Optimizing Multicast Content Delivery over Novel Mobile Networks

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Abstract—**The rapid growth in mobile traffic leads to the current evolution trend of mobile networks towards a flat architecture. However, the centralized mobility management protocols (e.g. MIPv6, PMIPv6) are not optimized for the flat architecture due to their limitations e.g. complex tunnel management, scalability issue, etc. Hence, a novel mobility management has been proposed for the flat architecture, called distributed mobility management (DMM). IP multicast, an effective mechanism for traffic delivery, can be enabled in DMM by deploying MLD Proxy function at mobile access routers (MARs) with the upstream interface being configured to the multicast infrastructure (before mobility) or to the tunnel towards the mobile node's mobility anchor (after mobility) (namely tunnel-based approach). In case of mobility, the utilization of the tunnel may result in the tunnel convergence problem when the multiple instances of the same multicast traffic converges to a MAR due to the multiple tunnels established with several mobility anchors (leading to the redundant traffic at the MARs). Compared to PMIPv6, the tunnel convergence problem may become much more severe, especially in highly mobile regime. In this paper, we propose some mechanisms to greatly reduce the amount of redundant traffic at the MARs with a minor increase of service disruption time compared to the tunnel-based approach.**

Keywords-Future Internet; IP multicast; multicast mobility; tunnel convergence problem; handover delay; Distributed Mobility Management.

I. INTRODUCTION

The explosion of wireless devices like smartphones, tablets makes a dramatic increase in mobile traffic [1]. How to manage a large number of mobile terminals as well as a huge mobile traffic increase becomes a major challenge to network operators. Also, the evolution of wireless application and services lead to new requirements such as seamless mobility across the heterogeneous access technologies (session continuity, application transparency), consistent quality of experience and stringent delay constrains.

With the evolution of wireless technology, heterogeneous networks provide the possibility for great capacity increase at a low cost. However, only increasing capacity is unable to address the network challenge as well as to meet the new service requirements. In this context, several strategies have been proposed for efficiently delivering the traffic such as traffic offloading e.g. Local IP Access (LIPA), Selected IP Traffic Offload (SIPTO) [2] and Content Delivery Networks (CDNs) mechanisms [3]. They reflect the current evolution trend of mobile networks - shift to a flat IP architecture to lower costs, reduce system latency, and decouple radio access and core network evolution [4].

Still, the current IP mobility management protocols like Mobile IPv6 (MIPv6) [5], Proxy Mobile IPv6 (PMIPv6) [6] do not work perfectly with such a flat architecture due to their limitations e.g. complex tunnel management, poor performance (like non-optimal route, tunneling overhead) and scalability issue [4][7]). Thus, a novel approach, called distributed mobility management (DMM) [8][9], has been proposed to cope with the flat architecture and overcome the limitations of centralized mobility management. The idea is that the mobility anchors are placed closer to the user; the control and data plane are distributed among the network entities. In addition, mobility service is provided dynamically to the terminal/service that really needs to simplify the network and lower the cost. As a result, the DMM concept enables networks to be scaled up cost-effectively as data increases. DMM is currently a quite hot topic in the IETF and 3GPP.

In the future, multimedia will be indeed a main service as well as a major challenge of the networks [1]. Thus, how to efficiently distribute this type of traffic becomes one of the key questions. In this context, IP multicast which provides an effective mechanism for video delivery plays a very important role.

Regarding the multicast over DMM environments, multicast mobility support can be enabled by deploying Multicast Listener Discovery (MLD) Proxy function [10] at mobile access routers (MARs). When an MN starts a multicast session at the current MAR, it receives the multicast traffic from the multicast infrastructure via the current MAR. In case of mobility, the traffic will be forwarded via the tunnel from the previous to the current MAR. This resembles the tunnel-based approach in PMIPv6 [11]. This scheme can be applied for both multicast source and listener in DMM. However, in this paper, we mainly focus on the multicast listener support.

Although this simple scheme can bring multicast listener support into DMM environments, there are some issues e.g. tunnel convergence problem and sub-optimal routing, among others [12]. 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) will be much more than that in a PMIPv6 domain (LMAs - in the core network). Thus, the tunnel convergence problem may get more serious than that in PMIPv6 especially in highly mobile regime. This problem can be eliminated by using the native multicast infrastructure for delivering multicast traffic (direct routing approach). However due to the delay related to multicast join process; it may cause significant service disruption (large handover delay and number of packet loss) during handover.

