Experimental Evaluation of the Source Specific Multicast Model in Mobile Environments

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***Abstract*— Although the Single Source Multicast model is quite mature, the implementation of its protocols became available only very recently and experimental results to evaluate this model are still missing, specially in mobile environments. Hence, our goal is to experimentally evaluate the Single Source Multicast model against the two multicast mobility proposals of the IETF: remote subscription and bi-directional tunneling techniques. We experimentally confirm that the group management query, in remote subscription, and the router advertisement interval, in bi-directional tunneling are unacceptably high and not adjusted for mobile environments. The handover latency of both techniques is closely related with those intervals. Other results show that both techniques have similar throughput and packet loss in home network, having the remote subscription higher throughput in remote access networks. This throughput decrease in remote access networks reveals one of the drawbacks of the bi-directional tunneling technique: the non-optimal routing. Its was also concluded that RFC 3810 is not prepared to deal with mobile environments.**

I. Introduction

Deploying multicast in a mobile environment has some challenges since while mobile receivers between different attachment points, communication sessions should not be disrupted or severily interrupted. This seamless continuity requires a minimum loss of packets and a correct management of the multicast tree. Several techniques were developed to address mobile multicast over IP. The IETF proposed the remote subscription and the bi-directional tunneling techniques [1], [2]. With the remote subscription technique a new multicast group subscription is made every time a mobile receiver changes its point of attachment to the network. This new subscription is followed by the reconstruction of the multicast tree in order to accommodate the new position of the mobile node. This technique has the advantage of not requiring special encapsulation, of being simple and similar to the multicast concept by offering the shortest path for multicast data delivery. However it is not suitable for nodes that change their point of network attachment very often as this would require frequent re-subscriptions, what would lead to packet losses. In the bi-directional tunneling technique, the Single Source Multicast (SSM) protocols are used together with the Mobile IPv6 (MIPv6) [3]. This technique does not require changes in the multicast tree every time the mobile node moves from one network to another, as data is multicasted to the MIPv6 Home Agent (HA) and tunneled to the mobile node. The drawback is that the routing is not optimal and presents scalability problems, due to the use of per-node tunnels. Moreover, the home agent represents a single point of failure.

In our work the SSM model [4], [5] is represented by the Protocol Independent Multicast - Source Specific Multicast (PIM-SSM), which is one of the PIM protocol operation modes [6], [7], as the multicast routing protocol and the Multicast Listener Discovery Version 2 (MLDv2) protocol [8] as the group membership protocol. One of the first implementations of the SSM model was developed by the KAME project [9] in 2001 for the FreeBSD operating system. The first Linux implementation appeared in 2004 [10]. However, experimental results that can evaluate the protocol behavior and performance are still missing, even more if we consider mobile environments.

This work aims to provide experimental results to evaluate the performance of the two IETF proposals to handle multicast in mobile environments, while using the SSM model. Based on the achieved results, several problems are identified and some solutions/adjustments are proposed.

This paper is organized in the following way: section

II gives an overview of the experimental work done in relation to the SSM model. In section III a detailed description of the experimental environment is given, namely, the network topology and the used tools. Section IV describes the tests and discusses the obtained results, while section V relates our suggestions to improve some of the drawbacks emerged from the results. Section VI presents conclusions and future work.

II. Related Work

This section describes experimental approaches on the area of mobile multicast and Mobile IPv6, helping us to understand the main difficulties to develop an experimental environment and to acquire the theoretical background.

Bettstetter et al. analyzed the inter-operation of the PIM Dense Mode (PIM-DM) protocol and the MIPv6 protocol [11]. Although PIM-DM is not suitable for our scenario, this work provides a study of the MLDv2 protocol, namely its default timer values and the way they affect multicast handoffs. Despite the presentation of some conclusions, no simulation or experimental results were described. Wu et al. [12] developed a testbed with PIM Sparse Mode (PIM-SM) as the multicast routing protocol and IGMPv2 as the group management protocol. Additionally they propose a new architecture, based on mobility agents, to reduce the handoff latency. This work is important, because it describes an experimental work, uses protocols similar to PIM-SSM and MLDv2, analyses the multicast handoff latency and proposes a solution to reduce that latency.

