Design Considerations for Introducing Micromobility in MPLS

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Abstract

In this paper we deal with the design issues that need to be considered when creating a mobility protocol for MPLS. We explain what decisions need to made when the connection-oriented static MPLS architecture is to be combined with the connectionless and dynamic mobile IP protocol. In addition to the outlining of the design considerations, we describe a protocol that is based on the interworking of MPLS with Hierarchical Mobile IPv6 (HMIPv6) in an “overlay” fashion. The combined protocol is explained with the use of detailed signaling diagrams.

1 Introduction

Next-generation mobile networks are evolving towards network architectures relying entirely on IP. These networks have to support future IP traffic, namely new multimedia services and real time applications, while providing an effective mobility management mechanism to cope with increasingly mobile users. This new mobility management approach will be a combination of the existing Mobile IPv4 (MIPv4) [1] and Mobile IPv6 (MIPv6) [2] with the mobility mechanisms already in place in cellular wireless networks like GSM and UMTS. This future internet can be called the “Mobile Internet” [3]

In addition to global connectivity, next-generation mobile networks will have to provide quality of service guarantees such as assured bandwidth, low rate of packet loss, low delay and jitter in order to satisfy the specific qualitative demands of the envisioned services.

The distinguishing feature of Multiprotocol Label Switching (MPLS) [4] is the ability it offers to users to specify, and tightly control, the communication paths based not only on hop information but also on a wide range of Quality of Service (QoS) parameters and policies. Given the tremendous increase in the use of wireless devices to access the Internet and multimedia services, concerns related to providing and maintaining specific service levels arise.

It is therefore reasonable to consider an extension of MPLS into the mobile domain.

There has been significant research in the past few years tackling the issue of the combination of MPLS with mobile protocols. The related work is spanning all incarnations of mobile IP, starting with MIPv4 and hierarchical MIPv4 [5][6][7], MIPv6 [8] and HMIPv6 [9,10]. The use of MPLS in Radio access networks has been also examined in [11] and [12].

The main goal of this paper is to provide some guidelines and examine what protocol design decisions must be made when introducing mobility into MPLS. We illustrate these principles by overlaying hierarchical mobile IPv6 (HMIPv6) [13] over MPLS to create a Micromobility-enabled MPLS network. The overlay paradigm was chosen for its simplicity and because it lends itself well to the problem in question; namely how to organize and coordinate the operation of two protocols on two different layers of the protocol stack.

The design conclusions reached in the overlay environment can be used without many modifications on cross-layer designs as well. This work stems and builds on our previous work on mobility-enabled MPLS [9][12] which proposed and examined a framework for the cross-layer integration of MPLS and HMIPv6 for use in a Radio Access Network.

The rest of the paper is organized as follows. Section 2 enumerates the issues the protocol designer needs to consider and justifies the assumptions and basic requirements used to develop the proposed solution. Section 3 details the operation of the resultant proposed overlay HMIPv6-MPLS framework. Special attention is given to the data delivery processes. Section 4 summarizes the contributions of this work

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‡ We give reference only to the initial works in each category. The proposals are too numerous to be listed here.
2 DESIGN CONSIDERATIONS

We distinguish between an overlay and an integrated framework at the level of interaction between the different architectures. In the overlay method, HMIP, and MPLS remain as separated as possible, without having any merged processes or signaling. Simple events or processes may then require additional messages or additional interaction between architectures to achieve the same result. Therefore, overlay frameworks usually introduce more latency and overhead. On the other hand, an integrated framework merges and relates many of the functions of its composing members. There exists a tradeoff between the simplicity of operation and the optimization and system performance. In this work we are focusing on the overlay paradigm. The process of taking design decisions is the same in both cases.

2.1 Radio Access Network

The basic topology for this research work is a Radio Access Network (RAN) as shown in Figure 1.

![Figure 1. Radio Access Network (RAN)](https://example.com/figure1.png)

The RAN consists of at least three layers of label switched routers (LSRs). The edge components of the architecture are the radio access routers (RAS), which are the first IP aware devices of the network seen from the mobile terminal. One, or more, base stations (BS) are attached to a RAS (or integrated into it) and provide the physical radio link to the mobile node (MN). Several RASs are interconnected to one or more Edge Gateways, which in turn provide access to outer (backbone) networks including other RANs. The RASs and the EGWs are linked through a network of MPLS-capable routers. We assume that all routers in the RAN can act as mobility agents (MA) to support mobility management based on hierarchical mobile IP.