In this paper, we propose two mechanisms which are able to reduce the impact of tunnel convergence problem (redundant traffic at MARs) with an acceptable service disruption time. The first proposal is a trade-off between direct routing and tunnel-based approach. The DMM domain is divided into "virtual multicast domains" (m-domains) in which the MARs are configured to the same upstream multicast router (MR). When an MN moves between MARs in the same m-domain, the direct routing takes place; while the tunnel-based approach is applied for handovers between MARs in different m-domains. As a result, it can significantly reduce the utilization of mobility tunnel for delivering multicast traffic, and reduce redundant traffic at MARs accordingly, with a minor increase of service disruption time compared to the tunnel-based approach. The second proposal uses a single multicast mobility anchor (MMA) for all attached listeners in a DMM domain, similar to [13]. This solution eliminates the redundant traffic but may cause a noticeable service disruption during handover when considering a large domain.

The rest of this paper is organized as follows. Section II describes related work on the mobility management and multicast mobility. In section III, the solutions including different approaches are introduced. Section IV provides performance analysis in terms of redundant traffic and service disruption time. Section V shows numerical results taking into account the impact of different factors. Eventually, section VI concludes the paper and provides perspectives for the future work.

II. RELATED WORK

A. Distributed Mobility Management (DMM)

Due to the lack of DMM standard, in this paper, a generic approach considers that a DMM domain consists of the MARs which implement the functionality of a plain access router, a mobile access gateway (MAG), and a local mobility anchor (LMA) [9][14]. In a DMM domain, an 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 MAR in which the using MN's prefix is allocated. Hence, the packets can be redirected via the tunnel from the previous to the current MAR. Distributed mobility management can be applied fully where both data and control plans are distributed; or partially where the central mobility anchor is still present, but for control plane only.

B. Multicast Mobility

Multicast support for mobile listener can be enabled within a PMIPv6 domain by deploying MLD Proxy function at MAGs while LMA provides multicast router or MLD Proxy function. In this scenario, the upstream interface of an MLD Proxy instance at MAG is configured to the tunnel towards the corresponding mobile node's LMA (called tunnel-based solution) [11]. The presence of the tunnel raises the issues of tunneling overhead, non-optimal route and tunnel convergence problem. Another possibility for multicast support is the direct routing approach [13] that takes advantage of the native multicast infrastructure for delivering multicast traffic, thus avoiding tunnel convergence problem. Yet, this approach may require the multicast tree reconstruction during handover, which may result in a significant service disruption.

Regarding multicast in DMM environments, there is no detailed solution for multicast support, since the DMM is still in its infancy. In [15], 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: MLD Proxy or multicast router.

In the first scenario, the direct routing approach is used for new multicast sessions while the tunnel-based is used for the sessions after mobility (handoff sessions). When an MN initiates a multicast session at the current MAR, the multicast traffic will be delivered from the multicast infrastructure to the MAR. Thus, the upstream interface of an MLD Proxy instance at MAR is configured towards the multicast infrastructure. Once the MN moves to a new MAR (nMAR), an MLD Proxy instance at the nMAR adds the downstream interface to the MN and configures its upstream interface to the bi-directional tunnel towards the previous MAR (pMAR). Then, the multicast traffic is routed from the pMAR to the nMAR. It is noted that the tunnel can be dynamically created or pre-established for sharing between MNs as similar as in PMIPv6 [6].

Nevertheless, this scheme does not address any specific optimizations and performances issues such as tunnel convergence, sub-optimal routing, and service disruption. In particular, the tunnel convergence problem becomes a severe issue since the number of mobility anchors in a DMM domain is supposed to be increased. Also, tunneling encapsulations impact the overall network performance and incur delays in multicast packet delivery [14].

In the second scenario, the multicast router function is deployed at all MARs that allows them to select the upstream multicast router based on multicast routing information and/or network management criteria. Thus, the tunnel convergence problem and sub-optimal routing are avoided. However, due to its implementation or operational costs, operators may not want to support multicast routing on MAR. For that reason, in this paper we focus on the case where MAR acts as an MLD Proxy.

III. DESCRIPTION OF THE SOLUTIONS

As described in the previous section, in DMM environments, the tunnel convergence problem becomes more severe compared to that in PMIPv6 especially in highly mobile environment. In this paper, we propose two solutions to address this problem taking into account the service disruption time. Both solutions are considered in two schemes: fully and partially distributed.

