Load Balancing Mechanism for Proxy Mobile IPv6 Networks: An IP Multicast Perspective

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***Abstract*—In Proxy Mobile IPv6 (PMIPv6), the local mobility anchor (LMA) is responsible for maintaining the mobile node's (MN) reachability state and forwarding traffic from/to the current location of the MN. With the explosion of the mobile terminals as well as the traffic, it is easy to make the LMA a bottleneck and single point of failure. Load balancing (LB) mechanism among LMAs is a promising solution for these issues. However, the existing LB proposals have neglected the multicast service which may degrade their efficiency when considering IP multicast. Furthermore, applying LB mechanism can raise several issues not only for ongoing unicast sessions but also multicast ones. To tackle these issues, a new LB solution which mainly focuses on the multicast service is proposed. The experiments and the numerical results show that this solution helps to better distribute the load among the LMAs while greatly reducing the multicast service disruption as well as avoiding the influence on the ongoing unicast sessions caused by LB. In addition, the proposed solution can co-operate with the existing LB proposals to improve the performance of the network.**

***Keywords*—Load Balancing, Multicast-based Load Balancing, Proxy Mobile IPv6, IP Multicast, Multicast Listener Mobility.**

I. INTRODUCTION

Recently, Proxy Mobile IPv6 (PMIPv6) [1] has been standardized by the Internet Engineering Task Force (IETF), and widely adopted in 3GPP and WiMAX architecture. Taking advantages of a network-based mobility management, PMIPv6 enables IP mobility for moving nodes (MNs) without their involvement. However, as a centralized/hierarchical mobility management, PMIPv6 relies on a centralized entity to provide the mobility service for the MNs. Thus, both the context and the traffic encapsulation of the MNs need to be maintained at the mobility anchor (LMA). A large amount of mobile terminals and a huge mobile traffic increasing in the near future [2] could make LMA a bottleneck and single point of failure, which will degrade the quality of service of the ongoing sessions. Load balancing (LB) which helps to distribute work-load across multiple LMAs is expected to become an efficient solution to improve the reliability, scalability and availability of the PMIPv6 networks.

Several LB proposals [3]–[5] have been introduced to allow the LMA to be dynamically assigned and changed according to the load of all LMAs in the domain. When an MN initially attaches to the domain, the LB will be executed to select the appropriate LMA in terms of load to serve this MN (namely proactive-MN approach). However, the varying session rate (of the existing MNs) and data rate (of the existing sessions) may cause load-unbalanced situation between the LMAs. In order to address this issue, the LB can be triggered when LMA load exceeds a specified threshold (called reactive-MN approach). In this case, an MN will be selected to move from the overloaded LMA to a less loaded one. Yet, changing LMA causes some issues for the ongoing sessions such as service disruption and packet loss.

In the near future, the mobile Internet traffic will be dominated by the mobile video: it is expected that mobile video traffic will account for 66.5 percent of total data traffic by 2017 [2]. In this context, the scalability and bandwidth efficiency from multicast routing makes the IP multicast a valuable solution from application point of view to deal with a huge number of traffic. Besides, the mobile video content typically has much higher bit rates than the other content types. As a result, the multicast sessions, in general, put much more load on the LMA than the unicast ones. However, the existing LB proposals have neglected the multicast service. Thus, their efficiency can be degraded when considering IP multicast. In addition, these proposals may bring about some multicast-related issues such as tunnel convergence problem and service disruption (packet loss).

To tackle these issues, this paper introduces a new LB mechanism. Unlike the existing LBs which can be considered as an MN-based solution, the proposed solution is a multicast-based one. That means when an LMA is overloaded, a multicast session will be selected to move to a less loaded LMA. It can be done thanks to the deployment of the Multicast Listener Discovery (MLD) proxy supporting multiple upstream interfaces at the mobility access gateway (MAG) [7]. The LB will also be evolved when a new multicast session is initiated. Via a near-to-real testbed, the experiments shows that the proposed solution helps to balance the load among LMAs. Also, the multicast service disruption caused by the changed LMA is greatly reduced. To the best of our knowledge, this paper is the first attempt to consider IP multicast with LB mechanism in a PMIPv6 domain. It is noted that this paper mainly focuses on the multicast listener.

The rest of this paper is organized as follows. Section II describes the related work on LB. Section III highlights the issues when considering IP multicast with the existing LB mechanisms. Section IV introduces the multicast-based LB mechanism while Section V presents an evaluation of the proposed solution. Section VI discusses the limitations of the proposed solution and considers the multicast service disruption. Finally, Section VII concludes the paper and provides perspectives for future works.

