Performance Analysis of the Proxy Mobile IPv6 (PMIPv6) and Multiprotocol Label Switching (MPLS) Integration

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Abstract

This article analyzes and develops the integration of the PMIPv6 (Proxy Mobile IPv6) and MPLS (Multiprotocol Label Switching) protocols in order to determine the impact at the time of handover in an IP micro mobility environment. The proposed integration suggests the establishment of abi-directional Label Switched Path (LSP) between the Mobile Access Gateway (MAG) and the Local Mobility Anchor (LMA), in order to replace the IP-over-IP tunnels that support PMIPv6. The proposed integration is a semi-soft integration, and NS-2 is used to evaluate the impact of introducing MPLS technology in a PMIPv6 domain. PMIPv6/MPLS was compared with PMIPv6. The results indicate an improvement in the performance of the handover, when PMIPv6 and MPLS integration is used.

Keywords— Handover, Integration, IP micro mobility, MPLS, PMIPv6.

I. INTRODUCTION

The progress in telecommunications systems and their need to provide ubiquitous connectivity to services users is becoming more and more important especially in New Generation Wireless Networks (NGWN), due to the emergence of mobile devices that make necessary mobility support and access to Internet services [1]. One of the biggest challenges faced by wireless networks is when the mobile moves from a coverage area to another, a process known as handover, during which a momentary interruption of communication happens, leading to problems such as signaling overload, packet loss, delay, etc. [2]. The quality of the communication, the services and the applications are dependent highly on the efficiency with which the process of handover is performed; being necessary to provide solutions that optimize performance and terminal mobility within All-IP architecture.

It is essential that the protocols that support mobility solutions become increasingly robust and are easily deployed, to propose operating schemes for several of these protocols or integrating characteristics of other protocols as an effective strategy to improve protocol efficiency and optimize the overall performance of the network in a mobile IP environment. [3]

This article develops the integration of protocols PMIPv6 and MPLS from a semantics and synchronization perspective, and analyzes it by simulation in NS-2. The paper is organized as follows: section II presents the types of integration protocols. Section III describes the performance of protocols PMIPv6 and MPLS. Section IV presents the integration strategy from the semantic and synchronization perspective. Section V presents the integration PMIPv6/MPLS conducted in the NS-2 simulator. In Section VI, we analyze the simulation results. Finally, Section VII presents the conclusions.

II. INTEGRATION PROTOCOL

The definition of a communications protocol indicates the set of rules necessary to initiate and maintain a communication [4]. These standards are what define its syntax, semantics and synchronization, from which is possible to identify three types of integration schemes at the protocol level: Soft scheme (Interoperability), Semi-soft scheme (Overlay) and Hard scheme (Integrated) [5-9].

A. Soft Scheme

In this scheme each protocol operates under the respective pre-established rules that were created with and according to the layer where they run in the Open Systems Interconnection model (OSI). In this operation, only one alteration of the set of rules that define synchronization protocols occurs, as each side makes its processes and events normally operating synchronously as required by the event or running process.

This integration scheme allows a fast and easy deployment of the architecture that uses it, with a simple process, however, access to routing table information and data stored by the protocol that establishes connection with is limited, being impossible to do events or combine processes in a single protocol. The problems of latency and overload in the network are critical in the integration scheme because the protocols' synchronization mechanism requires more confirmation messages than the usually employed to communicate the implicated parts with protocols in the same layer or next layer, increasing the level of delay [5-9].

B. Semi-soft scheme

In this scheme, the protocols still need to operate in their respective layers according to the OSI model. In its operation, protocols assume a complementary behavior, i.e. a protocol performs a process (sending a confirmation message, update message, signaling message, etc.) which generates a particular reaction in the other protocol; in this way, the process directly affects the behavior of the network domain where this integration scheme deploys [5-9].

In this scheme, the set of rules that define the protocols' syntax are preserved, but the rules defining semantic and synchronization are modified, when considering the use of some fields within the datagram (experimental fields). Interacting protocols can access the stored data and routing tables of each other, allowing to substantially enhance certain processes and increase the efficiency of the architecture implemented, maintaining a balance between ease of implementation and system performance, but processes and events will not take place as a new protocol entity [5-9].

Despite the above-mentioned benefits, latency and network overhead overload issues are generated; however, the setting and session continuity processes are lightly affected during the handover process in a mobility domain [5-9].

C. Hard Scheme

In this scheme, the level of integration of the protocols is superior, without the strict need to operate separately in their respective layers according to the OSI model. In its process certain protocol characteristics are combined to generate a new protocol entity, from the modification or creation of the set of rules that define the syntax, semantics, and synchronization, establishing new routing tables, identifying the entities that store data, modifying or creating fields within the datagram (as needed), defining the logical interpretations of these new or modified fields and establishing settings in the operating times of the processes [5-9].

The processes and events of these protocols are performed as a single entity, using the features of both to improve the efficiency of network operations (e.g. signaling and control processes) and system performance compared with the previous schemes, contributing to optimize network resources, providing a good TE support , and incorporating end to end QoS mechanisms, making this a reliable and robust scheme for its implementation; however, modifying the syntax, semantics, and synchronization, requires a complex and extensive research process to identify the standards, specifications and recommendations for its integration. Resulting in an architecture which deployment is slow and complex in a global scale [5-9].

III. PROTOCOLS TO INTEGRATE

A. PMIPv6

It was proposed and designed by the IETF as a specification for providing a Mobile Node (MN,) Network-Based Localized Mobility Management (NETLMM) [10], which allows the MN not to require modification to the protocol stack, installing extra drivers or software to support mobility protocols, since the terminal is not a participant in the signaling process because the network executes the messages exchange with mobile agents [11].

In PMIPv6 domain two primary entities for operation are defined: the Local Mobility Anchor (LMA,) and the Mobile Access Gateway (MAG,) and messages: Proxy Binding Update (PBU,) and Proxy Binding Acknowledgement (PBA,) [11], [12].

- **LMA**: This entity is the Home Agent (HA,) for the MN, responsible for maintaining MN access to the outside PMIPv6 domain and providing the network prefix for this domain. This entity has the LMA Address (LMAA,) to which the MAG sends its messages. Additionally it has the Binding Cache Entry (BCE,) where it stores the association of MNs with their respective MAGs.