2.2 Design Assumptions and Specifications

The design of the MIPv6- and HMIPv6-based MPLS frameworks is based on the following assumptions:

- All MPLS nodes in the RAN are mobility-enabled
- Mobile IP procedures for agent discovery, mobile node registration, and routing remain unchanged.
- Mobile nodes have no MPLS related protocols in their stack
- Only point-to-point LSPs are considered.
- MPLS operates in the following modes:
  - Downstream on demand: An LSR explicitly requests a label binding for an FEC from its next hop for that particular FEC.
  - Ordered control: An LSR only binds a label to a particular FEC if it is the egress for that FEC, or if it has already received a label binding for that FEC.
  - Conservative retention: An LSR discards any label bindings from downstream routers if those routers are not its next hop (or no longer its next hop) for a particular FEC. This retention mode requires an LSR to maintain fewer labels.
- There is a unique label per LSP (i.e., there is no label merging). An LSR can support label merging if it has bound multiple incoming packets to an FEC that uses a single outgoing label. Once packets are transmitted using this method there is no way of differentiating them in terms of their source (input interface or incoming labels). Without label merging, if two packets for the same FEC arrive with different incoming labels they must be forwarded with different outgoing labels.
- No aggregation allowed (i.e., more than one LSPs for the same FEC is acceptable). Aggregation is the procedure of binding a single label to a union of FECs; it is itself an FEC (within a domain).
- In our framework we would like to be able to have the finest granularity of label switched paths. For that reason we allow more than one LSPs for the same FEC from the same end node. FECs are defined on end-node pairs and QoS requirements.
- No penultimate hop popping is considered

Besides the configuration of MPLS, other design issues need to be considered. We explore these issues by varying the total number of nodes connected to the RAN of Fig. 1 and the percentage of traffic traversing the network and getting through the EGW.

2.2.1 LSP Setup Methods.

Label switched paths in general can be established using two methods:
Data driven LSPs - established only if data needs to be transferred between nodes.

Control driven LSPs - established before any data packets arrive, based on information from a routing protocol or explicit information from a connection list.

![Figure 2. Number of messages for data-driven UD method](image)

![Figure 3. Number of messages for data-driven DoD method](image)

Usually, the control-driven method is used with the Unsolicited Downstream (UD) mode of label distribution, while the data-driven method is used with either the UD or the Downstream On-Demand (DoD) method of distribution. In our simulations of the radio access network under consideration (see Figure 1), the control-driven method required 800 LSR-to-LSR mapping messages to distribute 320 labels.

In this case the LSPs cover only the 25 fixed nodes of the RAN using label aggregation (i.e., one label per FEC). The data-driven, downstream on demand (DoD) method, required 328 messages to set up 76 unique LSPs (38 bi-directional connections) for 25 RAN and 10 mobile nodes. The data-driven, unsolicited downstream (UD) method required 245 messages for the same number of nodes and LSPs. A special control driven case establishing three explicit routed LSPs per edge router for the 25 RAN nodes needed 6286 messages for 1100 LSPs. All the data above were obtained for a scenario where ten percent of the total traffic was directed through the EGW.

The number of LSP setup messages, for different percentages of traffic going through the EGW and for a larger number of nodes, are displayed in Figure 2 and Figure 3 for the data-driven UD and DoD methods respectively. The control driven method’s numbers do not change with either the percentage of EGW traffic or the number of mobile nodes.

![Figure 4. Overhead for data-driven UD method](image)

![Figure 5. Overhead for data-driven DoD method](image)

It takes sixty (60) nodes at 20% EGW traffic or 140 nodes at 60% EGW traffic in the data-driven UD method to reach the same number of messages as the control driven method. These numbers are halved in the data-driven DoD method because it uses two
messages instead of one in the LSP setup. However if the control driven method was also using the DoD mode, the number of messages required would double and the DoD method would have the same benefits as the UD method. For high values of EGW traffic the data driven method is the best because it re-uses existing labels and does not set up LSPs for not required routes.