In the areas of IPv6 and multicast there are two well-known initiatives closely related with our work: the 6NET European project [13] and the the POZNAN center [14]. The POZNAN center describes some available implementations of the SSM model in IPv6 networks [15]. A testbed was developed, but lacks experimental results. The 6NET European Project has many contributions on the areas of MIPv6 and SSM. The contributions in the area of MIPv6 [16], [17] are a support guide to develop a testbed with MIPv6, and to analyze and evaluate the performance of handoffs, by studying the steps that constitutes the handoff. Specifically in the area of SSM the 6NET project produced a deliverable reporting the use of multi-point applications over SSM [18], with focus on session announcement, source discovery and SSM applications. In the area of mobile multicast, the 6NET project presented a study [19] that analyzed the use of the MIPv6 Home Agent as a multicast proxy. This proxy is needed to overcome the problem brought, at that time, by Linux not implementing the IPv6 multicast forwarding cache needed in the bi-directional tunneling technique. However, this work does not present any experimental results.

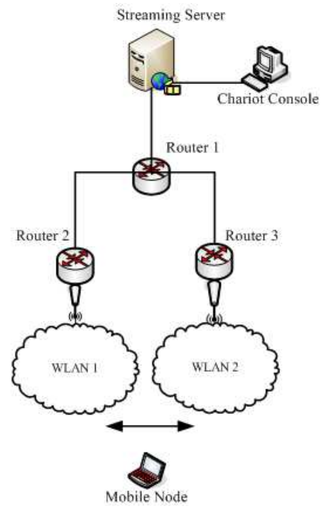

Fig. 1. **Topology used for the experimental evaluation**

Our work differentiates from the above approaches, because it consists of an experimental study, based on a prototype testbed, aiming to evaluate the inter-operation of PIM-SSM and MLDv2 against the two IETF techniques for multicast mobility. The throughput and multicast handoff latency are the evaluated parameters. So, we may argue that all the conditions involved in our study, namely the evaluated parameters, the used protocols, the testbed topology, together with the experimental nature of the work is innovative when compared to the approaches described in this section.

III. Experimental Environment

This section introduces the experimental environment used in our work. Figure 1 illustrates a testbed that fulfills the requirements described above. It is constituted by one server, three routers, two of them acting as wireless access routers and a wireless receiver, moving repeatedly between the two routers.

The operating system used in all nodes is Linux Fedora Core 3 with kernel 2.6.11, which grants the MLDv2 protocol and complies with the last release of the mobility package. The PIM-SSM daemon (*mrd6)* for linux [20] was installed in all the routers, while the MLDv2 protocol is enable in wireless access routers and disable in core routers. The source, router3, which acts as Home Agent when testing the unicast mobility and the bidirectional tunneling technique, and the mobile node have the MIPv6 package called *mipv6-2.0-rc3* [21] implemented. There are two daemons that are very important to this work: the *mrd6* mentioned before, and the router advertisement daemon (*radvd*) [22]. In terms of tools, the evaluation process comprises two types: traffic generators and monitoring tools. The tool used to measure the unicast throughput was the *IxChariot* tool [23]. For the multicast tests it was used the *mad-flute* tool [24] to send and received multicast SSM traffic together with the *iptraf* [25] and *tcpdump* [26] tools to monitoring and collect the statistics. Having the log files produced by the *tcpdump* tool, the *trpr* [27] tool was used to produce the throughput graphics. All the machines are equipped with PCI network devices 10/100 Mb/s, and the Wireless LAN (WLAN) 802.11b access points and cards work at 11 Mb/s.

Of importance to our analysis are the frequency of the router advertisements, when testing the bi-directional tunneling, and of the MLDv2 Queries when testing the remote subscription. By default, the router advertisement interval has a maximum of 600 s and a minimum equal to $\frac{1}{3} * max$. The MLDv2 Query interval has the default value of 125 s. The default values were used in some of the tests, while in others those values were optimized for fast mobility. This optimization consists in reducing the router advertisement interval to a maximum of 5 s and a minimum of 3 s has suggested by the radvd authors. For the MLDv2 Query the default value was changed to 15 s. The radvd values are the minimum advisable values suggested by the authors and it was our intention to reduce, as much as possible, the time spent by the mobile node to aquire the link-local address. The MLD Query value was chosen to enable high mobility but without overload the network.

