Supporting Mobility Events within a Hierarchical Mobile IP-over-MPLS Network

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***Abstract*— This paper examines mobility events, and particularly handovers in an overlay environment, where Hierarchical Mobile IP is operating over MPLS. The overlay operation is examined in detail under two scenarios and a comprehensive explanation of the operation of intra- and inter-cell handovers is presented. Furthermore, it improves on existing methods of MIP-MPLS interworking first by defining a simple framework based on Hierarchical Mobile IPv6 (HMIPv6), and second by outlining the relevant protocol design aspects.**

***Index Terms*— MPLS, Hierarchical Mobile IPv6, Micromobility, Handover.**

I. Introduction

The evolution in mobile networks has given rise to several different yet complementary access networks such as second and third generation wireless cellular (2G/3G), wireless local area networks (WLAN), and high altitude and satellite networks that offer a broad range of services targeted towards diverse subscriber needs. IP-based wireless networks are a research area of importance since the networks proposed for the latest releases of Universal Mobile Telecommunications System (UMTS) and the next generation (4G) of wireless networks are all-IP based. To provide satisfactory services to the customers, handover delays, control messages and radio link inefficiencies need to be reduced. Innovative interfaces and smaller cells are solutions proposed to address these problems. From a signalling point of view, smaller cells mean increased traffic when legacy mobility protocols are used. However, in IP-based networks micro-mobility can be handled by hierarchical mobile IP (HMIP) since HMIP reduces the amount and scope of signaling traffic during handovers. The increased requirements of an IP-based radio access network (RAN) can be met when the scalability and reduced latency of HMIP is combined with the switching performance and traffic engineering capabilities of multiprotocol label switching (MPLS). The distinguishing feature of MPLS 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.

We propose a framework for micro-mobility enabled MPLS, called *Overlay MMPLS*. The goal of this paper is to explain how mobility can be introduced, and especially how handovers can be handled, in Overlay MMPLS. The framework creates a micromobility-enabled MPLS network, using hierarchical mobile IPv6 (HMIPv6). We combine the two protocols in an overlay fashion since we believe this is the simplest form of interaction and operation. In addition, it does not involve any changes in the existing protocols and its field deployment can be gradual. This work builds on, and extends our previous work [5] [6] which proposed and examined a framework for the integration of MPLS and HMIPv6 for use in a Radio Access Network.

The rest of the paper is organized a follows. Section II provides brief background information on the major protocols and architectures. Section III presents the design issues that need to be considered during the development of a framework for the interaction of MPLS and hierarchical mobile IP. Section IV presents our proposed overlay HMIPv6-MPLS framework. Section V details the operation of intra- and inter-cell handovers in the resultant framework. Section VI discusses related work and Section VII summarizes the contributions of this work.

II. Background

A. Multiprotocol Label Switching

MPLS [1] is a packet forwarding technology that assigns packet flows to label switched paths (LSPs). Packets are classified at the network edge based on forwarding equivalence classes (FECs). FECs summarize essential information about the packet such as destination, precedence, VPN membership, QoS information, and the route of the packet chosen by traffic engineering (TE). Based on the FEC, packets are labeled, and then transported over a label switched path. Packets belonging to the same FEC get similar treatment by all intermediate nodes in the path. MPLS operates between layer two (data link) and layer three (network) of the protocol stack, thus it is referred to as a 2.5 layer architecture. To forward an unlabeled packet, MPLS first relates the FEC with an entry in its next hop forwarding equivalence class table (NHLFE).

This paper is an expanded version of "Handover Operation in Mobile IP-over- MPLS Networks," by Vasos Vassiliou, which appeared in the Proceedings of the Fifth IFIP Networking Conference (NETWORKING 2006), Coimbra, Portugal, May 2006, LNCS 3976, pp. 568579. © 2006 IFIP

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This is done in the FEC-to-NHLFE (FTN) table. The NHLFE table contains the next hop, the operation to be performed on the packet (pop, push, swap)[1] and a new label (if necessary). In a practical implementation the NHLFE also includes the incoming label of a packet so that it can handle labeled packets as well. The resulting table is called the label forwarding information base (LFIB)

B. Mobile IP

Mobile IP (MIP) allows a mobile node (MN) to move from one link to another without changing the mobile node's home IP address [2]. A home address is an IP address assigned to the mobile node within its home subnet prefix on its home link. Packets may be routed to the mobile node using this address regardless of the mobile node's current point of attachment to the Internet, and the mobile node may continue to communicate with other nodes (stationary or mobile) after moving to a new link. While a mobile node is attached to some foreign network, it is also addressable by one or more care-of addresses (CoA) assigned by a router in the foreign network (Foreign Agent). When away from home, a mobile node registers its care-of addresses with a router on its home link; requesting this router to function as the home agent (HA) for the mobile node. The HA intercepts, encapsulates, and forwards packets to the mobile node through its registered CoA.

C. Hierarchical Mobile IP

Hierarchical Mobile IP (HMIP) is a micro-mobility management model. Its purpose is to reduce the amount of signaling to correspondent nodes and the home agent and improve the handoff speed performance of mobile IP. HMIPv6 [3] is based on MIPv6 [4] and introduces a new entity called the Mobility Anchor Point (MAP), and minor extensions to the mobile node and home agent operations. The major idea is that the mobile node registers the MAP's CoA with its home agent. Therefore, when the mobile node moves locally (i.e. its MAP does not change), it only needs to register its new location with its MAP. Nothing needs to be communicated with the home agent or any other correspondent nodes (CN) outside the RAN. By using this method, signaling is contained in a smaller area, does not overwhelm the core network and the time to complete the location update is smaller.