- **MAG**: This entity is responsible for managing the mobility signaling messages on behalf of the MN connected to the access link, notifying the LMA an event of association or disassociation of an MN. This entity has the MN Address on a Proxy Care of Address (Proxy-CoA,) to which the LMA sends its messages. Additionally it has the Binding Update List (BUL,) containing the MNs associated to its link.

- **PBU**: is a request message sent by the MAG to LMA indicating the Proxy-CoA of the associated MN.

- **PBA**: is a message sent by the LMA entity in response to a PBU message issued by the MAG, indicating the result of the Binding Update (BU).

In a PMIPv6 domain is possible to have multiple LMA and MAG. Fig.1 shows a typical topology of a PMIPv6 domain.

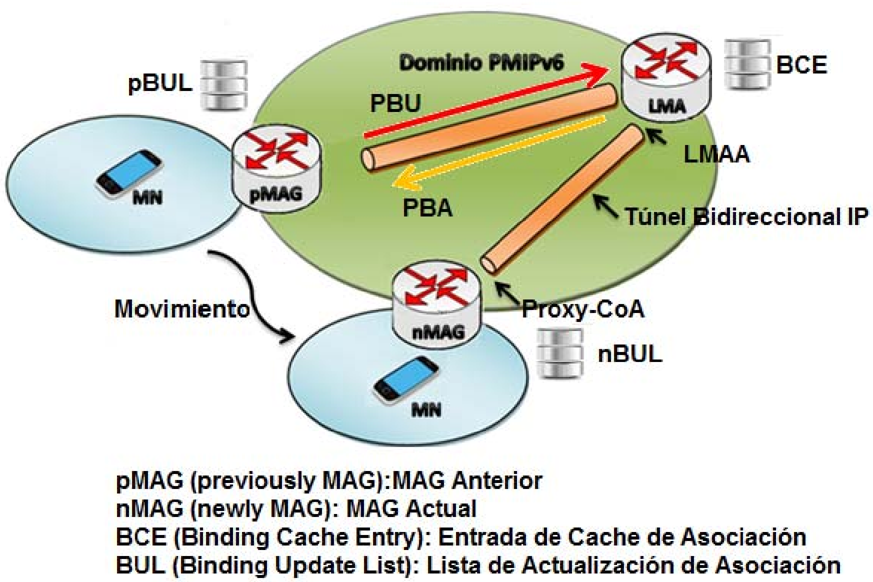

Figure 1. Overview of the PMIPv6 domain [12]

B. MPLS

It is a technology that having fast label switching paradigm and mechanisms to establish tunnels, tends greatly to be incorporated in highly mobile environments, to reduce processing time in the mobility entities in the network [5 - 9], having a significant impact in the process of establishing connections and continuity of sessions initiated by the end user in the context of mobility [13].

Within the MPLS architecture three elements that are central to its operation should be defined: Label, Forwarding Equivalence Class (FEC) and Label Switched Path (LSP) [13], [14].

- **Label**: is a fixed size identifier that distinguishes IP packets belonging to the same class of traffic data in an MPLS network.

- **FEC**: the representation of a set of packets that are forwarded over the same route through the

MPLS network. The FEC contains the packet path and defines the treatment that the packet will receive when going through each Label Switched Router (LSR).

- **LSP**: is a unidirectional virtual path that packets of the same connection follow. It has an assigned label at each hop and it is established through routing protocols or manually.

In this architecture two devices that allow its operation are defined: the LSR and the Label Edge Router (LER).

- **LSR**: is a router located in the MPLS network backbone, is specialized in swapping labels and re-sending packets based on the identification given by the label to the packet flow entering the network.

- **LER**: is a router located on the edge of the MPLS network, connecting different access networks. It specializes in pushing and popping labels from IP packets.

The MPLS network routers do not need to examine and process the IP header, they only require to re-send the packet depending on the value of its label, this is one of the advantages of MPLS routers over IP routers, where the re-sending process is more complex. In an IP router each time a packet is received, the IP header is analyzed to compare it with the Routing Table and see what the Next Hop (NH) is. The fact of examining the IP header of these packets in each one of the transit points that it must travel to reach its final destination, means more processing time at the nodes and therefore, longer time in the path.

Figure 2 shows a typical topology of an MPLS domain.

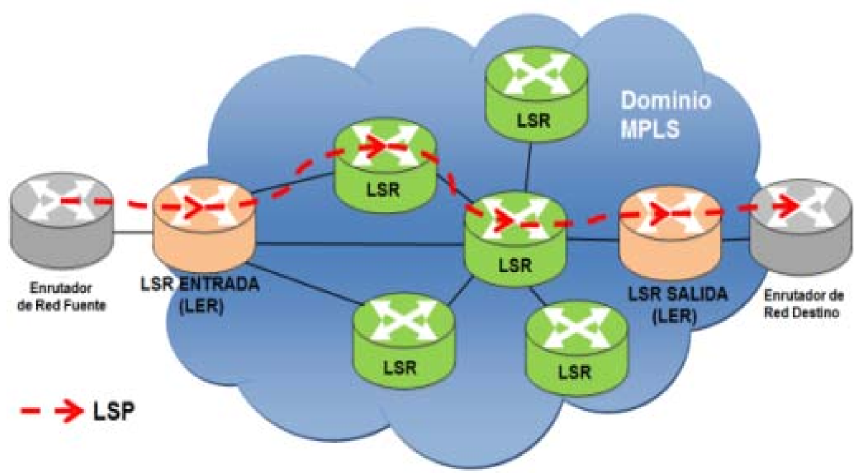

Figure 2. MPLS domain [14]

IV. PROTOCOL INTEGRATION

The integration between PMIPv6 and MPLS based on the semi-soft scheme is proposed, considering its realization from the semantic perspective and from the synchronization perspective.

A. Semantic Integration perspective

It requires that the LMA/LER and MAG/LER retain their original functions, with the addition of LER routers exclusive functions, to accurately interpret the messages used in a PMIPv6 domain, necessary for the construction of an LSP. Figure 3 illustrates this process.