- Optimizing multicast content delivery solution (in short OMCD): Similar to PMIPv6, there are two possible approaches for multicast mobility support in DMM environments: direct routing and tunnel-based. The direct routing can helps avoid the limitations of the tunnel-based approach (e.g. tunnel convergence problem, tunnel overhead and sub-optimal routing) but can cause significant service disruption time. Thus, we propose a hybrid solution: direct routing for handoffs inside an m-domain, tunnel-based for handoffs between m-domains. This solution can bring some benefits like reducing tunnel convergence problem and tunnel overhead (compared to tunnel-based approach); and decreasing service disruption time (compared to direct routing approach).
- Multicast Mobility Anchor in DMM (MMA-DMM): A network entity called multicast mobility anchor (MMA) is introduced to provide multicast service access to all attached listeners in a DMM domain, similar to [13]. This simple method helps to avoid the tunnel convergence problem but may result in a significant service disruption during handover.

A. *Optimizing multicast content delivery (OMCD)*

The DMM domain is divided into m-domains in which the MARs have the same upper MR. When an MN moves between MARs in the same m-domain, the direct routing approach is applied. Otherwise, the tunnel-based takes place (for handoff between m-domains). It should be noted that the using of the mobility tunnel for delivering multicast traffic is temporary and it is kept till the new MAR starts receiving packets from the multicast infrastructure.

The decision to apply which approaches will be based on the comparison between the addresses of the upstream multicast router (UMRA) of the MARs (pMAR, nMAR). In partially distributed scheme, the decision will be made by a Multicast Mobility Control (MMC) which acts as a mobility signaling relay [9]. The address of multicast upstream router of all MARs needs to be stored at MMC. It can be done by a static configuration or during Proxy Binding Update (PBU) / Proxy Binding Acknowledgement (PBA) messages exchanging between MARs and MMC (PBU/PBA need to be extended to convey the address of the MAR's upstream MR). In fully distributed scheme, the nMAR which deploys an enhanced function called Mobility Decision Function (MDF) can make the decision.

The solution is described in Fig 1. In this figure, MAR1 and MAR2 belong to the m-domain 1 (with the common upstream multicast router MR1); while MAR3 and MAR4 belong to the m-domain 2 (MR2's m-domain). A listener (MN1) subscribes to a multicast channel (S, G) at MAR1 and latter moves from MAR1 to other MARs. The operations of the solution are briefly described as follows:

- Step1: When the MN1 starts a multicast session at MAR1, the multicast traffic is routed directly from the native multicast infrastructure to MAR1

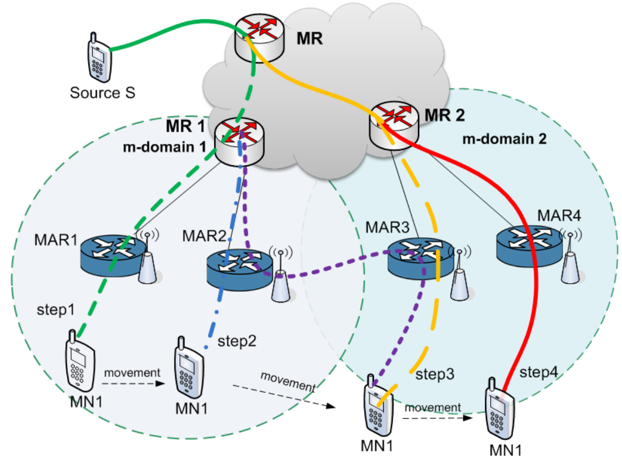

Figure 1. Demonstration of OMCD solution.

(following the route S-MR1-MAR1-MN1).

- Step2: The MN1 moves to MAR2 (handoff inside an m-domain). Thus, direct routing scheme is applied. The MAR2 configures its upstream interface to the common MR in its m-domain (MR1) and receives the multicast traffic from this MR (S-MR1-MAR2-MN1).
- Step 3: Then, the MN1 moves to MAR3 which belongs to the m-domain 2. First, MAR3 configures its upstream interface to MAR2 and receives multicast traffic for (S, G) from MAR2 (S-MR1-MAR2-MAR3-MN1). Then, MAR3 sends an aggregated MLD Report to its default MR (MR2) to get the traffic from the multicast infrastructure (S-MR2-MAR3-MN1). Once MAR3 receives multicast packet from MR2, it sends a MLD report to MAR2 to discontinue receiving multicast traffic from the tunnel between them (MAR2-MAR3). These operations of MAR3 can be done by using a MLD Proxy with multiple upstream interfaces [16].
- Step 4: Again, when the MN moves inside an m-domain from MAR3 to MAR4, the direct routing scheme takes place to deliver the multicast traffic from the native multicast infrastructure to MAR4 (S-MR2-MAR4-MN1).