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2.2.2 Binding Update – LSP Setup Relationship

The relationship between the home agent binding update procedure and the home agent-mobility agent LSP setup can take many forms. Previous work has considered two methods for combining them: sequential (Figure 7a) and encapsulated (Figure 7b).

In the sequential method the two procedures are initiated one after the other, with the LSP setup following a successful binding update (exchange of BU and BU Ack). In the encapsulated method the home agent initiates the LSP setup after it receives the binding update message from the mobile node. However, a binding update acknowledgement message is not sent back until the LSP setup is complete.

Simulation of the two methods provides the data in Table 1. Here we measure the latency of procedures 4 to 7 and the associated lost packets. The sequential method provides less disruption time, which translates to less UDP packets lost. TCP packet loss is similar in both cases because TCP sources stop sending as soon as they recognize missing acknowledgements.

Table 1. Encapsulated vs. Sequential LSP setup method simulation results

<table>
<thead>
<tr>
<th>Method</th>
<th>Disruption Time (sec)</th>
<th>Dropped TCP Packets</th>
<th>Dropped UDP Packets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encapsulated</td>
<td>0.05</td>
<td>22</td>
<td>133</td>
</tr>
<tr>
<td>Sequential</td>
<td>0.025</td>
<td>20</td>
<td>79</td>
</tr>
</tbody>
</table>

Conclusion: It is our opinion that a MIP operation should not be dependent on an MPLS operation. In addition, if the LSP setup is data-driven, an HA-MA path should only be setup when data is communicated. Therefore we choose to use the sequential method.
2.2.3 Binding Update Acknowledgement

Most of the current proposals use binding acknowledgement messages during registration, even though they are not a requirement of the mobility protocol.

**Conclusion:** We believe that LSPs should be set up after a binding update acknowledgement is sent back from the correspondent node, so as to avoid setting up LSPs for connections that are not going to be accepted.

Not setting the LSP before an acknowledgement is also helpful in an Integrated Services QoS environment. Though they are not a requirement of the mobility protocol, they are often utilized to make sure that any LSPs to the mobile node are set up only after the service level agreements between the different domains and the mobile node are fully negotiated and accepted. Even though we do not address them in this work, security considerations are also a factor for expecting an acknowledgement from the home agent or other nodes before proceeding.

3 Hierarchical Mobile IP - MPLS Overlay Framework

The following subsections explain the protocol based on the specifications described above. We consider an operating scenario in which only MPLS is used as the transport. This would be the case if mobility was added in an already existing MPLS network.

3.1 HMIPv6 over MPLS

![Figure 9. Data Driven HA-MA LSP](image)

### 3.1.1 Correspondent Node Initiates Transmission

The basic signaling diagram for this scenario is shown in Figure 9.

When a correspondent node initiates communication toward a mobile node it first examines its binding cache for an entry of mobile node’s new CoA. If the correspondent node does not have an entry it sends the packet to the mobile node’s home address. The correspondent node’s label edge router (MA10) cannot send that packet all the way to the mobile node’s label edge router, (which also happens to be its HA - MA11) using legacy IP, but has to set up an LSP to it and use MPLS for all data packets destined to the mobile node. The label request will be for the mobile node’s home address. The HA will respond with a label mapping and the LSP will terminate at it. At the end of this operation the correspondent node’s LER will have an outgoing label for sending packets to the mobile node and the mobile node’s LER an incoming label for receiving packets for the mobile node.

![Figure 8. Reference Network](image)
When a labeled packet arrives at MA11 it will use the incoming label value as an index to look up its label table. Since the out label and out port are empty, the router strips off the label and sends the packet to the IP layer. At the IP layer the HA will try to forward the data packet to the mobile node. If the mobile node is at its home network the home agent will not intercept the packet and it will be delivered to the mobile node directly. However, if the mobile node is in a foreign network, the home agent will have an entry for it in its binding cache. The CoA in the binding cache will be that of MA0.

The home agent uses the RCoA as a forwarding equivalence class (FEC) to find an entry in the FEC-to-NHLFE (FTN) table. The referred entry in the Next Hop Label Forwarding Entry (NHLFE) 2 table will initially have no outgoing label, meaning that no LSP has been setup between the home agent (MA11) and the MAP (MA0). The home agent will initiate an LSP setup to the mobile node’s CoA for this connection.