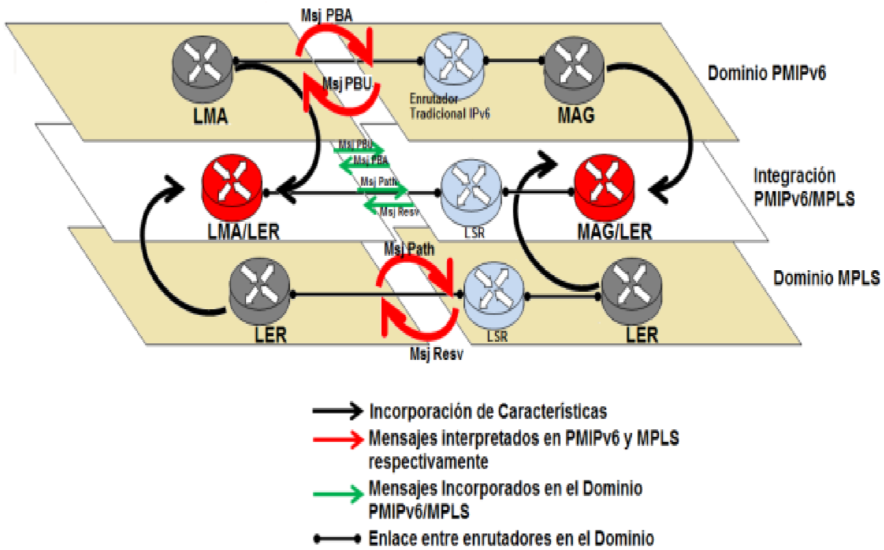

Figure 3. Semantic Integration perspective

In this strategy a different interpretation of the MPLS label fields is not required, it is was not necessary to define a new algorithm (syntax) that allows label switching, adapting the MPLS labels switching functions that allow the construction of a LSP, within the LMA/LER and MAG/LER, is enough, in order to substitute the establishment of PMIPv6 IP-over-IP tunnels.

In the PMIPv6/MPLS domain, the LMA/LER and MAG/LER do not add the tunnel header to the IPv6 packet, in this case, the MAG/LER sends the PATH message to the LMA/LER to start the construction of an LSP, then, the LMA/LER sends a RESV message to the MAG/LER confirming the establishment of the LSP that handles upstream data flow. This process is done the same way in direction LMA/LER - MAG/LER to handle the downstream data flow.

The LMA/LER must register all associated mobile node's address to a specific MAG/LER in its BCE and update the input label in its LFIB, the output label, the input interface and the output interface of the LSP that is being established in direction MAG/LER - LMA/LER. The same way, the MAG/LER records the MNs address in its BUL, providing a network prefix and updating its LFIB for the LSP being established in direction LMA/LER - MAG/LER, completing the bi - directional LSP as shown in figure 4.

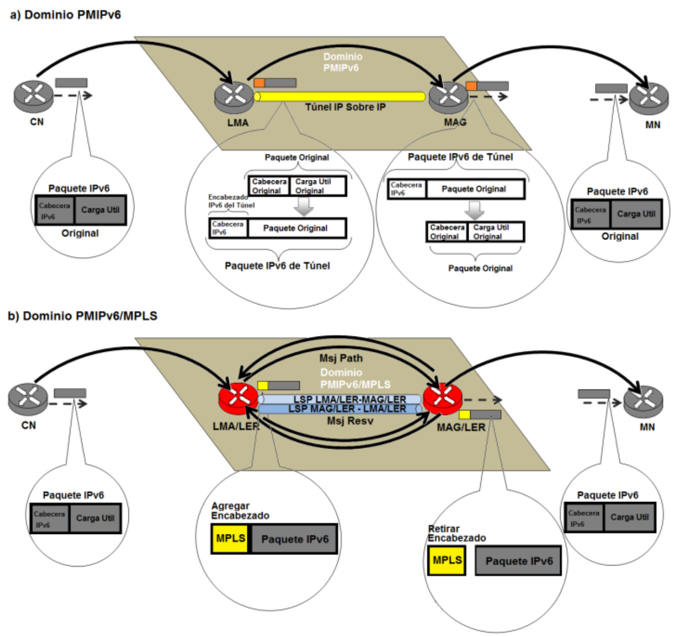

Figure 4. Route construction, PMIPv6 domain vs. PMIPv6/MPLS domain

In the PMIPv6/MPLS protocol stack, adoption of MPLS features on the operation of LMA/LER and MAG/LER, can be seen, it is also important to note that the backbone consists of LSR and not traditional IP routers. PMIPv6 was designed to provide Network-Based Localized Mobility Management (NETLMM), so the MN should not perform mobility related signaling, which is why there is no change in its protocol stack. The Correspondent Node (CN) is not part of this integration and is considered as a node with IPv6 support only.

B. Integration in terms of synchronization

As indicated, the operation of the MAG/LER from the semantic perspective should interpret the PBA message and the PATH message to operate properly, the same way, the LMA/LER must understand the PBU message and the RESV message to build the LSP and allow data arriving at the MN, however, for PMIPv6/MPLS to operate properly, to interpret the messages is not enough, it is essential to develop the strategy from the synchronization standpoint, as described below:

1. A MN within a MAG/LER coverage area, requests association to receive information.

2. When identifying an MN's association event, the MAG/LER module, must synchronize the forwarding of a PBU message to the LMA/LER.

3. When the LMA/LER interprets the PBU message reception event, synchronizes the forwarding of a confirmation with the PBA message.

4. MAG/LER module attends the event and synchronizes the forwarding of the PATH message to LMA/LER, identifying the start of the label switching algorithm which leads to the establishment of the LSP.

5. The LMA/LER module interprets the PATH message event sent by the MAG/LER and responds with a RESV confirmation message, which synchronizes the process of building the LSP in LMA/LER - MAG/LER direction.

6. The LMA/LER synchronizes the forwarding of a PATH message to the MAG/LER.

7. The MAG/LER interprets this event and synchronizes the forwarding of a RESV message to the LMA/LER resulting in the construction process of the LSP in MAG/LER - LMA/LER direction, completing the event of the establishment of bi-directional LSP.

8. Once the bi-directional LSP is constructed, PMIPv6/MPLS (LMA/LER and MAG/LER) entities are ready to send and receive data. Figure 5 illustrate these events.