III. Framework Design Considerations

A. Overlay and Integrated Frameworks

In order to provide the proper mechanisms for the interworking of Mobile IP and MPLS we need to define first the basic framework of operation. There exist two methods: ***a) Integrated*** and b) ***Overlay***.

[1]Push is the process of inserting a label into an unlabeled packet. Swap is the process of changing a label in an MPLS header at an LSR. Pop is the process of removing the Label at the egress router

We distinguish between an overlay and an integrated framework at the level of interaction between the different architectures. An *integrated framework* merges and relates many of the functions of its composing members, thus creating a new protocol with combined data structures and signaling. Usually, such combined operation is more optimized and more efficient.

On the other hand, in the *overlay method* the two architectures (in our case HMIPv6 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. However, it is understandable that since existing protocols remain unchanged, then the overall deployment is faster and the resulting system is simpler in its operation.

There exists a tradeoff between the simplicity of operation and the performance of the system. In this work we opt for simplicity and we consider the overlay method of combining Mobile IPv6 and MPLS.

B. Network Topology

The proposed mobility-enabled MPLS combined architecture is envisioned to be used to provide mobility options to an established MPLS domain, or to be used as an access network extension of a larger infrastructure, where MPLS is used as the forwarding architecture. The former could be the case of an enterprise extending its network with wireless network solutions. The latter could be the case of using MPLS in the UTRAN of a GPRS or UMTS network. In both cases, we recognize the need to use a micro-mobility protocol like HMIPv6 in order to better manage the changes in the local domain.

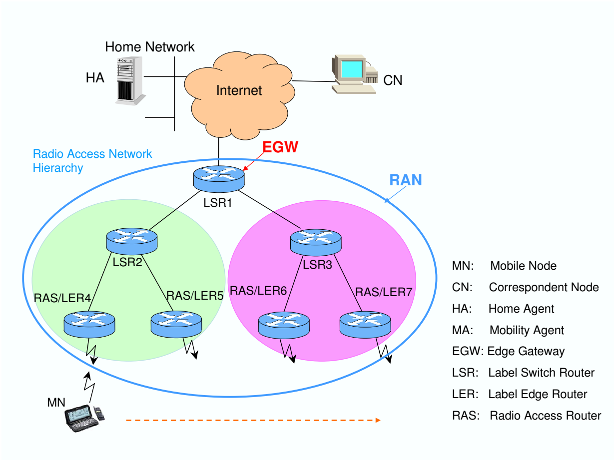

Fig. 1. Mobile MPLS Radio Access Network

The basic topology considered for this research work is a Radio Access Network (RAN) as shown in Figure 1. The RAN consists of two or more layers of label switched routers (LSRs) to make sure that HMIP provides any benefits. The edge components of the architecture

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are the radio access routers (RAS), which are the first IP and MPLS 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 routers. We assume that all edge routers can act as mobility agents (MA) to better support mobility management based on hierarchical mobile IP. The addition of more mobility agents in the RAN can benefit the operation of HMIP, but must be made carefully to avoid an increase in processing times. The location of such agents can be found optimally using [9].

The design of the reference network has been based on network architectures used by well-established providers and was also influenced by traffic engineering considerations as these are described in [7]. Enhancements to the network may include additional layers of hierarchy and more complex interconnection like full mesh or double homing.

C. Design Assumptions and Specifications

To facilitate the best cooperation between HMPv6 and MPLS and to enable the network administrators to have control at a fine granularity level we make certain assumptions and define some specifications.

The design assumptions of the HMIPv6-MPLS overlay framework can be found in [8]. An abbreviated list is included here:

- Edge MPLS nodes in the RAN are mobility-enabled
- Mobile IP procedures for agent discovery, address autoconfiguration, 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 allows an LSR to maintain fewer labels.
- There is a unique label per LSP (i.e., there is no label merging). 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 is allowed (i.e., more than one LSPs for the same FEC are established). FECs are defined on end-node pairs and QoS requirements.
- No penultimate hop popping is considered
- The Data-driven method is used for the establishment of paths in a mobile network. An LSP is established only if data needs to be transferred between nodes.
- The sequential method of registering the MN to HA and establishing the related LSP is used. 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 BUAck).
- LSPs between the MN and the CN are set up after a binding update acknowledgement is sent back from the correspondent node.

IV. Hierarchical Mobile IP - MPLS Overlay Framework

A. Overview

The overlay framework we propose is based on the assumptions and requirements stated in Section III. In terms of architecture, the mobility agents are co-located with the LSRs in the RAN. The interaction of the two is limited to the LSRs using the routing tables updated by HMIP. Procedures like HMIP registration and LSP setup are independent and databases do not share entries or reference each other.

The following outlines the operation of the framework in an algorithmic way:[2]

(1) MN performs MIP Discovery functions
(2) MN performs HMIP Registration functions
At each new connection request
If request from CN (Figure 2(a))
- (3) CN establishes connection to HA
- (4) HA establishes connection to MAP
- (5) MAP creates LSP to MNs current RAS and sends data to MN. This LSP is associated only with data arriving from the HA.
- (6) MN notifies CN of new location (binding update)
- (7) CN establishes connection to MAP
- (8) MAP creates LSP to MNs current RAS and sends data to MN. This LSP is associated only with data arriving from the CN.