After this set of actions, the home agent has two entries into its tables, one for an LSP from the CN to HA (MA10 to MA11) and the other from HA to MAP (MA11 to MA0). The MAP also has an LFIB entry for the mobile node.

The packet is delivered from HA to MAP along the recently set up LSP by label swapping at the intermediate LSRs. The first time a labeled packet arrives at the MAP, the router has to go through the process of associating the received label with an RCoA. Again, since no path has been set up, the out-label/out-port entries in the table will be empty sending the packet to the IP layer for further processing. At the MAP’s binding cache the RCoA will be related to the mobile node’s LCoA. The packet will be taken again by the MPLS protocol and a new LSP will be set up toward the mobile node with the LCoA as the FEC.

Intermediate LSRs will also have updated entries in their LFIB table. The edge router whose LCoA was used by the mobile node will have an entry in its LFIB table linking the label it distributed upstream with an entry showing that the label needs to be popped and delivered using IP.

2 We will refer to the modified NHLFE table as Label Forwarding Information Base (LFIB).
In Figure 10 and Figure 11 we see that the home agent and the MAP cannot directly swap one label for another (if they act as the egress router) because their MPLS modules do not communicate directly with Mobile IP. For that reason they have to go through a Label Pop, a binding cache association, and a Label Push every time a packet is sent to them from the correspondent node. The intermediate LSRs do not have to go through this procedure because they are not edge routers and do not deal with unlabeled packets. They will swap the label and the packet will eventually arrive at MA5 where the label will be popped and the address associated with the FEC will be used to send the packet to its final destination.

### 3.1.2 Mobile Node Initiates Communication

When a mobile node sends packets to a correspondent node, it sends the packets directly – without using the home agent. At the beginning of the communication MA5 will have to create an LSP to the correspondent node’s LER (MA10) before it can forward any packets. Figure 12 shows the details for this scenario.

The LSP will comprise of {MA5, MA3, MA0, MA11, MA2, MA9, MA10}. All intermediate LSRs will just have to swap labels. The edge routers MA5 and MA10 will have to Push and Pop the labels respectively. At the end of the process the edge routers’ tables will look like:

<table>
<thead>
<tr>
<th>Input I/F</th>
<th>Input Label</th>
<th>FEC</th>
<th>Operation</th>
<th>Out I/F</th>
<th>Out Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>LCoA</td>
<td>Pop</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>1</td>
<td>31</td>
<td>LCoA</td>
<td>Pop</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>CN</td>
<td>Push</td>
<td>1</td>
<td>40</td>
</tr>
</tbody>
</table>

### MN’s LER – MA5

<table>
<thead>
<tr>
<th>Input I/F</th>
<th>Input Label</th>
<th>FEC</th>
<th>Operation</th>
<th>Out I/F</th>
<th>Out Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>--</td>
<td>--</td>
<td>MN1</td>
<td>Push</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>--</td>
<td>--</td>
<td>RCoA</td>
<td>Push</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>CN</td>
<td>Pop</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

If bi-directional LSP setup is used, the LSP setup process can be initiated by either the mobile node’s LER or the correspondent node’s LER. Use of bi-
directional LSP is also an implementation decision and depends on the type of traffic in the LSP. If the mobile node only downloads or only uploads data, then traffic is asymmetric and a bi-directional LSP with the same characteristics upstream and downstream makes inefficient use of resources.

In a mobile environment LSP setup and data delivery are of course complemented with appropriate handoff procedures. Details on handover operation in HMIPv6-enabled MPLS network can be found in [9] for the integrated and [10] for the overlay framework.

4 Conclusions

In this work we define the issues that need to be taken into account when introducing mobility into MPLS. The paper presented all the design considerations and justified certain decisions through analysis or simulation.

Based on this design conclusions we describe a framework that integrates Multi-Protocol Label Switching (MPLS) and Hierarchical Mobile IPv6 (HMIPv6) in an overlay fashion. The design conclusions reached in the overlay environment can be used without many modifications on cross-layer designs as well. Detailed operation signaling diagrams as well as forwarding table contents were presented.

In conclusion, we find that MPLS, when paired with a suitable mobility protocol can function well in a radio access network and provide the same benefits it offers when used in wired networks.

References