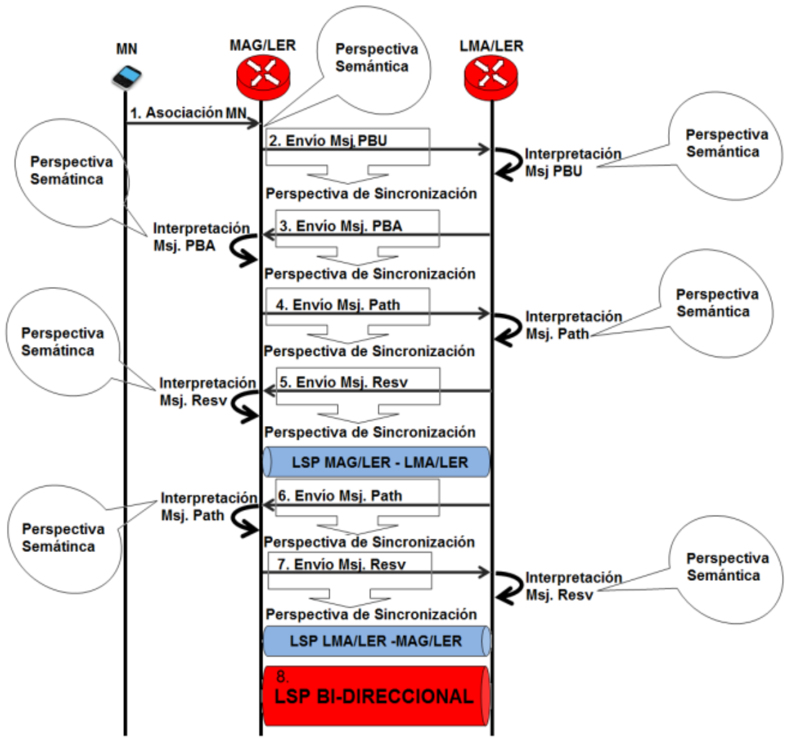

Figure 5. Integration in terms of synchronization

After receiving the PBA message, the MAG/LER does not run the IP-over-IP bi-directional tunnel construction process; on the contrary, it leads to the construction of the bi-directional LSP.

LSP construction was considered from the RFC 3209, and the lifetime of the bi-directional LSP between PMIPv6/MPLS entities is determined by the RSVP-TE protocol (soft state), so the PBU message field that determines IP-over-IP tunnel lifetime (as explained in section 5.3 of RFC 5213), is ignored.

For the setup of the bi-directional LSP, the Data-Driven setup was selected in the first instance, which sets up the path after the MN association with a particular MAG/LER, when the signaling messages forwarding is over (PBU and PBA). This setup method is called Data-Driven LSP and allows MNs to associate afterwards to this MAG/LER, using the mentioned LSP. Figure 6 summarizes this process.

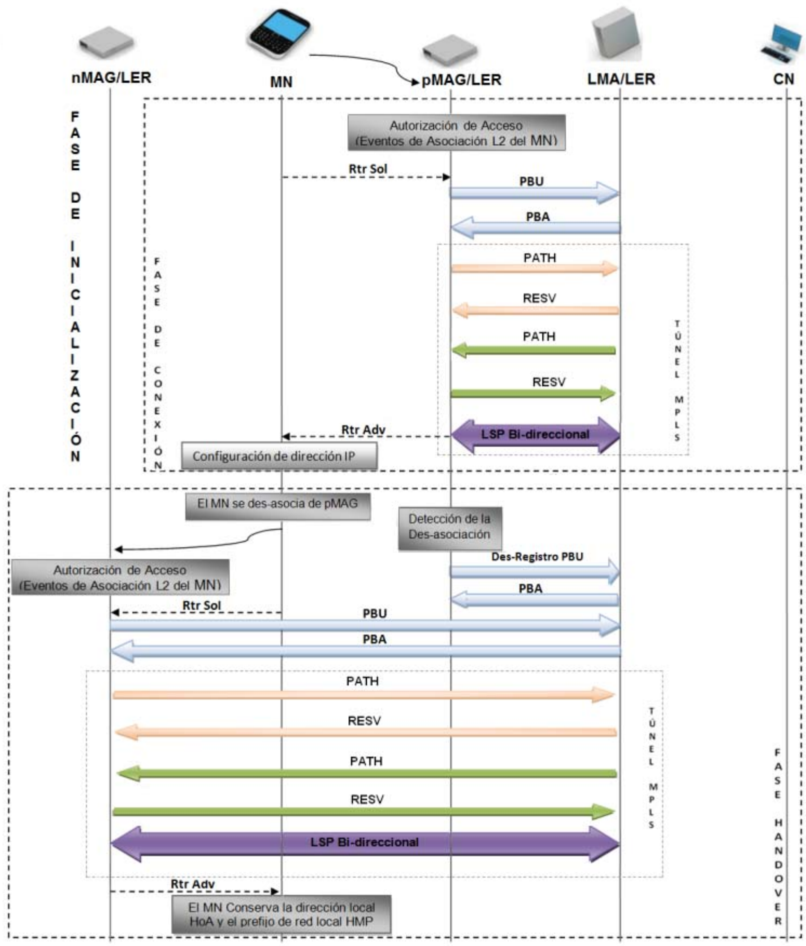

Figure 6. PMIPv6/MPLS events flow, with Data-Driven LSP-setup

From the Data-Driven LSP setup, the Control Driven method was considered for the setup of the bi-directional LSP before the association request sent by a MN to a specific MAG/LER. This setup method is called Control-Driven LSP and the MN that subsequently associate to the MAG/LER can use this LSP. These set up methods are described below. Figure 7 summarizes this process.