If request from MN (Figure 2(b))
- (3) MN establishes LSP to MAP. This LSP is associated only with the MN-CN FEC.
- (4) MAP establishes connection with CN and forwards data.

[2]The MIP signaling between MN, HA and MAP is not treated as MPLS data. This work deals only with the actions required to transfer data between the MN and the CN.

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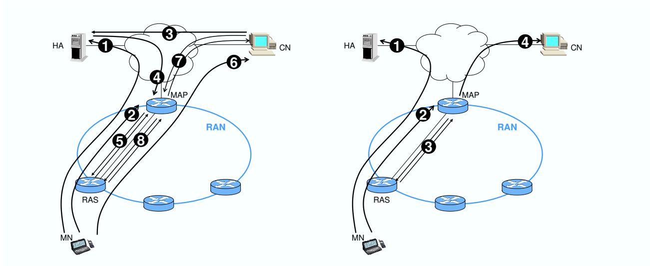
Figures 2(a) & (b) illustrate the sequence of messages exchanged between the MN, the HA, the MAP, the CN and the RAS before (or while) the first data packet traverses the network. The first two messages are the same whether the CN or the MN initiates the data communication.



(a) CN Initiated (b) MN Initiated

Fig. 2. Signaling prior to data transmission (a) CN initiated communication, (b) MN initiated communication.

B. Framework Operation

The following subsections explain the protocol, based on the specifications and operation steps described above.

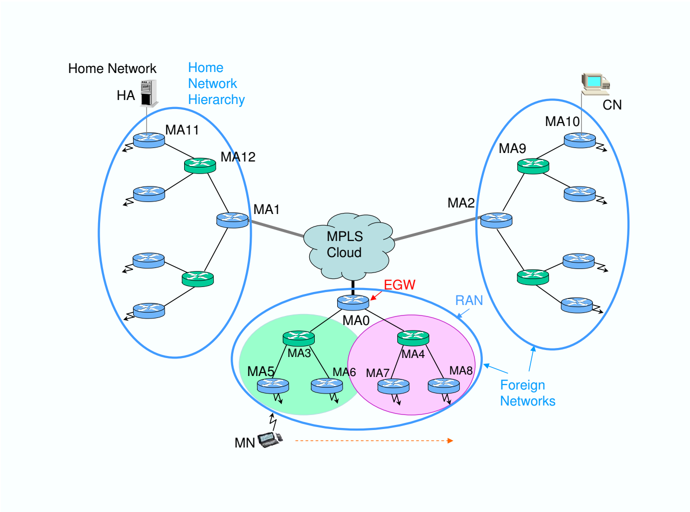


Fig. 3. Reference Network.

We consider two slightly different scenarios: one in which only MPLS is used as the mechanism to transfer data and one in which some IP packets are allowed to traverse the network. In section III we made the assumption that the Data-driven method is used for the establishment of paths in a mobile network, which means that an LSP is established only if data needs to be transferred between nodes. Therefore, we have to distinguish between the cases where the CN or the MN initiates the communication.

In the examined setup, the mobile node traverses the center RAN of a multi-RAN network. The detailed explanation is based on Figure 3 where the HA and the CN are also parts of MPLS-based RANs. This configuration creates the most MPLS-related signalling in the network and can be considered as the worst-case scenario. In the cases where the HA and/or the CN are in IP-based networks, the MPLS signaling is limited inside the proposed RAN architecture (as it is also evident from the algorithm in section IV-A). References will be made to nodes in this schematic in later sections.

*1) **Scenario 1 - MPLS Data Packets Only:*** The signaling diagrams for this scenario are shown in Figures 4 and 5. Since the HA and the CN are also in MPLS-based RANs, steps 3.a.i, 3.a.ii, 3.a.v and 3.b.ii of the algorithm involve setting up LSPs between the respective nodes.

Correspondent Node Initiates Transmission:

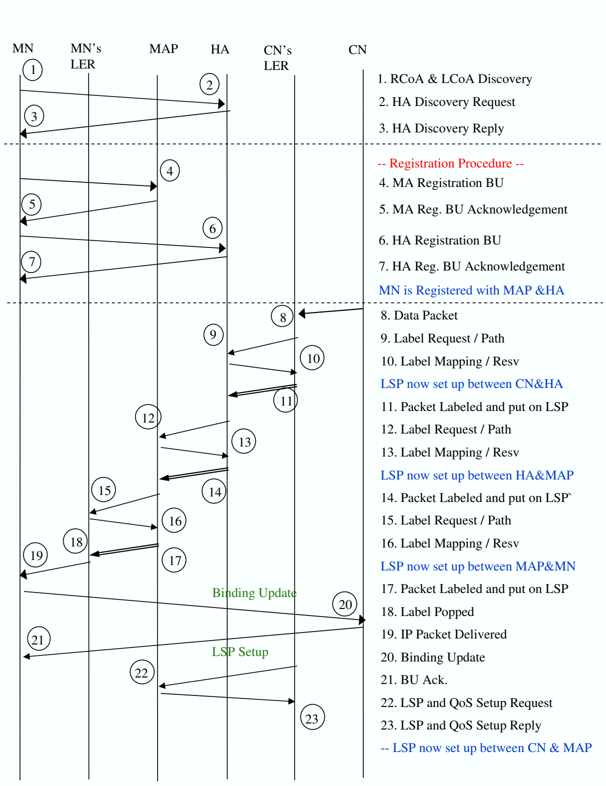


Fig. 4. MPLS data only - CN initiated communication.