II. Related Work

A. Load Imposed on LMA

As described in the base solution [8], to support multicast in a PMIPv6 domain, the multicast router (MR) function and the MLD proxy function [9] need to be deployed at the LMA and the MAG, respectively. In this case, a listener always receives the multicast traffic from its LMA via the LMA-MAG tunnel. Thus, the load of LMA is imposed by both the typical LMA's tasks and the MR's tasks. As a typical LMA, the load comes from three main logic functions: mobility routing, location management and home network prefix (HNP) allocation [1]. Regarding the MR role, the load can be split into three main contributions: packet replication, reverse path forwarding recalculation and state maintenance [6]. In this paper, we focus on the mobility routing which processes the traffic from/to the associated MNs (unicast session) as well as the packet replication factor (forwarding multicast traffic) since the load imposed by the other factors are almost the same at all LMAs in the PMIPv6 domain.

B. Load Balancing among LMAs in PMIPv6

There are two main approaches for LB among LMAs in PMIPv6, namely, proactive-MN and reactive-MN. In the proactive-MN approach [3], [10], the LB will be executed in the initial phase of an MN to select the least loaded LMA. All mobility sessions of this MN then would be anchored at the assigned LMA during their lifetime in the domain. The main advantage of this approach is that it does not influence the ongoing sessions of the registered MNs. However, since it is executed in the initial phase of an MN, the varying session rate and data rate may cause the unfair load distribution among the LMAs. When an LMA is overloaded, it may drop the new sessions. It also causes several issues for the ongoing sessions such as service disruption and packet loss.

In the reactive-MN approach [4], [5], the LB will be triggered when the LMA load exceeds a specified threshold. The overloaded LMA will select one (or several) MN(s) to move to a less loaded LMA (called target LMA, or tLMA). The load information of all LMAs can be collected and managed at the authentication, authorization and accounting (AAA) server which then selects the tLMA among the LMAs in the domain. This approach allows the network to adapt to the current situation. Thus, it may give a better performance e.g., distributing load among LMAs and increasing the reliability. Since the LMA plays the role of the mobility anchor for the MN, changing LMA during the mobility session could impact the selected MN's ongoing sessions. The existing proposals only consider the ongoing sessions as the unicast ones. How the LB works with the multicast is still an open question. It is also necessary to consider IP multicast to avoid the potential impact of multicast service on the efficiency of LB.

III. IP Multicast Considerations with the Existing Load Balancing Mechanisms

This section will discuss the issues from both multicast and LB points of view when considering IP multicast with the existing LB proposals.

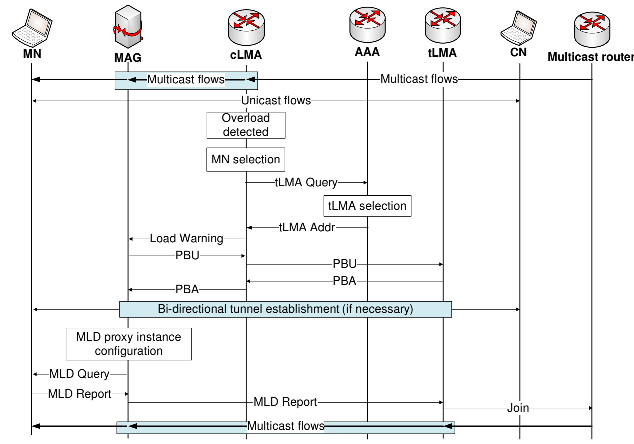


Fig. 1: Multicast consideration in the reactive-MN approach.

A. Multicast Considerations in the Proactive-MN Approach

In this approach, the LB will be executed when an MN initially enters the PMIPv6 domain. Thus, this approach only takes the current load of the LMAs (neither unicast nor multicast service) into account. As a result, this approach does not influence the ongoing sessions. Yet, the varying session and data rate (especially multicast session) of the registered MNs may cause unfair load distribution between LMAs.

B. Multicast Considerations in the Reactive-MN Approach

If an LMA (current LMA or cLMA) is overloaded, an MN will be selected to move to a less loaded LMA (say tLMA). The tLMA selection then can be done by the AAA server [4] (see Fig. 1). The cLMA can wait until receiving a refresh PBU message for this MN or force the MAG to send this message via a load warning message. The PBA/PBU then are exchanged between the cLMA and the tLMA allowing the tLMA to serve as a new mobility anchor of the MN.