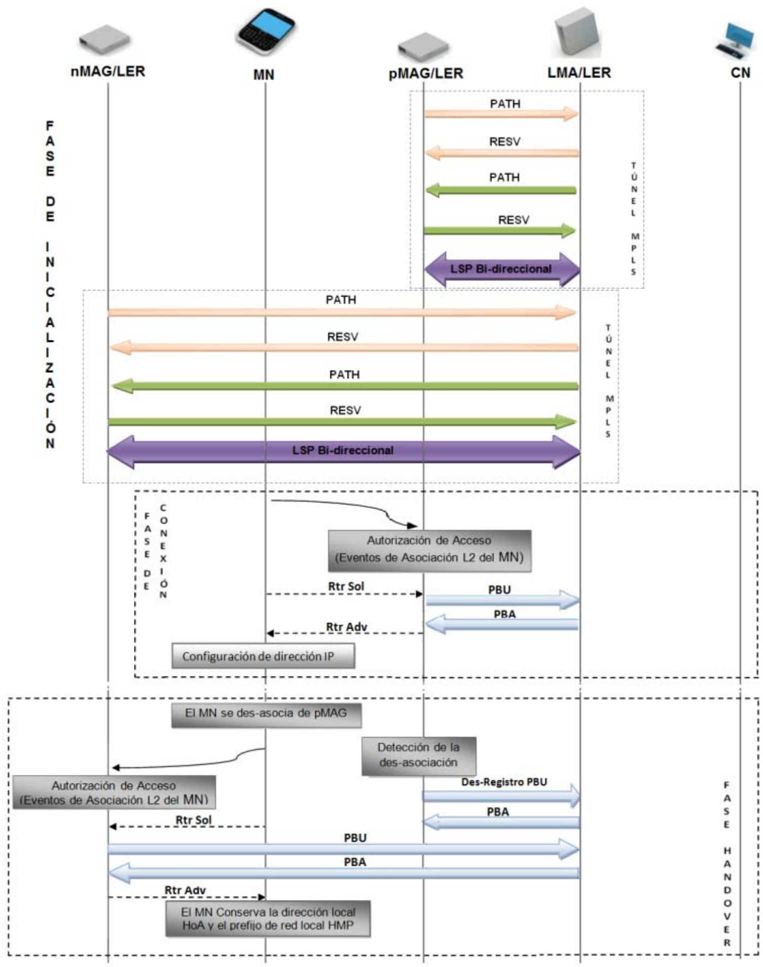

Figure 7. PMIPv6/MPLS events flow, with Data-Driven LSP setup

V. INTEGRATION IN NS-2

The PMIPv6 and MPLS semi-soft Integration is implemented using the free code NIST MOBILE module, distributed by NIST and the extension implemented by RFC 5213 [15], to which the MPLS architecture is incorporated, it is implemented as a separate routing module known as MPLS for NS-2 (MNS, MPLS Network Simulator) [16] and which has been modified to support hierarchical routing necessary for operation in mobile environments [17].

In the script developed in OTcl language, the type of hierarchical routing for the nodes in the network is defined first of all, using the command:

$ns node-config -addressType hierarchical

This command allows the hierarchical module to be added to the list of modules that are loaded when a node is created in the network.

The next step is to load the MPLS module with the command execution:

$ns node-config -MPLS ON

It is important that the MPLS module is added after the hierarchical module, since reversing the commands order, prevents the MPLS module from using directions with hierarchy, generating a routing conflict, since mobile networks in NS-2 are implemented with this routing type, affecting the PMIPv6/MPLS domain integration.

Then, it is necessary to manually add all the nodes that must support these capabilities, to the MPLS nodes list, with the following commands:

set lma/ler [$ns node 1.0.0]
$ns add-to-mpls-list $lma/ler

It is essential to install the LMA agent in this node to support the mobility agent capabilities in PMIPv6; the following command should be used:

set lma/ler_pm [$lma/ler install-lma]

With this, the LMA/LER node provides support to PMIPv6 and MPLS capabilities. Then, a node is created that in turn is added to the list of MPLS nodes, with these commands:

set mag/ler1 [$ns node 1.3.0]
$ns add-to-mpls-list $mag/ler1

In this node, the MAG agent is installed to provide support to PMIPv6 capabilities, with the command:

set mag/ler1_pm [$mag/ler1 install-mag]

This way, the MAG/LER node provides support to the PMIPv6 and MPLS capabilities. Now the RSVP-TE agent must be configured in the network nodes that have MPLS support capabilities, with the command:

$ns configure-rsvpte-on-all-mpls-nodes

To setup the LSP, the Data-Driven or Control-Driven method is chosen through the following commands as appropriate:

$ns enable-data-driven
$ns enable-control-driven

At this point it is necessary to establish the bi-directional LSP through a session between LMA/LER and MAG/LER nodes that establishes the first LSP in direction MAG/LER – LMA/LER and another session between MAG/LER and LMA/LER establishing the LSP in the opposite direction, using the commands:

set ses(1) [$LMA/LER session $mag/ler1 1]
set ses(2) [$MAG/LER session $lma/ler 1]

Finally, the path for each session is set in order to create the LSPs that make the bi-directional LSP. This is done using the following commands:

$ns at 0.2 "$LMA/LER PATH-resv-er $ses(1) 1Mb 50 50 $mag/ler1 1000 5 5 1.0.0_1.3.0"

$ns at 0.0 "$MAG/LER PATH-resv-er $ses(3) 1Mb 50 50 $lma/ler 1200 5 5 1.3.0_1.0.0"

VI. SIMULATION AND ANALYSIS RESULTS

To analyze the impact of the PMIPv6/MPLS integration compared to the PMIPv6 protocol in a micro-mobility environment, two simulation scenarios are proposed. The first scenario considered "baseline scenario", operates with PMIPv6 in its protocol stack, the second scenario maintains the same above structure, but in operates with PMIPv6/MPLS in its protocol stack. Figure 8 represents the nodes distribution in the network.

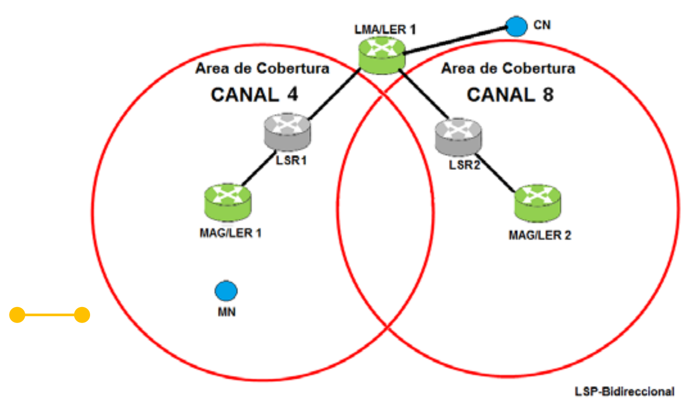

Figure 8. Nodes distribution in the network

Once the simulation process in NS-2 is done, the following graphs were obtained; they summarize the signaling events, the performance of the end to end delay and jitter of PMIPv6, PMIPv6/MPLS Data-Driven LSP and PMIPv6/MPLS Control-Driven LSP, respectively.