The multicast tests described in next section were done in two scenarios: first, using the remote subscription technique with the PIM-SSM and MLDv2 protocols. In this case the mobility of end hosts is supported by the multicast protocols, which rebuild the multicast tree in order to accommodate the new position of the mobile node. The second scenario involves the bi-directional tunneling technique with the MIPv6 protocol and with the multicast protocols, PIM-SSM and MLDv2. Here, the multicast protocols have the responsibility of built the multicast tree from the source to the Home Agent, which in turn manages the end-host mobility.

IV. Evaluation

The first test, which can be consider as preliminary, intends to measure the unicast throughput. The other two set of tests are performed in a multicast environment, with the remote subscription and bi-directional tunneling techniques, respectively. The evaluated parameters for these tests are the throughput, packet loss and the handoff latency. The remaining of this section presents and analyses the results of the described tests.

A. Unicast Environment

This test evaluates the throughput and handoff latency of a UDP and TCP unicast communication between the source and the mobile node, being the MIPv6 responsible to manage the mobility. The home network is WLAN2.

This test was made using *IxChariot.* The script used by *IxChariot* to evaluate the throughput assumes the operating system default values for the file and sending buffer sizes.

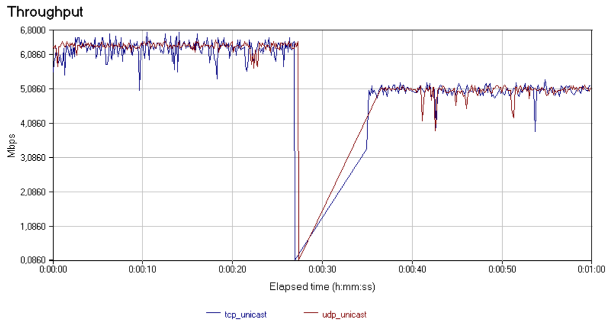

Fig. 2. Unicast Throughput in Mobile Node

The results presented in Figure 2 show that the unicast UDP and TCP throughput rounds the 6 Mb/s, being 6.504 Mb/s and 4.458 Mb/s the maximum obtained value and the average for the UDP throughput, respectively. The maximum TCP throughput was 6.723 Mb/s and the average 4.904 Mb/s. The slightly higher throughput in the TCP communication, which is not generally expect, is not to take in consideration as it may be due to the used application or some network temporarily state.

In both flows the throughput falls during, approximately 3.5 s, period that corresponds to the latency of the handoff made from WLAN2 to WLAN1. After the handoff the mobile node starts to receive traffic again, but with a lower throughput. This decrease in the throughput after the handoff is due to the fact that data after reaching the HA, in our case Router3, has to be tunneled and return to Router1, which forwarded to Router2. These two additional hops is what causes the degradation in the throughput. This behavior (triangular routing) was not avoid to illustrate one of the drawbacks of the bi-directional tunneling technique, the non-optimal path between the source and the mobile node when he visits a foreign network.

This test was repeated ten times, revealing an average handoff latency of 3.07 s and a variance of 0.89 s.

B. Multicast Environment with Remote Subscription

In this test the mad-flute tool was used to generate UDP traffic in the source, and to join a SSM session in the receiver. The source sends data, at 8 Mb/s, to a specific multicast group. Each packet has 1024 bytes. The transmission rate of 8 Mb/s was select to sature the link since it was showed, in previous experimental tests with the same scenario and settings, that the multicast throughput in mobile node could achieve values slightly higher than 7 Mb/s.