Regarding the multicast-related operations, the MAG creates a new MLD proxy instance (if necessary), configures its upstream interface towards the tunnel MAG-tLMA and adds the selected MN to a downstream interface. Since there is no common database between the proxy instances, the new instance is unaware of the MN's ongoing channels. It will obtain this information after the regular MLD Query/Report process. If these channels are not available, the MAG then sends an MLD Report to the tLMA to subscribe to these channels. After joining these channels, the LMA forwards them to the MAG which finally reaches the MN. Hence, it experiences a noticeable service disruption for the ongoing multicast channels. To reduce the service disruption time, a combination of the explicit tracking function and the multicast context transfer which allows the new proxy instance obtaining the multicast subscription information in advance is required as similar as in [12].

If there are another MNs (associated to the cLMA) subscribing to the same channel as the selected MN, the cLMA will continue forwarding this channel. Consequently, the effectiveness of the LB mechanism will be reduced, especially in case of the main load imposed by this MN on the LMA from this channel. As a result, moving the MN cannot help significantly reduce the LMA load. Moreover, the total load of all LMAs may be increased since the tLMA may need to join the channel. Also, since many proxy instances are installed at MAG, it may cause the tunnel convergence problem.

IV. Multicast-based Load Balancing Solution

As explained in the previous section, the existing LB proposals may not enhance the effectiveness of the network when considering the IP multicast. They can also bring about some multicast-related issues e.g., service disruption and tunnel convergence problem. In this section, a multicast-based LB will be introduced. By separating the multicast LB from the unicast LB, the multicast session which could be a crucial factor in terms of load imposed on the LMA can be served at the suitable LMA without influencing other ongoing sessions.

In the multicast-based solution, LB can be invoked when an MN starts a new multicast session (called proactive-multicast), or when an LMA is overloaded (called reactive-multicast). In the former case, an LMA will be selected to serve as a multicast anchor for the new session at its initial phrase. In the latter case, a multicast session will be selected to move from the overloaded LMA to the less loaded one. It can be done thanks to an extension to MLD proxy to support multiple upstream interfaces [7]. In this case, only one proxy instance is deployed at MAG with the multiple upstream interfaces towards different LMAs. Consequently, the MN can receive the multicast traffic from the least loaded LMA, while obtaining the unicast traffic from its LMA. It is noted that, at this stage, the load is defined as the CPU utilization rate.

A. Load Balancing in the Proactive-Multicast Approach

When a registered MN expresses its interest in receiving a multicast channel (see Fig. 2), the MLD proxy instance at the MAG adds the MN to a downstream interface. If this channel is not available at this MAG, an LMA will be selected. The LMA selection is based on the following policies (from high to low priority): i) The least loaded LMA among the LMAs (not overloaded) having a multicast forwarding state for this channel; and ii) The least loaded LMA in the domain. The reason is if the channel is already available at the selected LMA (target LMA, or tLMA) with a negligible increase of load, the tLMA can forward this channel to the MAG [6].

To do so, a new logical entity, the so-called load balancing controller (LBC), has been introduced. This entity collects and manages the load information of all LMAs in the domain. It is also responsible for the LMA selection. The LMAs periodically report their current load to the LBC by using an extension to the PBU / PBA message with the load information. However, the frequency of the workload report should be carefully examined as the trade-off between the precision of the current load and the signaling/processing overhead. One possible solution is that the LMA only reports its workload when its load is greater/lower than a certain load level.

After selecting a tLMA, the LBC sends the tLMA's address to the MAG. The LBC also requests the tLMA to join the multicast channel in advance in order to reduce the service disruption. After establishing the bi-directional tunnel between the MAG and the tLMA (if necessary), the MAG configures its upstream interface (UI) to this tunnel and sends an MLD Report to join the channel. Finally, the multicast traffic will be routed to the MN via the tunnel MAG-tLMA.

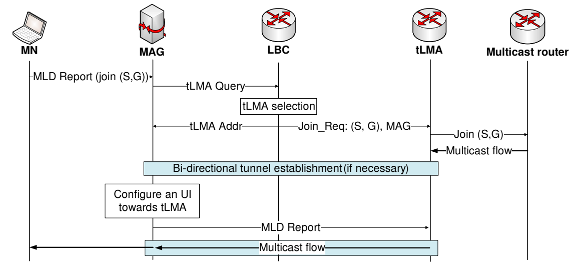


Fig. 2: Proactive-multicast approach.