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A. PMIPv6

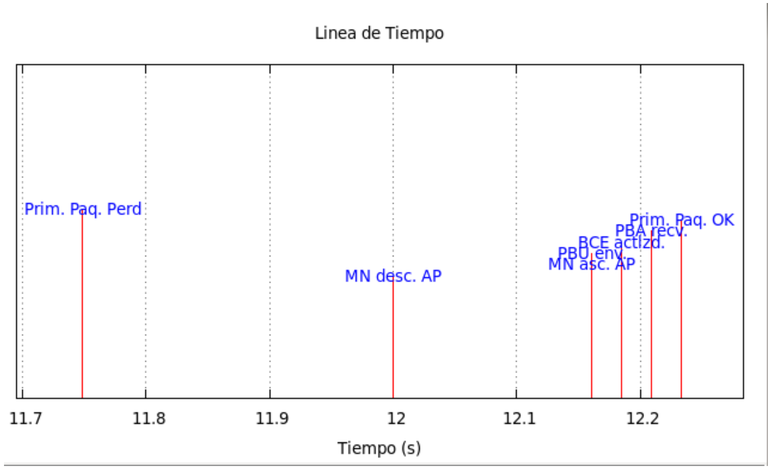

Figure 9. PMIPv6 signaling events

Figure 9 shows in a timeline, the signaling according to the PMIPv6 operation explained in the RFC 5213.

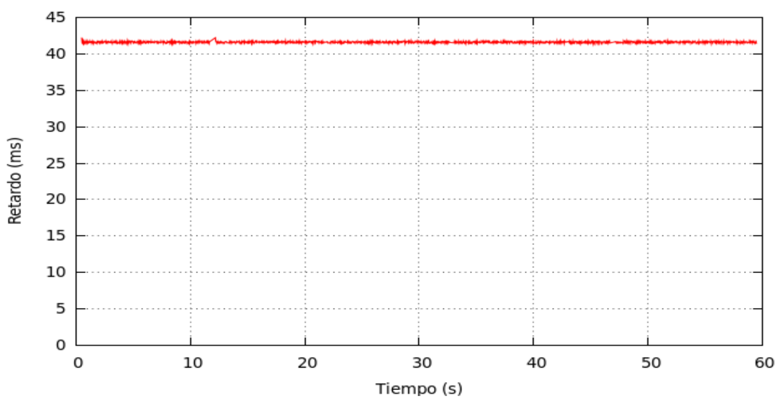

Figure 10. PMIPv6 delay performance

Figure 10 shows that the delay has an average value of 41.60 ms, fulfilling adequately the quality conditions suggested in the ITU recommendation G.1010.

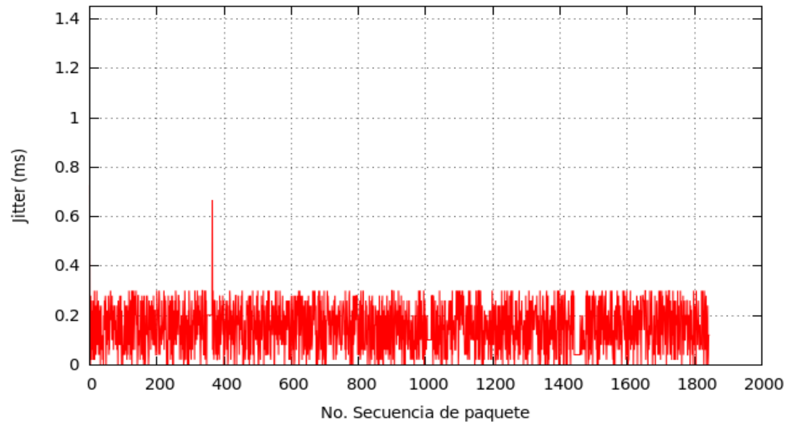

Figure 11. PMIPv6 jitter behavior

Figure 11 shows that the variation delay during simulation takes values between 0 and 0.3 ms, evidencing compliance with ITU-T's G.1010 recommendation, being affected when the handover is carried out due to the packet loss. When packets are lost during a handover, their delay is undetermined because the simulator has departure time information but no arrival time, this is represented by the straight line that should not be interpreted as a constant jitter value, it is only used by the tool to indicate that packets are lost.

The peak seen in the figure represents an increase in delay variation, resulting from the MN connection to the MAG 2 for the first time, requiring a signaling process which introduces additional delays when establishing the IP-over-IP tunnel that allows to reach the LMA.

B. PMIPv6/MPLS Integration-Data-Driven LSP

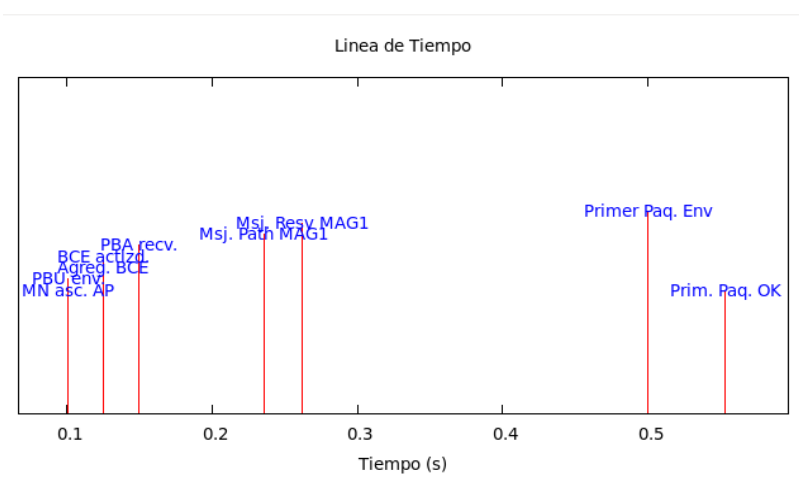

Figure 12. PMIPv6/MPLS Data-Driven LSP signaling events (initialization phase)

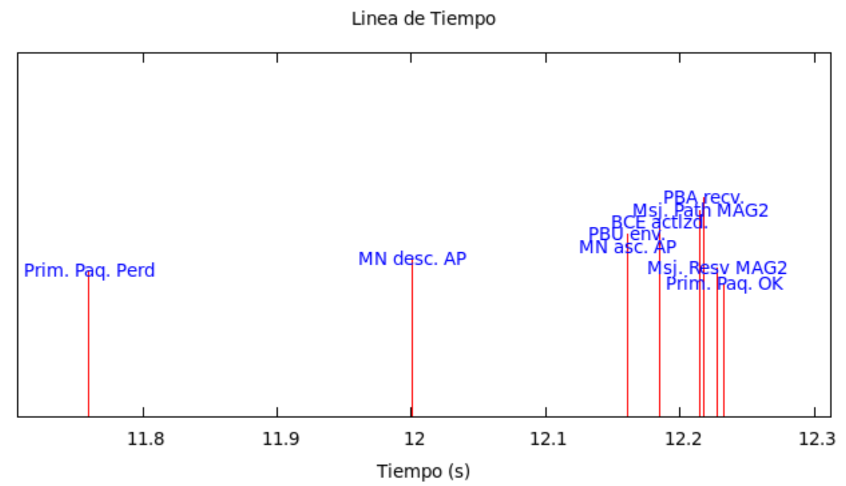

Figure 13. Signaling events in PMIPv6/MPLS LSP-Data-Driven (Handover Phase)

Fig 12. Displays in a timeline, signaling according to the performance of PMIPv6/MPLS-Data-Driven LSP, where LSP setup is executed once the MN performs its association with MAG / LER 1 and Figure 13 shows signaling after a handover process, when the MN is associated with the MAG / LER 2.