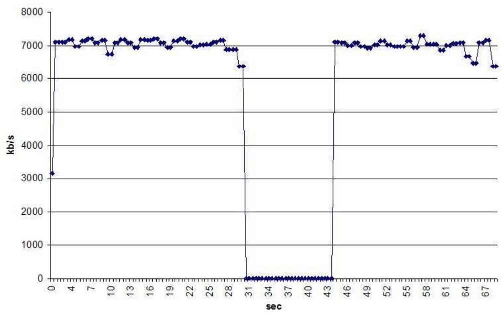

Fig. 3. Throughput and Latency with Remote Subscription

Figure 3 illustrates the throughput, obtained with the remote subscription technique, at the mobile node. The measured throughput oscillates around the 7 Mb/s. This represents an increase of ~ 1 Mb/s when compared with the measured unicast throughput. Except during handover, the packet loss during the communication between the source and the mobile node, at 8 Mb/s, is around 2% (1060 of 36834 sent packets).

In terms of handoff latency two scenarios were tested: first, with the default MLDv2 Query interval (125 s) and second with this value optimized to 15 s. The explanation for this differentiation resides in the observation that when the mobile node travels to a remote access network has to wait for the MLD Query in order to be able to re-subscribe the multicast group. This fact shows the inefficacy of MLDv2 protocol, namely RFC 3810, to deal with mobility. The difference in the results is clear: with the default MLDv2 Query interval the average handoff latency of ten handoffs is 40.02 s, while this value decreases to 12.22 s when the MLD Query interval is 15 s.

Description	Average	Variance	% of handoff time
Latency of handoff	12,22 s	3.01s	-
MN receives the MLDv2 Query	8.92 s	-	73,40
MN responds with MLDv2 Report	3.17 s	-	26.06
MN receives data	0.13 s	-	0.54

TABLE I

PERCENTAGE OF LATENCY ATTRIBUTED TO EACH HANDOFF STEP

Table I shows the percentage of the total average latency caused by each step of the handoff process. The major slice, 73.40 %, is consumed while waiting for the MLDv2 Query. When the MN responds with the MLDv2 Report 99.46 % of the handoff time was already achieved. The remaining 0.54 % of the handoff time is the arrival of data to the MN, after the MLDv2 Report is sent.

With this test is possible to take several conclusions: the first one is the importance of optimizing the MLDv2 Query. With this optimization it was possible to reduce the handoff latency in 69.47 %. The second conclusion is that if the multicast tree takes, approximately, 0.20 ms to be built (calculated in a preliminary test done with the *ssmping* tool [28] and with the same scenario and settings) and if the handoff takes 12.22 s, it is possible to conclude that the PIM-SSM itself (the time spent by the join to reach the router nearest the source plus the multicast tree built), is responsible for ~ 8.20% of handoff time.

C. Multicast Environment with Bi-directional Tunneling

The goal of this test is to evaluate the behavior of the bi-directional tunneling technique in a mobile multicast environment. In this test, the source acts as correspondent node and the access router of WLAN2 operates as HA.

Figure 4 shows the throughput in the mobile node while it stands in his home network, WLAN2, and when he moves to WLAN1.

Two different cases are visible in Figure 4: first, before the handoff the measured throughput oscillates around 7 Mb/s just like in the remote subscription technique. This is the expect behavior because the HA just forward the packets to its home network, which means that the process is the same as in the remote subscription. When the mobile node makes the handoff, the throughput decreases around 700 kb/s. The fact that the multicast traffic always pass by the HA, increasing the path by two hops (the multicast data path is S->R1->R3->R1->R2), together with the additional overload caused by the

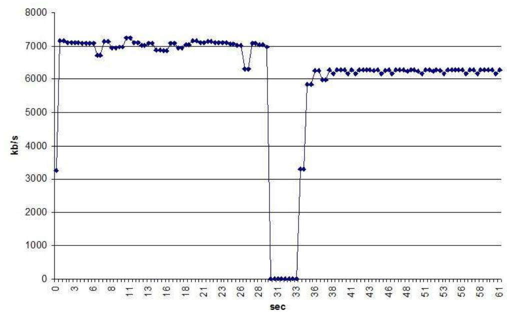

Fig. 4. Throughput and Latency with Bi-directional Tunneling

packet encapsulation can justify the decrease observed in the throughput after the handoff.

In terms of packet loss, before the handover it is equal to the one obtained for the remote subscription, 2 %. After the handover the packet loss increases to 3.4 %.