When a correspondent node initiates communication toward a mobile node it first examines its binding cache for an entry of mobile node's 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. A label request will be issued 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 edge router will have an outgoing label for sending packets to the mobile node and the mobile node's LER an incoming

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label for receiving packets for the mobile node.

It is important to remember two of the design assumption made earlier: 1) a node performs an LSP setup for each new connection request, even if the node already has other LSPs associated with that FEC and 2) LSRs do not merge labels, i.e. there is a unique label per LSP.

CN's LER - MA10

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
–	–	MN1	Push	1	10

MN's LER/HA - MA11

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	10	MN1	Pop	–	–

When a labeled packet arrives at the HA (MA11), the node 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 regional care-of-address (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) table [3] 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.

HA - MA11

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	10	MN1	Pop	–	–
–	–	RCoA	Push	1	20

MAP - MA0

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	20	RCoA	Pop	–	–

After this set of actions, the home agent has two entries in 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.

MAP - MA0

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	20	RCoA	Pop	–	–
–	–	LCoA	Push	2	30

MN's LER - MA5

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	30	LCoA	Pop	–	–

After a mobile node receives encapsulated messages to its new location it understands that the correspondent node does not have an updated binding of its location. It then sends a binding update to the correspondent node. The correspondent node's LER (MA10) will decide if a request/path message needs to be sent to establish an LSP with the mobile node's MAP (MA0). This decision is based first on the fact that this is not a home agent binding update, and on the knowledge of continued flow of packets in the downstream direction. The LSP setup request will create relevant entries for all the LSRs between MA10, MA0 and MA5. At the end of that process the LFIB tables of the affected LSRs will contain the following information.

MN's LER - MA5

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	30	LCoA	Pop	–	–
1	31	LCoA	Pop	–	–

MAP - MA0

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	20	RCoA	Pop	–	–
–	–	LCoA	Push	2	30
1	21	RCoA	Pop	–	–
–	–	LCoA	Push	2	31

Since each new connection request gets its own LSP and since each LSP has its own label allocation, the MAP (MA0) and the egress LER (MA5) will have two entries related to the MN in their tables. The same is true for all intermediate LSRs. One entry is for the LSP coming

[3] We will refer to the modified NHLFE table as Label Forwarding Information Base (LFIB).

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CN's LER - MA10

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
–	–	MN1	Push	1	10
–	–	RCoA	Push	1	21

from the home agent, and the other for the LSP coming from the correspondent node.

The intermediate LSRs, however, do not Push or Pop because they do not deal with unlabeled packets. They swap the labels and the packet eventually arrives 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. This is a feature of the overlay operation.

It should also be recognized that even though this process is inefficient, the two protocols (HMIPv6 and MPLS) can still work one on top of the other in an overlay fashion.

Mobile Node Initiates Transmission: 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 5 shows the details for this scenario.

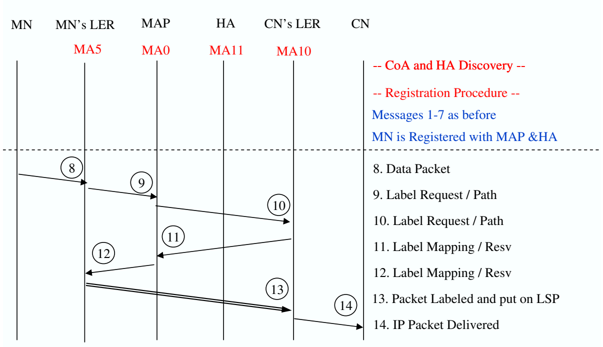

Fig. 5. MPLS data only - MN initiated communication.

The LSP will comprise of MA5, MA3, MA0, ... , 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:

MN's LER - MA5

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	30	LCoA	Pop	–	–
1	31	LCoA	Pop	–	–
–	–	CN	Push	1	40

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

CN's LER - MA10

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
–	–	MN1	Push	1	10
–	–	RCoA	Push	1	21
1	40	CN	Pop	–	–

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.

*2) **Scenario 2 - IP Data Packets Allowed**:* It is obvious from Figure 4 that a lot of messages (messages 9-18) are communicated to set three initial LSPs between the correspondent node, the home agent, the MAP and the mobile node's LER . These LSPs are not used for long since the correspondent node creates a more direct path to the mobile node soon after it receives a binding update. For this reason the case where this initial communication is allowed to happen in the IP domain is also examined in later sections.

The information allowed to be communicated in pure IP format is limited to the packets originating from a correspondent node and directed to the home address of a mobile node when there has not been an LSP set up for such communication before.

Correspondent Node Initiates Transmission: There are three slightly different cases considered for this scenario:

- Case 1. CN has no binding for the MN, and CN's LER has no LSP to MN's address
- Case 2. CN has no binding for the MN, and CN's LER has LSP to MN's address
- Case 3. CN has a binding for the MN, and CN's LER has LSP to MN's new location

Case 1: When a data packet arrives, or is created at the correspondent node, the node first examines its binding cache for an entry of mobile node's home address. If the correspondent node does not have an entry it sends the packet to the mobile node's home address. If the CNs LER (MA10) does not have an LSP already established between the correspondent node and the mobile node, it proceeds by sending it using pure IP as described in the basic HMIP operation. The Regional CoA associated with the mobile node is that of MAP (MA0). When the mobile node receives a tunneled message it will send a binding update for its Regional CoA to the correspondent node, which will use it for the establishment of an LSP to the mobile node if there is a need. The operation is illustrated in Figure 6.