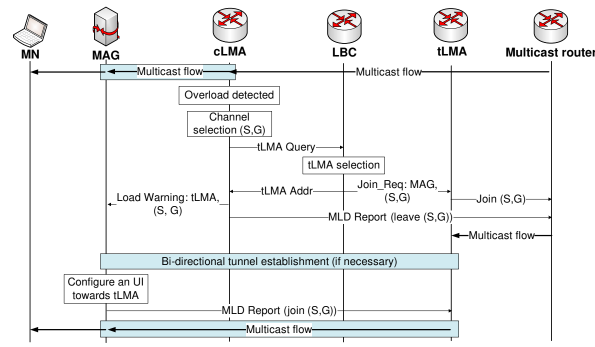


Fig. 3: Reactive-multicast approach.

B. Load Balancing in the Reactive-Multicast Approach

When an LMA is overloaded, a multicast session will be selected to move from this LMA (cLMA) to a less loaded one (tLMA) (see Fig. 3). The multicast session can be selected following some criteria: i) The real-time and delay-sensitive sessions should not be selected. However, if all sessions are real-time and delay-sensitive, the session with the highest data rate should be selected; and ii) The session requiring the highest data rate should be selected.

The tLMA then will be selected similarly to that in the proactive-multicast approach. Note that the LMA selection algorithm should take the expected load of the selected session into account. The cLMA sends the address of tLMA and the multicast session information to all related MAGs via a load warning message (e.g., using the Update Notification message (UPN) [11]). The cLMA then can leave this channel to lower its load. The MAGs, after configuring their upstream interface towards the tLMA and joining the channel, can receive the multicast traffic from the tLMA instead from the cLMA.

V. Performance Evaluation

This section evaluates the performance of the multicast-based solution in comparison with the MN-based solution and the pure-PMIPv6 environment (no load balancing) by using a near-to-real testbed. At this stage, the experiment focuses on the case where the traffic is dominated by the multicast traffic. The experiment also aims at showing the load distribution among LMAs. The other metrics such as queuing delay and packet dropping probability will be left for future works.

A. Testbed Implementation and Scenarios Description

As illustrated in Fig. 4, the testbed is a combination of a virtualized environment which consists of the virtual machines (e.g., using User-mode Linux) and the Network Simulator NS-3 as similar as in [12]. The testbed is composed of one LBC, three LMAs, three MAGs (and three access points (APs)), three multicast sources (MSs), and 60 MNs which play the

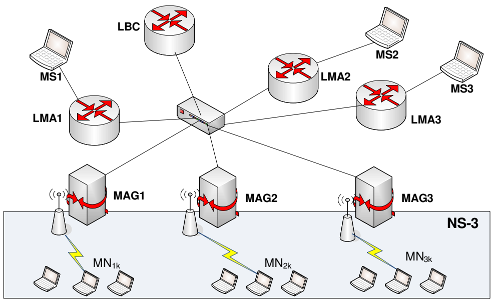


Fig. 4: Evaluation testbed.

role of a multicast listener. The LBC, PMIP entities (LMA, MAG) and the MSs are the virtual machines while the APs and MNs are NS-3 nodes. More precisely, a PMIPv6 domain is deployed using an open source PMIP namely OAI PMIP [13]. The LBC functionality is implemented by extending the LMA functionality. Thanks to the virtualization technique, this testbed helps to achieve realistic results and supports a large number of MNs with low cost (running on a single machine).

At the beginning, each multicast source MSi (i=1,2,3) broadcasts six multicast channels C_{ij} (j=1,…,6) which have identical traffic characteristic (1000 packets/second, packet size = 1024 bytes). By using the virtual mechanism, the performance and the capacity of the LMAs are almost the same. In the experiment, we use the same threshold value for all LMAs, for example, 85 percent of the CPU utilization rate. At first, the MN_{ik} (k=1,…,20) attaches to the MAGi and the LMAi (i=1,2,3), respectively. The unicast flow is also created between each MN and the corresponding MS (180 packets/second, packet size = 800 bytes). Two scenarios are then defined to evaluate the proactive-multicast and the reactive-multicast approaches. The number of multicast sessions of the existing MNs and the data rate of the existing multicast sessions will be varied in the scenario 1 and the scenario 2, respectively.