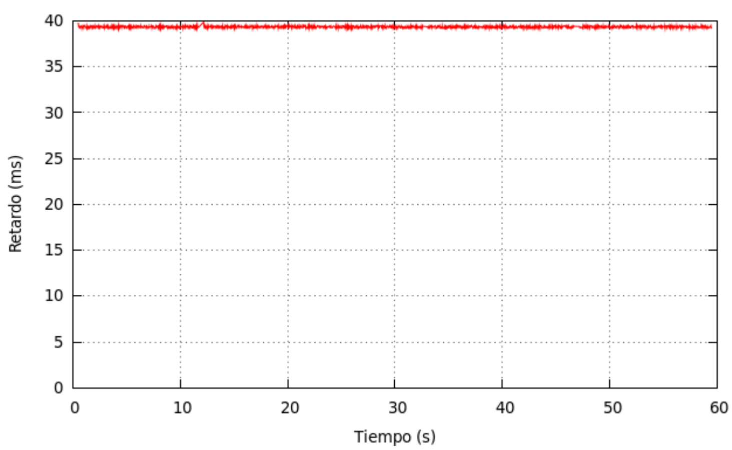

Figure 14. Delay performance in PMIPv6/MPLS LSP Data-Driven

In Figure 14, we see that the delay has an average value of 39.29 ms, reducing the average delay in 2.31 ms when compared to PMIPv6, as a result of replacing the IP-over-IP tunnel for the bi-directional LSP. This delay value corresponds with recommendation G.1010 of the ITU-T.

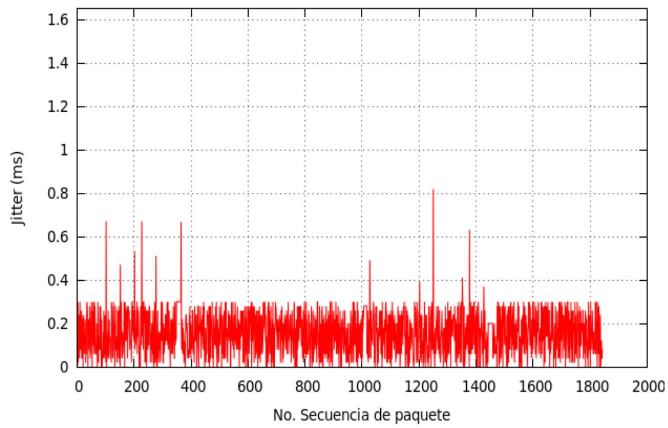

Figure 15. Jitter performance in PMIPv6/MPLS LSP Data-Driven

In Figure 15, it is observed that the delay variation during the simulation behaves similarly to PMIPv6; therefore, its analysis corresponds to what was mentioned in Figure 11. The peaks shown in the graph are below the value suggested in recommendation G.1010 ITU-T and are a product of the priority processing of the messages that maintain the LSP setup (RSVP-TE soft state), which are processed with higher priority than a data packet.

C. PMIPv6/MPLS-Control-Driven LSP Integration

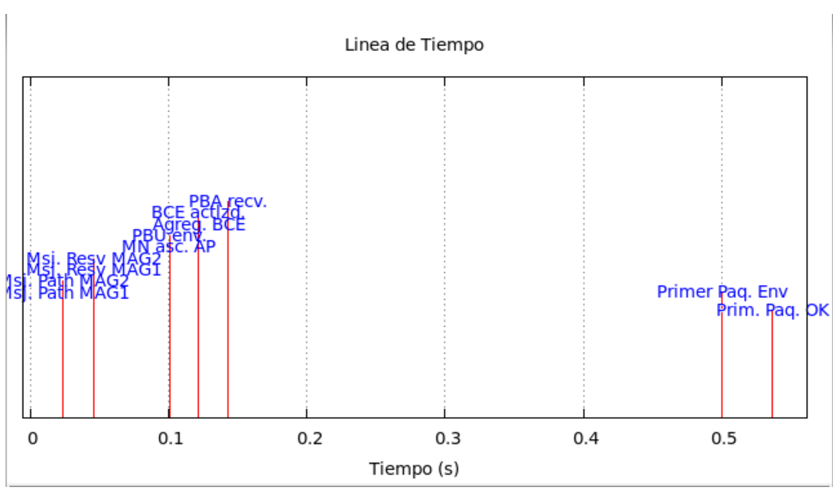

Figure 16. Signaling events in PMIPv6/MPLS LSP-Control-Driven (initialization phase)

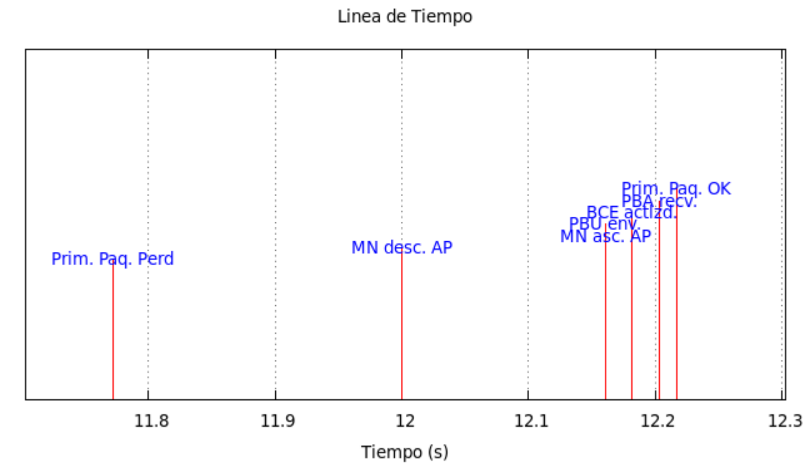

Figure 17. Signaling events in PMIPv6/MPLS LSP-Control-Driven (Handover Phase)

Figure 16 shows in a time line, the signaling according to the performance of the PMIPv6/MPLS line-Control-Driven LSP, where the LSP setup is executed before the MN performs its associations with the MAG/LER1 and Fig. 17 shows the signaling after a handover process, when the MN is associated with the MAG / LER 2, where the LSP setup does not take place, because it was done previously.