This operation reduces the amount of MPLS related overhead at the initial stages of a communication. At the same time, no MPLS based QoS support is provided to those packets. DiffServ support in IP using the DSCP fields in the IP header could be used in such circum-

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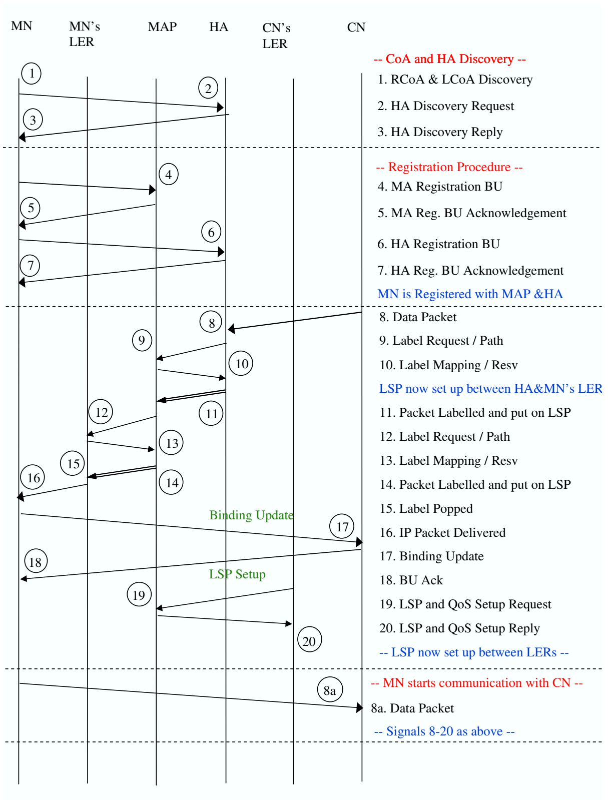

Fig. 6. IP Packets allowed.

stances. In addition, if the CN-MN LSP is set up quickly, then there may be no reason for concern even if no QoS is provisioned for those packets.

Case 2: If the CNs LER does have an LSP set up toward the mobile node's home address, it uses MPLS to send the packet. The home agent will intercept the packet after the MPLS header is stripped off and recognize that there is an entry in its binding cache for that mobile node. It will then create an encapsulated header and send the packet to the mobile node through the MAP. The rest of the operations are as in the first case.

CN's LER - MA10

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
–	–	MN1	Push	1	10

MN's HA - MA11

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	10	MN1	Pop	–	–

Case 3: In the third case the CN has a binding to MN and the corresponding LER already has an LSP set up towards the MAP. The correspondent node uses the mobile node's Regional CoA from its binding cache. The CN's LER will find the corresponding entry in the LFIB table and form MPLS packets with label 21 as the outgoing label.

CN's LER - MA10

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
–	–	MN1	Push	1	10
–	–	RCoA	Push	1	21

Mobile Node Initiates Transmission: In this scenario (shown at the bottom of Figure 6), some IP packets can be routed from the mobile node to the correspondent node without using MPLS. The mobile node's LER (MA5) will forward pure IP packets until it recognizes that a flow is in place. Then it will establish an LSP to the CN's LER as in Fig. 5.

V. Handovers in the Overlay Framework

When a mobile node moves out of the range of a mobility agent and into the range of another, the movement is understood by the difference in the router advertisements received. If the movement is inside the RAN (below the MAP), the handoff is an intra-RAN handoff. If the change in position is such that a new MAP is going to be used, the handoff is called inter-RAN handoff. Regardless of the type of handoff (intra- or inter-RAN), there are many ways to perform path rerouting following a location change:

- LSP re-establishment - A new LSP created to/from the new location.
  - Advantages: simple
  - Disadvantages: Packets in transit are lost
- LSP extension - The LSP is extended from the old edge router to the new edge router
  - Advantage: fast, no packets are lost
  - Disadvantages: LSP length is increased, delay may be increased, loop prevention is required
- LSP extension and modification - the LSP is first extended and then modified.
  - Combination of the first two methods
  - Advantages: Fast, simple, no packets are lost
- LSP multicast - LSPs are created in multiple locations around the MN
  - Advantages: enables fast and smooth handoff Disadvantages: point-to-multipoint LSPs needed, extensive location knowledge is required.
  - Difficult to handle resources
- LSP dynamic rerouting - the LSP is modified starting from the lowest (closest to the MN) common router between the old and the new path. Partial path re-establishment.
  - Improvement on extension and modification method.
  - Advantages: full LSP re-establishment is not required. Parts of LSP remain the same, which means less signaling.
  - Disadvantages: increased complexity

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All of the rerouting methods described above have been used in current proposals. Multicasting and dynamic rerouting seem the most popular and efficient. However, most of the proposals utilising these methods make certain assumptions that do not fit the realities of our model of an overlay framework. Therefore, we propose the use of the LSP extension and modification method. This method is simple; it can be used without any additions to the architectures; uses existing functions (like the old MA notification and MN-CN BU) as the basis; and also limits packet loss.