1) *Partially distributed scheme*

Once an MN attaches to a MAR, it acquires an IP address issued from the prefix (Pref1) which is allocated by the current MAR. It then can use this address to initiate new multicast sessions. The current MAR will receive multicast traffic from the multicast infrastructure then forwards them to the MN as described in the previous section.

When the MN moves to a new MAR (nMAR), the nMAR allocates a new prefix (Pref2) for the MN and sends a PBU to the MMC (see Fig. 2, Fig. 3). After checking its database, the MMC forwards it to the previous MAR (pMAR) which then replies by a PBA. After checking the UMRAs of pMAR and nMAR, the MMC send a PBA to the nMAR which consists of pMAR's address and an addition (M) flag. The flag M is set to 1 if two UMRAs are the same,

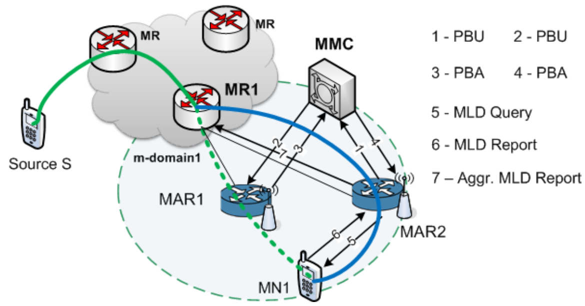

Figure 2. Handover inside an m-domain (partially distributed scheme).

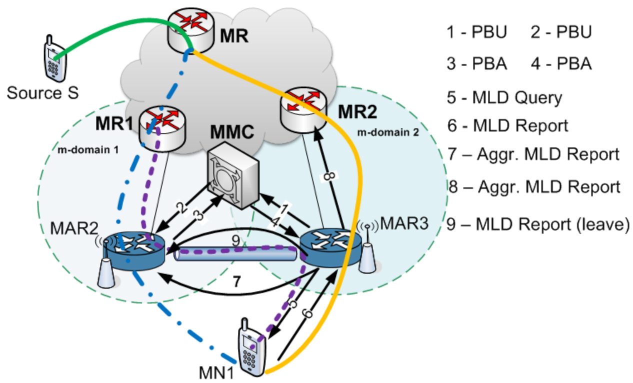

Figure 3. Handover between m-domains (partially distributed scheme).

otherwise 0. Then a tunnel is established between two MARs to route the unicast traffic from/to MN1 using Pref1.

For multicast service, after obtaining the MN multicast subscription information by using a regular MLD Query/Report procedure, and checking the M flag, the nMAR will decide to configure its upstream interface towards the pMAR or the multicast infrastructure. If the flag M is equal to 1, the nMAR then sends an aggregated MLD Report to the upper MR, otherwise to the pMAR (M=0), in order to subscribe to the necessary multicast groups on behalf of the MN. In case two MARs belong to different m-domains (M=0), the nMAR also sends an aggregated MLD Report to the MR in the multicast infrastructure to get multicast traffic from this MR (direct routing approach). Thus, the using of the tunnel between the nMAR and the previous one is temporary and it will be kept till the nMAR starts receiving packet from the native multicast infrastructure. Upon receiving multicast packets, the nMAR will check the sequence number of the packet from the tunnel. If there is any missing packet, it will wait till the packet is forwarded from the pMAR. It then requests to leave the multicast groups from the pMAR.

2) Fully distributed scheme

In fully distributed scheme, it is supposed that the nMAR knows the address of the previous one. There are several methods to get this address such as using a layer 2 handover infrastructure (e.g. IEEE 802.21), or using a distributed LMA-discovery mechanism. The exact process to get this address is out of scope of this paper.

