, for example, 14 hops and h_{sp} = h_{sc}+1. This scenario is used to illustrate the case where the source is extremely close to the aMAR (right-side of Fig. 8) or extremely close to the cMAR (left side of Fig. 8). As can be observed in Fig. 8, even when the source is very close to the aMAR (h_{sa}=2, h_{sc}=12), the MMA_cMAR approach gives a better performance in terms of end-to-end delay than the others (lower is better). Thus, the tunnel impact to the end-to-end delay is obvious. Also, there is a small additional delay in case of MMA_pMAR (case 1). In conclusion, for the delay-sensitive flow, the cMAR is the best choice while pMAR can be considered as a potential candidate.

VI. DISCUSSION

A. *Tunnel Management Consideration*

In a DMM environment, it is unfeasible to pre-establish all the tunnels between MARs since the number of MARs is supposed to be large. When considering the MLD proxy supporting multiple upstream interfaces in DMM, it may cause the complex tunnel management (e.g., maintenance of the tunnel and keep alive signaling). For example, we consider a scenario as follows.

At the beginning, two listeners (L1 and L2) subscribe to the same multicast channel at MAR1 and MAR2, respectively. Then, L1 moves to MAR3. Assuming that it continues receiving this channel from MAR1 (via the mobility tunnel MAR1-MAR3). Next, L2 also moves to MAR3. Since the multicast channel is already present, MAR3 sends it directly to L2. Afterwards, L1 moves to another MAR. Normally the tunnel MAR1-MAR3 should be deleted after a time out. However, in this case, it should be kept to route the multicast traffic for L2. As a result, the tunnel management has to take multicast state into account.

B. *How MMA Selection Works?*

This subsection provides one example of how MMA selection works. In order to collect and manage the considered contexts, a network entity, called Multicast Control Entity (MCE) is introduced. This entity can be collocated with the central mobility database [24], [10]. The MAR periodically updates the MN's mobility context, the multicast service context as well as its current load to the MCE by using an extension of PBU/PBA messages or an extension of the Heartbeat messages [22]. The MCE also manages all the multicast channels in the domain for the network policy configuration.

VII. CONCLUSION

This paper discusses the issues when considering the multicast listener mobility following the default mode in a DMM environment. We argue that, under certain scenarios, it is almost impossible to achieve the requirements in terms of service interruption and delay for specific services (e.g., real-time service). We then introduce the dynamic multicast mobility anchor selection mechanism in order to mitigate these issues. This mechanism takes into account various contexts ranging from the multicast service, the mobile node's mobility to the network context, thereby, enabling per-flow multicast support. Numerical results show that for each scenario these requirements can be satisfied.

In the next step, more possible MMA candidates corresponding to more contexts will be considered. More performance metrics such as signaling cost, tunneling cost as well as packet loss will also be taken into account. In order to achieve the realistic results, experiments will be conducted based on an existing multicast mobility testbed [11].

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