A. Intra-RAN Handoff

Suppose that MN1 moves out of the range of MA5 to a location closer to MA6. The mobile node will obtain a new LCoA from its new location. It will then send a binding update to MA5 with the new LCoA (LCoA2) so that packets in transit toward the MA5 are redirected toward MA6. At the same time, the mobile node will send a local binding update to its MAP (MA0) and any correspondent nodes inside the RAN. Prior to the handoff, MA5 has the following data in its LFIB:

Old LER - MA5 (before handoff)

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	30	LCoA1	Pop	–	–
1	31	LCoA1	Pop	–	–
–	–	CN	Push	1	40

After the handoff MA5 will initiate an LSP setup between itself and MA6. The LSP will be for LCoA2. MA5 and MA6 will update their tables accordingly.

Old LER - MA5 (after handoff)

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	30	LCoA1	Pop	–	–
1	31	LCoA1	Pop	–	–
–	–	CN	Push	1	40
–	–	LCoA2	Push	1	50

New LER - MA6

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	50	LCoA2	Pop	–	–

As a result, prior to an intra-RAN handoff the MAP has an entry in its binding cache relating the RCoA and LCoA used by the mobile node, and an LSP connecting to the LER serving it. After the handoff the MAP has a different LCoA associated with the mobile node and needs to establish a path toward it. If full LSP re-establishment is used, the MAP will establish a new LSP toward the mobile node and add the entry in the LFIB. The connection between the old and the new entries is done in the binding cache. Therefore, the trend of leaving the MPLS layer in order to get the new CoA and return to find the new path to it is continued here. One of the design choices made in Section III is that ”no Aggregation is allowed” which means that the MAP performs an LSP setup for every entry it has in its table. In this case, to differentiate between entries the FEC needs to denote end node pairs and not just the destination.

B. Inter-RAN handoff

Inter-RAN handoffs include everything done in intra-RAN handoffs with the addition that the mobile node's home agent and correspondent nodes outside the RAN will have to establish LSP(s) to the mobile node's new MAP. Let us consider the case where MN1 moves into the RAN served by MA2. The home agent will receive a binding update with MA2 as the new mobility agent and update its binding cache with the new RCoA value (RCoA2). If its connection with the mobile node is active (data present) it will also initiate an LSP setup to the new RCoA. Correspondent nodes outside the mobile node's new RAN will also have to do the same. The label forwarding information base of the HA will be changed to:

HA - MA11

Input I/F	Input Label	FEC	Operation	Out I/F	Out Label
1	10	MN1	Pop	–	–
–	–	RCoA1	Push	1	20
–	–	RCoA2	Push	1	60

The entry for the old RCoA will remain in the table until released by the ingress or withdrawn by the egress router. There is no provision at present for the release or withdrawal of these labels based on mobile IP information. Since the MAP/EGW will always be the correct downstream router for that particular domain, MPLS does not give the option to the upstream router to release the label. A downstream node can withdraw a label if it decides to break the binding between the label and the address prefix associated with it. The LSR withdrawing a label must do so from every LSR it has distributed that label. Label withdrawing is useful in the handoff framework only if there is a mechanism to inform MPLS that the binding is not needed anymore.

VI. Related Work

The subject of introducing mobility functions to MPLS has seen a large interest in the recent years. Research on this issues has appeared as soon as the work on MPLS and MIPv4 had stabilized in IETF (ca. 2001-2002).

Related work has been done on all incarnations of Mobile IP and its variants. MPLS has been considered in relation to MIPv4 [10] [11] [12] [21] [22] [23] [25] [27] [29], HMIPv4 [11] [12] [13] [14] [17] [19] [20] [23] [24] [26] [27] [29], MIPv6 [15] [16] [25] [28] and HMIPv6 [5] [6] [8] [15] [18].

The main idea of many proposals is that label switched paths in the MPLS network can replace the tunneling

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procedures of MIP. In [10] [14] and [17], the operations are as in normal MIPv4 and HMIPv4 respectively. The only change is that when a mobile node registers its new CoA to its home agent through a foreign agent, the home agent establishes an LSP to the foreign agent first, before sending back the registration reply. In [6], [11], [12], [16], [17], and in this work, the home agent sets up an LSP with the foreign mobility agent only after the registration is completed. This is the "sequential" method of establishment and maintains the separation of MIP and MPLS. The other proposals assume that only one message is used, or that there is some combination of functions, which denotes an *Integrated* operation.

Few previous papers have considered the overlay method of interworking. Most proposals fall under the category of integrated methods. [10] was the first to suggest the two options, even though it did not explain the overlay method in detail. It only compared the three mobility solutions (pure MIP, MIP over MPLS (overlay) and Integrated MIP and MPLS) and concluded that the integrated method has the best performance. To the best of our knowledge, the only work done so far on the overlay interworking of hierarchical mobile IP version 6 and MPLS has been in [6], [8] and [18].

In the hierarchical or regional registration cases, the home agent sets up an LSP between itself and the CoA registered by the mobile node. However, in this case, the CoA is that of the top router in the hierarchy -the edge gateway in a RAN. This edge gateway will then establish an LSP toward the mobile node through a number of regional FAs. Even though the overall process is the same, in HMIP the LSP does not go directly from the home agent to the lower foreign agent, but has to pass through specific routers along the way. This particular requirement may prove cumbersome in integrated frameworks, especially if full LSP re-establishment is used (as in [10]) or if multicast-based rerouting is used (as in [11] and [12]). [13] and [14] use pre-established LSPs to either all the access routers in a domain or the neighboring routers of the MN so that during a handoff no extra signaling is exchanged. [19] and [20] use a forwarding chain method of extending an LSP to the new location of a mobile node. This method increases the LSP length and consequently the delay experienced by the packets using that path. Additionally the method may end up creating loops. [27] also uses a similar concept, where the chain has a length of three. The partial re-establishment (or dynamic) rerouting used in [13] [15] [17] and [21] reduces the delay at the expense of a increased complexity. [6] [8], and this work, work on the middle ground, where the process is simpler, faster and reduces losses.