In the scenario 1, six MN_{1j} (j=1,..,6) join six multicast channels C_{1j} (via LMA1); MN_{21} joins C_{21} (via LMA2); MN_{31} and MN_{32} join C_{31}, C_{32} (via LMA3), respectively. Three approaches are considered: pure-PMIP, proactive-MN and proactive-multicast. In the scenario 2, six MN_{ij} (j=1,..,6) join three multicast channels (say C_{i1}, C_{i2}, C_{i3}) at the LMAi (i=1,2,3) (two MNs per channel, three channels at each LMA). Then the data rate of the existing multicast sessions is varied to make the LMA load changes. For instance, at the LMA1 the data rate of the channel C_{11} and C_{12} is increased with 2000 and 3000 packets/second, respectively. The channel C_{21} (at LMA2) and two channels C_{31}, C_{32} (at LMA3) are terminated. The results then are collected when the pure-PMIP, the reactive-multicast and the reactive-MN approach are applied.

B. Experiment Results

Fig. 5 shows the LMA load in the scenario 1. In the pure-PMIPv6 environment (see Fig. 5(a)), without any LB mechanism, it is clearly seen that the load of LMA1 is higher when the number of multicast sessions at the LMA1 is increased. The LMA1 then becomes overloaded (CPU utilization rate $\geq$ 85%) while the load of the LMA2 and LMA3 are not too heavy. The results are exactly the same when the proactive-MN is applied since the LMA assignment is already done for the MNs. By using the proactive-multicast approach, the load imposed by the new multicast sessions is better distributed among the LMAs as illustrated in Fig. 5(b). It is because the proactive-multicast approach takes the load of LMAs in real time when an MN joins a multicast channel. It is noted that the curve is not smooth since the results are collected from the virtual machines in which some background processes are running (generating a minor CPU load).

The load distribution of the LMAs in the scenario 2 is illustrated in Fig. 6. As observing in Fig. 6(a) the varying of the existing multicast sessions causes the unbalanced load among LMAs in the pure-PMIPv6 environment. When using the reactive-MN approach (see Fig. 6(b)), the LMA1 load is kept almost the same as in the pure-PMIPv6 environment (still overloaded) while the LMA3 load is increased. Consequently, the total load of all LMAs is increased. Applying the reactive-multicast solution (at about 360s) helps to balance the load among LMAs as described in Fig. 6(c). In this case, a multicast channel (the one with 3000 packets/second) has been moved from the LMA1 to the LMA3.

VI. Discussions

A. Limitation of the Multicast-based Solution

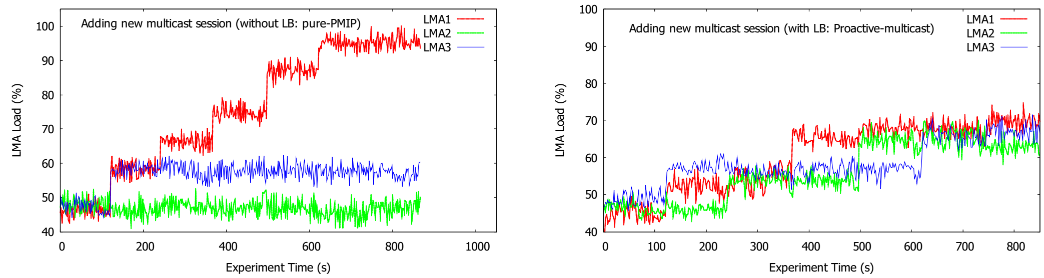
The multicast-based solution seems to be suitable for the domain where the mobile data traffic is dominated by the multicast traffic. For example, it may be the most appropriate solution to distribute load among the multicast tree mobility anchors (MTMA) which work as the topological anchor point for multicast traffic in a PMIPv6 domain [14] (as the MTMA only serves the multicast traffic). However, for the domain where the unicast is the main service, the MN-based solution may give a better performance. Thus, they should be used together to improve the network performance. For instance, it is obvious that the proactive-MN can co-operate with the multicast-based solution while the proactive-multicast with the MN-based solution. In addition, the reactive-multicast can be followed by the reactive-MN approach. For example, if any multicast session is not a real-time and delay sensitive one, the reactive-multicast approach will be performed. Otherwise, the reactive-MN will be executed. The main idea is that we try to distribute load among LMAs by using the multicast-based solution before applying the reactive-MN one to avoid the influence on the ongoing sessions. Therefore, the blocking probability of a new MN (session) and the dropping probability of the existing MNs (sessions) are obviously lower than the existing LB mechanisms.