Similar to partially distributed scheme, when an MN initiates a new multicast session, the multicast traffic is transmitted from the native multicast infrastructure to the MN (direct routing approach). When the MN moves to a new MAR (nMAR), the nMAR sends a PBU message to the previous one (pMAR). The pMAR then replies by a PBA that contains its UMRA. Upon receiving the PBA and checking its UMRA, the nMAR will make a decision to configure its upstream interface to the tunnel towards the pMAR; or towards the multicast infrastructure (MR2) as described in the previous section (see Fig. 4, Fig .5).

B. Multicast Mobility Anchor in DMM (MMA-DMM)

Serving as a mobility anchor for multicast traffic for all MARs in a DMM domain, the MMA can act as an additional MLD Proxy or a multicast router [13]. In this scenario, an MLD Proxy instance is deployed at each MAR with the upstream interface being configured to the MMA. The operations for both partially and fully distributed scheme are the same, and as follows.

When an MN starts a new multicast session, the current MAR sends an aggregated MLD Report to the MMA which then subscribes to the multicast group (if necessary) and forwards multicast traffic to the MAR. When the MN moves to nMAR, the similar processes are executed allowing the nMAR to receive multicast traffic from the MMA.

Since the MARs only receives the multicast traffic from the MMA, the tunnel convergence problem is avoided. However, the requirement of DMM for the distributed deployment (traffic does not need to traverse central deployed mobility anchors) cannot be respected [17]. Again, it raises the problem of single point of failure and sub-optimal routing. These problems can be slightly reduced by deploying several MMAs in which each MMA serves one or several multicast channels.

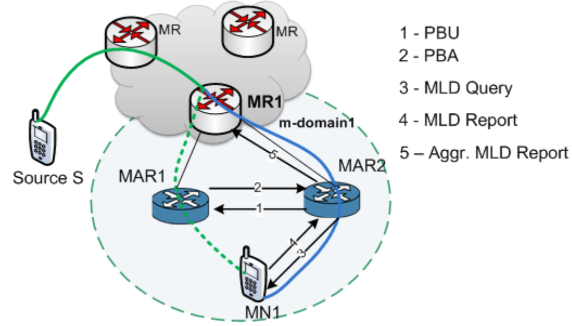

Figure 4. Handover inside an m-domain (fully distributed scheme).

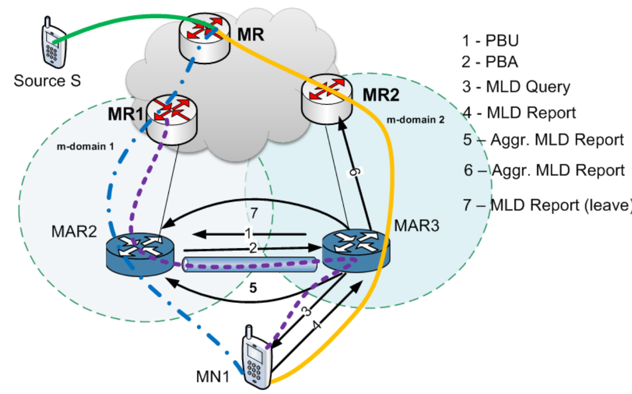

Figure 5. Handover between m-domains (fully distributed scheme).

IV. PERFORMANCE ANALYSIS

A. Comparison of Tunnel convergence problem

To measure the solutions proposed, it is assumed that an MN starts at least one new multicast session when it moves to a new MAR.

If the direct routing approach is used for both new and handoff sessions, the multicast traffic is always routed from the multicast infrastructure to the MAR. As a result, the tunnel convergence problem is eliminated. Similarly, the MMA-DMM solution also helps to avoid the tunnel convergence problem. In this section, we compare the number of tunnels established for multicast traffic between one MAR to the others or to the multicast infrastructure for the same multicast group (namely N_t) in case of tunnel-based approach (TB) and OMCD solution via the ratio between them (ϴ). ϴ is calculated as $\Theta = N_{t\,(OMCD)} / N_{t\,(TB)}$. Thus ϴ can be used to illustrate how efficient OMCD is, compared to tunnel-based solution in terms of reducing number of redundant traffic (tunnel convergence problem).