A number of mobility solutions for MPLS start from the premise that the MPLS network exists and that mobility functions are added to it. In such a case the mobility related signaling is either handled by changing the MPLS signaling protocols (LDR, CR-LDP or RSVP-TE) and introducing MIP-related objects [21] [24], [26] [27] or LSPs have to be established between the communicating nodes in order to support the initial signaling [5] [6] [10] [14] [16] [17]. On the other hand, some works [15] consider that MPLS is just the transport method *inserted*, in a way, into the mobile network and that the network is still able to communicate using pure IP or MIP packets on top of MPLS. Our work addresses both cases.

The type of architecture, that is the topology and the node capabilities, can also be influenced by the expected use of the resultant network. [30] was one of the first to consider that MPLS can be used in a 3G/4G radio access network to replace ATM/AAL2. This idea was extended in [5] [15] [21] [22] and [25] where specific proposals were made on how MPLS and Mobile IP can be incorporated into GPRS, UMTS or similar networks. Others, like [19] [24] [6] are more interested in the mobility events rather than interface with the technology.

Our work has many differences from the proposals described above. First it considers only an overlay method of interworking between MPLS and MIP. This provides for simpler and gradual deployment, scalability as it maintains the same structures as before, has the ability to provide QoS by exploiting the capabilities of MPLS to use explicit paths for certain classes of traffic and to easily enable traffic engineering. In addition the proposed solution can fit well into a 3G radio access network and it can provide mobility functions both in MPLS and in IP/MPLS combined networks.

VII. Conclusions and Future Work

This paper proposes a framework that integrates Multi-Protocol Label Switching (MPLS) and Hierarchical Mobile IPv6 (HMIPv6) in a Radio Access Network (RAN) in a simple overlay fashion. The need for such a framework stems from the increased drive toward high-speed multimedia-intensive services. The overlay method proposed improves on existing methods of MIP-MPLS interworking based on MIPv4 and HMIPv4 and utilizes HMIPv6 as the micromobility protocol.

Detailed operation signaling diagrams as well as forwarding table contents are presented and the ability of the protocol to handle mobility events (handover) is illustrated both for the intra and inter-RAN cases.

Our scheme is *scalable* due to its flexible and distributed implementation, allows for *gradual deployment* since it co-exists with other protocols in an overlay fashion, does not need protocol enhancements, but only *node co-location* and has the ability to *provide QoS* using the underlying MPLS traffic Engineering capabilities.

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.

Future work will include a complete simulation environment where both the overlay and the integrated methods of interworking MPLS and HMIPv6 will be compared. We expect to incorporate in the framework the enhancements identified in this paper, such as bi-directional LSP setup and unused label withdrawal and

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also to ensure that the framework is compliant to the security issues raised in the latest related standards.

REFERENCES

[1] E. Rosen, A. Viswanathan and R. Callon, ”Multiprotocol Label Switching Architecture,” Request for Comment 3031, Internet Engineering Task Force, Jan. 2001.

[2] C. Perkins Ed., ”IP Mobility Support for IPv4”, Request for Comment 3344, Internet Engineering Task Force, Aug. 2002.

[3] H. Soliman, C. Castelluccia, K. El-Makri, and L. Bellier, ”Hierarchical Mobile IPv6 Mobility Management (HMIPv6),” Request for Comment 4140, Internet Engineering Task Force, Aug. 2005.

[4] C. Perkins, D. Johnson, and J. Arkko ”Mobility Support in IPv6,” Request for Comment 3775, Internet Engineering Task Force, Jun. 2004.

[5] V. Vassiliou, H. L. Owen, D. A. Barlow, J Grimminger, H-P Huth, and J. Sokol, ”A Radio Access Network for Next Generation Wireless Networks Based on MPLS and Hierarchical Mobile IP,” *In Proc. IEEE 56th Vehicular Technology Conference Fall 2002* (VTC2002-Fall), 2002, pp 782-786.

[6] V. Vassiliou, H. L. Owen, D. A. Barlow, J Grimminger, H-P Huth, and J. Sokol, ”M-MPLS: Micromobility-enabled Multiprotocol Label Switching,” *In Proc. IEEE International Conference on Communications (ICC2003)*, 2003, pp. 250-255.

[7] D. Barlow,V. Vassiliou, S. Krasser, H. Owen, J. Grimminger, H.-P. Huth, and J. Sokol, ”Traffic Engineering Based on Local States In Internet Protocol-based Radio Access Networks”, *Journal Computer Networks*, Vol. 7, No. 3, pp. 377-384, 2005.

[8] V. Vassiliou, ”Design Considerations for Introducing Micromobility in MPLS,” *In Proc. of the IEEE Symposium on Computers and Communications (ISCC 2006)*, 2006, pp. 870-877.