The average latency of 10 handoffs is 3.13 s which represents a strong decrease when compared with 12.22 s obtained for the remote subscription. The explanation is in the fact that the steps involved in the handoff are quite different in both cases. In fact, with MIPv6 the time spent by the mobile node to acquire its global address and to be able to receive the multicast data is the step responsible for the majority of the handoff time. On the other hand, in the remote subscription the major contribution for the handoff time is the waiting for the MLD Query.

Again, as in the remote subscription with the MLD Query interval, the value for the handoff latency was obtained with the router advertisements interval set to its minimum. The difference in the results is also clear: with the default *radvd* values the handoff latency was 315.83 s . The MLD Query interval does not influence the handoff latency since the multicast tree is only built one time.

Parameters	Average	Variance	% of handoff time
Latency of handoff	3.13 s	1.21s	-
1st Binding Update send by the MN	2.57s	0.98s	65.2
time between the first bind update and arrival of data	1.36s	0.89s	34.8

TABLE II
PERCENTAGE OF LATENCY ATTRIBUTED TO EACH HANDOFF STEP

Table II shows the average of handoff latency and analyses the percentage of this latency attributed to each step of the handoff process. In average at least 65.2 % of the handoff time is consumed until the mobile node receives the router advertisement and sends the first Binding Update. After this, the HA has to respond with a Binding Acknowledgment confirming the new care-of-address registration, after which the HA can forward the data. These steps represents 34.8 % of the handoff time.

V. IMPROVEMENTS

The results of our study allow us to propose some improvements. The first one is related with the optimizations of the daemons. The chosen interval values of *radvd* and MLDv2 Queries should be adapted to each reality. High mobility implies short intervals and high signaling. In view of that, the *radvd* interval, in the case of bi-directional tunneling, and the MLD Query interval, in the case of remote subscription, must always be adapted or balanced for each case having in mind the overload caused by an excessive number of control/advertisement messages and the degree of mobility in the access networks. In our tests the router advertisements interval was set between 3 s and 5 s and the MLDv2 Query interval was set to 15 s. These values lead us to an handoff latency of 12,22 s for the remote subscription and 3.13 s for the bi-directional tunneling technique.

Other improvement is also needed in MLDv2 protocol, namely in RFC 3810 [8], which is not adapted to mobile environments. Our suggestion is to add a trigger that could enable an end-host to send and MLD Report when arriving to a new access network. This way it is possible to avoid the time spent waiting for the MLD Query, which is, in remote subscription, the major responsible for the handover latency.

VI. CONCLUSIONS AND FUTURE WORK

This paper evaluates the SSM model together with the two IETF proposed for mobile multicast: the remote subscription and bi-directional tunneling techniques.

In terms of throughput the conclusions are twofold: multicast communication receives a higher throughput than unicast; second, the remote subscription and bi-directional tunneling techniques achieve the same throughput in the home network, having the remote subscription higher throughput in remote access networks. In the case of bi-directional tunneling the throughput decreases as much as the distance from the MN to its HA increases.

In terms of handoff latency the first conclusion is that the standard values used by the *radvd* and *mrd6* daemons, for the router advertisement and MLDv2 Query intervals, make the handoff latency unacceptably high. The optimization of these intervals is mandatory. The second conclusion is that, in the case of remote subscription, the percentage of the handoff time responsible for the majority of the latency is SSM related, namely, waiting for the MLD Query (73,4 %). On the other hand, in bi-directional tunneling, the major slice of handoff latency (65 %) is related with mobility, namely, the acquisition of the IP device address. Comparing the two mobile multicast technologies in terms of handoff latency is clear that the bi-directional tunneling involves less time and packet loss.

The behavior of PIM-SSM, in this work, mainly its suitableness to mobile environments, has clearly more impact in the remote subscription technique. In the bi-directional tunneling the multicast tree is built just one time and hence the responsibility of PIM-SSM ends after the first subscription. Despite this and if it is consider other multicast alternatives, PIM-SSM simplicity, scalability and suitableness to one-to-many communication makes him a good solution to adopt.

As future work, it is planned to include QoS in the core network, namely the DiffServ model [29], and test the mobility, multicast and QoS technologies together and see if the introduction of QoS in the wired network has some impact in the mobile node performance.

ACKNOWLEDGMENTS

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