If the tunnel-based approach is used for handoff sessions, each time the MN moves to a new MAR, a new mobility tunnel will be established between this MAR and the previous one to redirect the multicast traffic to the current location of the MN. Consequently, the number of tunnels established (multicast tunnel) is proportional to the number of handoffs between MARs (proportion is α). Also, the number of multicast tunnels established in OMCD solution is proportional to the number of "virtual handoffs" between m-domains. Let E_{TB}, E_{OMCD} denote the expected number of handoffs between MARs and between m-domains, respectively. Each m-domain coverage area is supposed to be circular with n subnets (n MARs). Let m denote the number of MARs in the DMM domain. Then we have:

$$N_{t\,(TB)} = \alpha\, E_{TB} / m, \quad (1)$$

$$N_{t\,(OMCD)} = \alpha\, E_{OMCD} / m. \quad (2)$$

According to the [18], $E_{OMCD} = E_{TB} / \sqrt{n}$. Then we obtain:

$$\Theta = 1 / \sqrt{n}. \quad (3)$$

B. Comparison of Service disruption time

A service disruption time analysis has been done in [19] taking into account the different schemes (fully and partially distributed; reactive and proactive handover). However, only tunnel-based approach is considered. In this section, three approaches - tunnel-based (TB), MMA-DMM and OMCD are considered for both partially distributed (PD) and fully distributed scheme (FD).

Fig. 6 shows a reference topology for performance analysis. The delay between the entities is defined as follows:

- t_{wl}: the delay between the MN and access router (AR) (wireless connection).
- t_{am}: the delay between the AR and MAR.
- t_{mm}: the delay between two MARs.
- t_{mc}: the delay between the MAR and MMC.
- t_{ma}: the delay between the MAR and MMA.

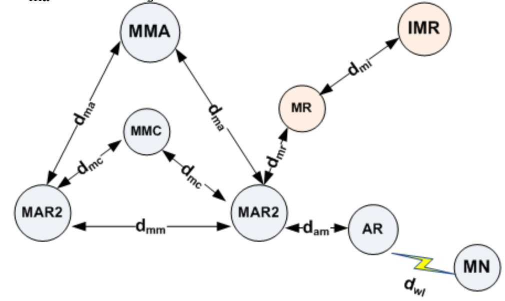

Figure 6. Reference topology for performance analysis.

- t_{mr}: the delay between the MAR and its upstream multicast router.

Similar to [19] the service disruption time is studied based on a well-known factor, called session-to-mobility ratio (SMR) that represents the relative ratio of session arrival rate to the user mobility rate. It is assumed that the subnet residence time (MAR subnet) and multicast session duration follow an exponential distribution with parameter η and μ, respectively. Hence, SMR is defined as $\rho = \eta / \mu$ [18]. Since each m-domain coverage area is supposed to be circular with n subnets (n MARs), the handoff probability between MARs in the same m-domain and between MARs in different m-domains are defined as $\rho_{MAR} = 1 / (1+\rho)$ and $\rho_{MR} = 1 / (1+\rho\sqrt{n})$, respectively as in the literature [18].

The average service disruption time for handoff between MARs is calculated as $T = D * \rho_{MAR}$ where D is the service disruption time. Let t_{L2} denote the Layer 2 handover delay. Assuming that the delay associated with the processing of the messages in the network entities (e.g. time for PBU processing and updating binding cache in pMAR) is included in the total value of each variable. Then the service disruption time is given detailed as:

$$D_{TB\text{-}PD} = t_{L2} + 3t_{am} + 3t_{wl} + 4t_{mc} + 2t_{mm}, \quad (4)$$

$$D_{TB\text{-}FD} = t_{L2} + 3t_{am} + 3t_{wl} + 4t_{mm}, \quad (5)$$

$$D_{MMA\text{-}PD} = t_{L2} + 3t_{am} + 3t_{wl} + 4t_{mc} + 2t_{ma}, \quad (6)$$

$$D_{MMA\text{-}FD} = t_{L2} + 3t_{am} + 3t_{wl} + 2t_{mm} + 2t_{ma}. \quad (7)$$

In the direct routing approach (DR), the nMAR's upstream MR needs to join and get multicast traffic from a multicast router in the multicast infrastructure that already had multicast forwarding states for this group (called common multicast router or CMR). Thus, an additional delay is taken into account: $2t_{mi}$. The service disruption time in the direct routing approach is calculated as follows:

$$D_{DR\text{-}PD} = t_{L2} + 3t_{am} + 3t_{wl} + 4t_{mc} + 2t_{mr} + 2t_{mi}, \quad (8)$$

$$D_{DR\text{-}FD} = t_{L2} + 3t_{am} + 3t_{wl} + 2t_{mm} + 2t_{mr} + 2t_{mi}. \quad (9)$$

When the MN performs handoffs inside an m-domain, the MR of this m-domain has already subscribed to the multicast group (the MR and CMR located at the same entity), thus $t_{mi} = 0$. We obtain the value of delay for direct routing approach when the MN moves inside an m-domain in case of partially and fully distributed scheme, called D^*_{DR-PD}, D^*_{DR-FD} respectively.