B. Multicast Service Disruption Consideration

The multicast service disruption time is defined as a period when a listener cannot receive the multicast packets caused by the changing listener's LMA. In the reactive-MN approach, (see Fig. 1) it can be calculated from the moment when the cLMA sends a PBU to the tLMA until the moment when the MN receives the multicast traffic. Let $t_{X,Y}$ denote the delay between node X and node Y, t_{QRD} the query response delay [9]. Assuming that $t_{LMA,LBC} = t_{LMA,LMA}$ and $t_{MAG,LBC} = t_{MAG,LMA}$. Thus, the service disruption time in the reactive-MN approach is given by:

$$D_{R\_MN} = 2t_{LMA,LMA} + 3t_{MAG,LMA} + 3t_{MN,MAG} + t_{QRD} + 2t_{tLMA,MR}. \quad (1)$$

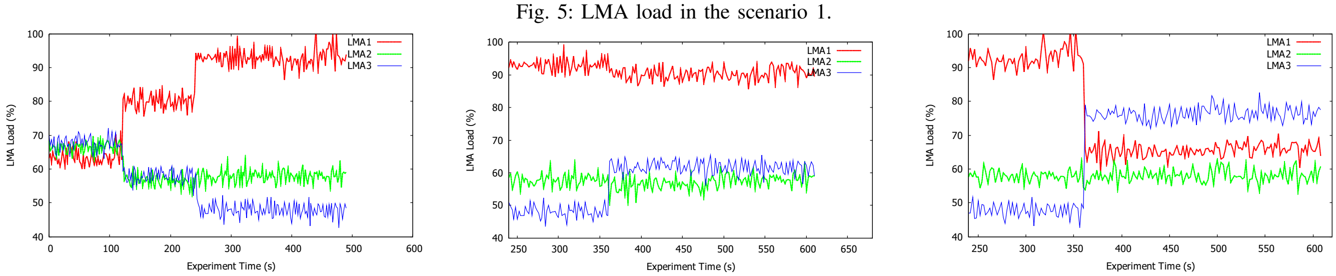
Similarly, the service disruption time in the reactive-multicast approach is defined as (see Fig. 3):



(a) pure-PMIP and proactive-MN approach

(b) proactive-multicast approach

Fig. 5: LMA load in the scenario 1.



(a) pure-PMIP approach

(b) reactive-MN approach

(c) reactive-multicast approach

Fig. 6: LMA load in the scenario 2.

$$D_{R\_M} = 3t_{MAG,LMA} + t_{MN,MAG} + 2t_{tLMA,MR}. \quad (2)$$

According to the literature [12], $t_{MAG,LMA}, t_{LMA,LMA}$ and $t_{MN,MAG}$ are assumed to be 10ms, 10ms and 12ms, respectively. Also, t_{QRD} is around 374.2ms. We suppose that $t_{tLMA,MR}$ = 0ms for simplicity (the multicast traffic is already available at the tLMA). We have D_{R_MN} = 460.2ms and D_{R_M} = 42ms. Thus, D_{R_MN} is clearly much greater than D_{R_M}. In other words, the reactive-multicast approach helps significantly reduce the service disruption compared to the reactive-MN solution.

Via the utilization of the explicit tracking function and the multicast context transfer into the reactive-MN approach, the $D_{R\_MN\_CXT}$ can be calculated as:

$$D_{R\_MN\_CXT} = 2t_{LMA,LMA} + 3t_{MAG,LMA} + t_{MN,MAG}. \quad (3)$$

Using the above-mentioned parameters, we obtain $D_{R\_MN\_CXT}$ = 62ms. Yet, this value is quite larger than that in the multicast-based solution (D_{R_M} = 42ms).

VII. Conclusions and Perspectives

This paper, at first, discuss the negative impact of IP multicast on the efficiency of the existing LB proposals among LMAs in PMIPv6. From IP multicast perspective, the multicast-related issues are also highlighted. To overcome these issues, a multicast-based solution has been proposed. The key benefit of the solution is that it does not influence the other ongoing unicast/multicast sessions. It can also co-operate with the existing proposals to improve the performance of the network. Via a near-to-real testbed, the experiment results show that the proposed solution helps better distribute the load imposed by the multicast service among LMAs. It also helps greatly reduce the service disruption time compared to the existing proposals.

In the next step, more experiments will be conducted to compare the different approaches (MN-based and multicast-based) in terms of packet loss, average queuing delay and session blocking/dropping rate. The LB which is based on other load metrics (e.g., number of sessions and number of registered MNs) will also be considered.

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