[9] F. Liers, R. Boringer and A. Mitschele-Thiel, ”Optimal Placement of Anchor Points within Large Telecommunication Networks” *In Proc. of the 4th International Conference Wired/Wireless Internet Communications (WWIC 2006)*, 2006, LNCS 3970 pp. 96-107.

[10] Z. Ren, C-K Tham, C-C Foo, and C-C Ko, ”Integration of Mobile IP and Multi-Protocol Label Switching,” *In Proc. of the IEEE International Conference on Communications (ICC 2001)*, 2001, pp. 2123-2127.

[11] T. W. Um and J. K. Choi, ”A Study on Path Re-routing Algorithms at the MPLS-based Hierarchical Mobile IP Network,” *In Proc. of the Region 10 International Conference on Electrical And Electronic Technology (TENCON)*, 2001, pp. 691-697.

[12] J. K. Choi et al., ”Extensions of LDP for Mobile IP Service through the MPLS network,” Internet Draft, Nov. 2001.

[13] H. Kim, K-S D. Wong, W. Chen and C. L. Lau, ”Mobility-aware MPLS in IP-based Wireless Access Networks,” *In Proceedings of IEEE Global Telecommunications Conference, (GLOBECOM)*, 2001, Volume 6, pp. 3444-3448

[14] T. Yang and D. Makrakis, ”Hierarchical Mobile MPLS: Supporting Delay Sensitive Applications over Wireless Internet,” *In Proc. of the International Conferences on Info-tech and Info-net 2001, (ICII 2001)*, 2001, Volume 2, pp. 453-458.

[15] F. M. Chiussi, D. A. Khotimsky, and S. Krishnan, ”Mobility Management in Third-Generation All-IP Networks,” *IEEE Communications Magazine*, pp. 124 - 135, Sep. 2002.

[16] J. K. Choi, M.H. Kim, and T.W. Um, ”Mobile IPv6 support in MPLS,” Internet Draft, Aug. 2001.

[17] T. Yang, Y. Dong, Y. Zhang and D. Makrakis, ”Practical Approaches for Supporting Micro Mobility with MPLS,” *In Proceedings of ICT 2002*, China, June 2002.

[18] V. Vassiliou, ”Handover Operation in Mobile IP-over-MPLS Networks,” *In Proceedings Fifth IFIP Networking Conference (NETWORKING 2006)*, 2006, LNCS 3976, pp. 568579.

[19] R. Langar, S. Tohme, N. Bouabdallah, ”Mobility management support and performance analysis for Wireless MPLS networks”, *ACM / WILEY International Journal of Network Management*, vol. 16 issue 4, pp. 279-294, July 2006.

[20] R. Langar, N. Bouabdallah, S. Tohme, ”On The Analysis of Mobility Mechanisms in Micro Mobile MPLS Access Networks”, *Journal of Communications*, vol. 1 issue 6, pp. 18-27, September 2006.

[21] R. Boringer, A. Saeed, A. Diab, A. Mitschele-Thiele and M. Schneider, ”I-MPLS: A Transparent Micro-Mobility-enabled MPLS Framework,” In Proc. 11th European Wireless Conference (EW 2005), April 2005, pp. 775-783.

[22] F. Palmieri, ”An MPLS-based Architecture for Scalable QoS and Traffic Engineering in Converged Multiservice Mobile IP Networks,” *Computer Networks*, vol. 47, pp. 257-269, 2005

[23] K. Xie, V. Wong and V. C.M. Leung, ”Support of Micro-Mobility in MPLS-based Wireless Access networks,” *IEICE Trans. Communications*, vol. E88-B, no. 7, July 2005.

[24] K. Xie, and V. C.M. Leung, ”An MPLS Framework for Macro- and Micro-Mobility Management,” *In Proc. IASTED Wireless and Optical Communications 2002 Conference (WOC2002)*, Jul. 2002.

[25] H. Nguyen, F. Li, and W. K.G. Seah, ”Integration of Micro-Mobility with QoS in IP/MPLS-based Radio Access Networks,” *In Proc. of the Vehicular Technology Conference, (VTC 2003-Spring)*, 2003, pp. 2261-2255.

[26] Q. Xie, H. Nguyen, P. Tan and W. K.G. Seah, ”Handover Supporting QoS in MPLS-based Hierarchical Mobile IPv6 Networks,” *In Proc. of the Vehicular Technology Conference, (VTC 2003-Spring)*, 2003, pp. 3523-3526.

[27] H. Zhou, C. Yeh, H.T Mouftah, ”Dynamic Hierarchical Mobile MPLS for next generation all-IP Wireless Networks,” *In Proc. of the Vehicular Technology Conference, (VTC 2005-Spring)*, 2005 pp. 2230-2234.

[28] Z. Qu, C. S. Hong, S. Lee, ”A QoS Provision Architecture for Mobile IPv6 over MPLS using HMAT,” *In Proc. of the EuraAsia-ICT 2002 Conference,* LNCS 2510, 2002, pp.569-579.

[29] S. Fowler and S. Zeadally, ”Fast Handover over Micro-MPLS-based Wireless Networks,” *In Proc. of the 11th IEEE Symposium on Computers and Communications (ISCC’06)*, 2006.

[30] Y. Guo, Z. Antoniou and S. Dixit, ”IP Transport in 3G Radio Access Networks: an MPLS-based Approach,” *In Proc. of the IEEE Wireless Communications and Networking Conference (WCNC2002)*, 2002 pp. 11-17.

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