Since in OMCD solution, the direct routing approach is applied when an MN performs handoffs inside an m-domain while tunnel-based takes place for inter m-domain handover. Thus, the average service disruption time is calculated as:

$$T_{OMCD-PD} = (\rho_{MAR} - \rho_{MR}) D^*_{DR-PD} + \rho_{MR} D_{TB-PD}, \quad (10)$$

$$T_{OMCD-FD} = (\rho_{MAR} - \rho_{MR}) D^*_{DR-FD} + \rho_{MR} D_{TB-FD}. \quad (11)$$

C. Comparison of End-to-End delay

In the direct routing approach, the end-to-end delay is calculated as $D_{e\,(DR)} = t_{S,\,MAR} + t_{MAR,\,MN}$. The delay between MN and MARs are supposed to be the same ($t_{MN,\,pMAR} = t_{MN,\,nMAR}$). If the tunnel-based approach is used, after handover, there is an additional delay compared to the direct routing approach: $t_{S,pMAR} - t_{S,nMAR} + t_{pMAR,\,nMAR}$. With a large delay between two MARs (tunnel delay), the end-to-end delay is significantly increased. In average, the end-to-end delay of the tunnel-based approach is increased $t_{MAR-MAR}$ that is the average delay between two MARs compared to that of the direct routing.

In the MMA-DMM solution, the end-to-end delay depends on the position of MMA. In a significant large domain, it may be much higher than that of the direct routing approach. For the OMCD solution, the using the tunnel pMAR-nMAR is temporary, thus, in average, the end-to-end delay is almost the same as in the direct routing approach.

V. NUMERICAL RESULTS

This section presents the numerical results based on the analysis given in the previous section. The default parameter values for the analysis are introduced in TABLE I, in which some parameters are taken from [19].

TABLE I. PARAMETERS FOR PERFORMANCE ANALYSIS

Parameters	***Values***	***Parameters***	***Values***	***Parameters***	***Values***
t_{L2}	100ms	t_{wl}	5ms	t_{am}	2ms
t_{mm}	2ms	t_{mc}	3ms	t_{mr}	5ms
t_{ma}	20ms	t_{mi}	0ms	n	32

Fig. 7 shows how efficient OMCD is in comparison with the tunnel-based solution in terms of reducing number of redundant traffic at MARs (tunnel convergence problem). As n increases, the amount of redundant traffic decreases. When all MARs in a DMM domain belong to only one m-domain (n = m), there is no redundant traffic at MARs (OMCD becomes MMA-DMM solution).

The average service disruption time as a function of SMR (ρ) is illustrated in Fig. 8, when the number of MARs

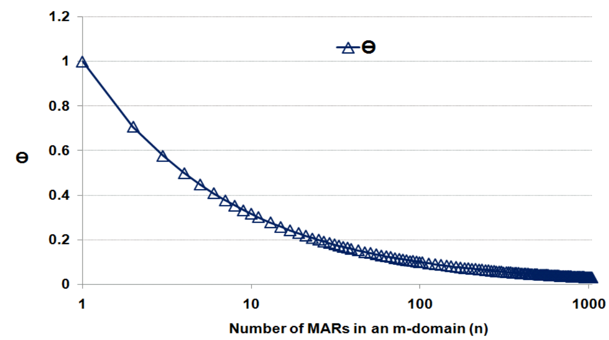

Figure 7. Ratio between number of redundant traffic in the OMCD solution and in the tunnel-based approach (Θ).