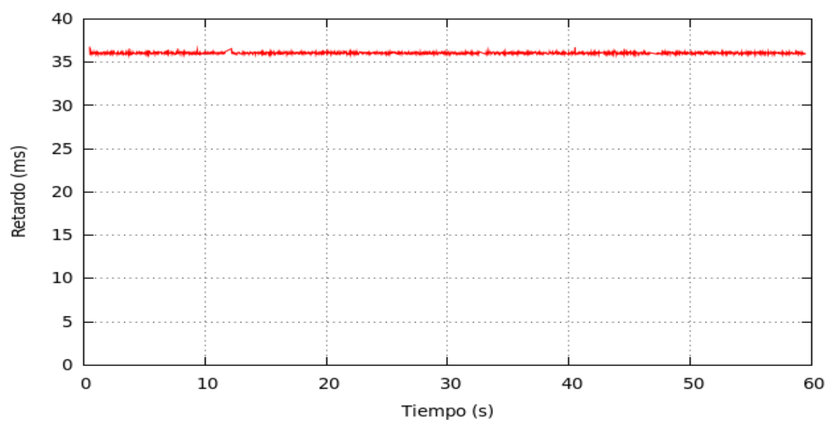

Figure 18. Delay Performance in PMIPv6/MPLS LSP -Control-Driven

In Figure 18, we see that the delay has an average value of 36.08 ms, thus reducing the average delay in 5.5 ms compared with PMIPv6 and 3.2 compared with PMIPv6/MPLS LSP -Data-Driven; resulting from replacing the IP-over-IP tunnel for the bi-directional LSP, which carries signaling messages and data. This delay value meets with what is suggested in recommendation G.1010 of the ITU-T.

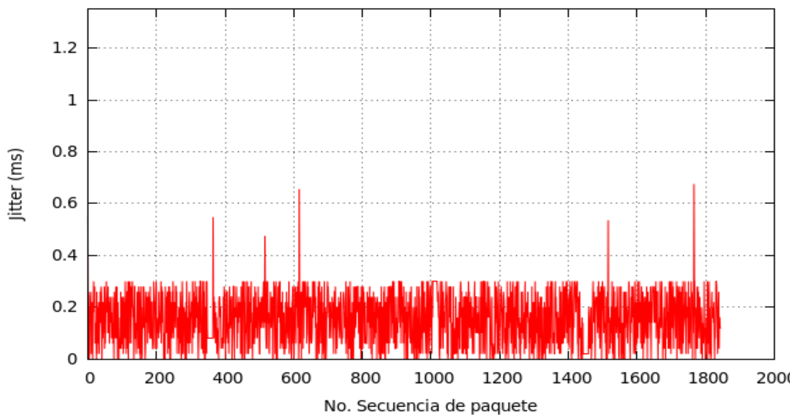

Figure 19. Simulation result

In Figure 19, it is observed that the delay variation during the simulation has a performance similar to PMIPv6. The analysis of the graph corresponds to what is expressed in figure 15.

The results obtained are summarized in Table I.

TABLE I

INTEGRATION PERFORMANCE RESULTS

	Escenarios de simulación		
Características	**Escenario 1 PMIPv6**	**Escenario 2 PMIPv6/MPLS**	
	Escenario Base	**Caso 1 *LSP-Data-Driven***	**Caso 2 *LSP-Control-Driven***
		Caso 1-a	**Caso 2-a**
Movimiento del MN	**Controlado**	**Controlado**	**Controlado**
Número de HO	3	3	3
Duración promedio del HO (Seg.)	0,4263	0,4148	0,4032
Paquetes Perdidos durante el HO	42	41	40
Promedio de Paquetes Perdidos durante un HO	14	13,66	13,33
Throughput durante el HO	0 Kbps	0 Kbps	0 Kbps
Retardo durante el HO	Indeterminado	Indeterminado	Indeterminado
Jitter durante el HO	Indeterminado	Indeterminado	Indeterminado
Porcentaje de Paquetes Perdidos	2,277	2,223	2,169
***Throughput* promedio**	64 Kbps	64 Kbps	64 Kbps
Promedio Retardo Extremo a extremo (mseg.)	41,605	39,29	36,08
Jitter	0 - 0,3	0 - 0,3	0 - 0,3

Table I summarizes the results obtained during the simulation. It is observed that the PMIPv6/MPLS Integration shows a better performance than PMIPv6, also LSP -Control-Driven compared to LSP-Data-Driven, shows in a better way the impact of the integration in a micromobility environment, presenting improvements in the reduction of the end to end delay, in the time and number of packets lost during the handover, having a positive impact on the network's performance.

VII. CONCLUSIONS.

The semi-soft integration scheme was selected in this work, since it allowed an integration at the protocol level that provides a coexistence solution and joint operation between PMIPv6 and MPLS. The level of complexity of this integration was moderate with respect to the implementation and execution time, presenting an acceptable efficiency in network operations.

Replacing the PMIPv6 IP-over-IP tunnel for the PMIPv6/MPLS bi-directional LSP, reduces the end to end delay because the routers must process a fixed size label and of shorter length compared with the IPv6 heading, speeding up the process of sending packets.

The integration at the protocol level using a semi-soft scheme, between mobility protocols and MPLS, offers in a high mobility domain, the possibility of having QoS mechanisms and TE support, which can provide users with an adequate quality of service.

In the PMIPv6/MPLS integration, the bi-directional LSP and LSP-Control-Driven setups significantly reduce the duration of the handover and therefore packets lost during this process, since both data and signaling packets are sent by bi-directional LSP, compared with the LSP Data Driven setup.

The introduction of MPLS features in an IPv6 micromobility environment does not alter the level of jitter and end-to-end delay as defined by recommendation G.1010 of the ITU-T, allowing services and applications in real time to have optimum quality levels and therefore meet the requirements expected by the same.

The PMIPv6/MPLS integration improves overall network performance in comparison to a PMIPv6 scenario, showing a reduction of 5.5 ms at the end to end delay and of 2.3 ms in the duration of the handover, enabling to reduce by 2 the packets lost during this process. This shows the positive impact of the introduction of MPLS in a PMIPv6 domain and therefore an IP micromobility environment.

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