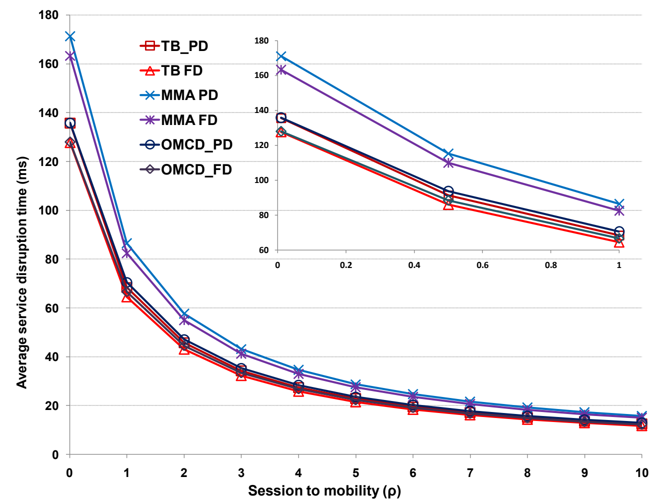

Figure 8. Average service disruption time as a function of SMR (ρ).

in an m-domain is fixed to 32. The service disruption time of MMA-DMM solution is definitely higher than that of the others. Although the service disruption time of OMCD solution is a bit higher than that of tunnel-based approach, the difference between them is negligible.

Now, the service disruption is considered when the number of MARs in an m-domain (n) is varied. Since the delay between two nodes depends on the bandwidth, the propagation delay and the distance between them, for simplicity, we suppose that the delay is proportional to the distance (proportion is τ). It is assumed that the architecture of an m-domain is hierarchically formed as a binary tree with a d_{mr}-layer [20]. Therefore, t_{mr} is calculated as $t_{mr} = \tau \log_2(n)$. It is noted that when n is equal to number of MARs in the network (n = m), OMCD becomes MMA-DMM solution. Fig .9 describes the average service disruption time as a function of number of MARs in an m-domain when $\rho = 0.1$ and $\tau = 2$. The average service disruption time in the OMCD solution is slightly increased when the number of MARs is increased as a result of the trade-off with the decreased of the redundant multicast traffic.

Regarding the tunnel delay impact, the value for t_{mm} is varied over a range from 0.1 to 30ms. In Fig .10, we can see how the different solutions are dependent on the mobility

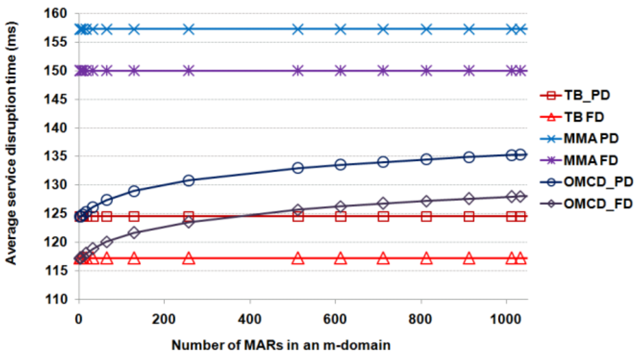

Figure 9. Average service disruption time as a function of n.

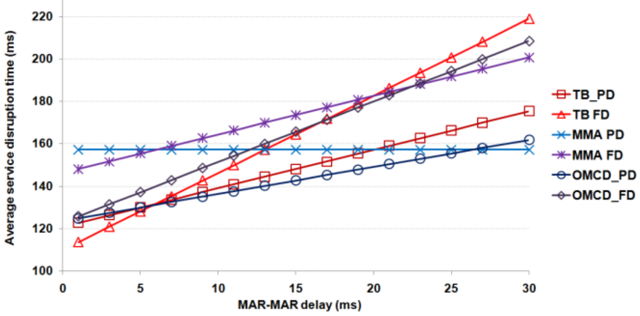

Figure 10. Tunnel delay effect.

tunnel. As t_{mm} increases, the average service disruption time for all approaches (except MMA_PD) increases. It is worth noting that if the tunnel delay is larger than a specific value, the OMCD becomes better than the tunnel-based solution. The MMA-DMM becomes the best solution in terms of service disruption time if the tunnel delay continues increasing.

VI. Conclusion And Future Work

In this paper, we proposed two solutions to address the tunnel convergence problem as a result of multicast listener mobility over DMM environments. The first solution helps to greatly reduce the number of redundant traffic caused by the tunnel convergence problem with a minor increase of service disruption time compared to the tunnel-based approach. The second one uses a network entity (or several) serving multicast service for all attached listeners in a DMM domain. It is an easy way to solve the tunnel convergence problem but may cause a significant service disruption.

In the future, the multicast source mobility will be considered in DMM environments. Also, the simulations will be made based on the Network Simulator NS-3 and a DMM implementation (extended version of OAI PMIP [21]) to better evaluate the performance of different approaches.

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