M-MPLS: Micromobility-enabled Multiprotocol Label Switching

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Abstract—**This paper presents the integration of multiprotocol label switching with hierarchical mobile IPv6. The resulting micromobility-based MPLS (M-MPLS) is defined in two modes of operation: overlay and integrated. In an overlay framework MPLS and HMIP operate on their respective layers without having common processes, tables, or signaling. In an integrated framework, related functions are merged. The overall goal of an integrated framework is to facilitate efficient and reliable network operations while simultaneously optimizing network utilization and system performance**

I. INTRODUCTION

Computer networking has dramatically changed the way people learn and interact; the way companies operate; and the way almost every personal, business, and professional activity is performed. One major paradigm shift has been mobile computing. Mobile computing has the general idea of enabling users to use wireless devices to access applications and services anywhere and without constraints in time or form. The challenge for mobile systems is to create an appropriate wireless infrastructure that can support mobile users in an integrated and seamless fashion.

To meet increasing demand for mobile multimedia services and to support the phenomenal growth in cellular communications, network providers are currently implementing the 3rd generation (3G) of cellular networks and are considering the next step of the evolution. The networks proposed for the evolution of Universal Mobile Telecommunications System (UMTS) and the next generation (4G) of wireless networks lean toward being Internet Protocol (IP) based.

With the increase in operating frequencies for future wireless-based networks, cell radii are expected to decrease. The decrease is necessary to ensure that higher data rates will be able to be supported at acceptable error rates. This means that to cover the same area next generation systems will require more base stations. The implication of having smaller cells and more base stations is that mobile nodes will cross cell boundaries more often and the amount of signaling they will exchange will be raised proportionally. We believe that the requirements of an IP-based radio access network (RAN) can be met when a micromobility management protocol and a fast switching transport protocol are combined [1].

This paper proposes the integration of hierarchical mobile IPv6 (HMIPv6) and multi-protocol label switching (MPLS. The proposed scheme merges the scalability, and reduced latency handoffs of HMIP with the performance and traffic management capability of MPLS. More specifically, MPLS adds several advantages to an IP-based RAN including faster table lookup, less control overhead, and the ability to be applied over networks using any Layer 2 switching. This proves to be very desirable in the multi-radio access architectures considered for future wireless networks.

Related research that introduces mobility to MPLS is mainly based on mobile IPv4 and hierarchical mobile IPv4 [2][3][4]. The only work that addresses mobile IPv6 [5] does not take into consideration any micromobility. All proposals are either based on simple ways of interworking (based on the overlay concept) or make assumptions of more involved integration without providing any details of the required operations. This paper not only introduces hierarchical mobile IPv6 as the mobility protocol, but also provides detailed methods for simple (overlay) and optimized (integrated) protocol interaction.

The paper is organized as follows: Section II provides a brief background on the basic protocols and architectures used. Section III presents the proposed radio access network based on MPLS and HMIPv6. Section III also includes descriptions of the overlay and integrated modes of operation. Emphasis is given in the signaling for path setup, the datagram delivery process, and the handoff methods. Finally, Section IV provides a conclusion of all the ideas presented.

II. BACKGROUND

Multiprotocol Label Switching: MPLS [6] 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 based on that label. Packets belonging to the same FEC get similar treatment by all intermediate nodes in the path.

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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 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) 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)[1]

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 [7]. 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). When away from home, a mobile node registers one of 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.

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 [8] is based on MIPv6 [9] 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. MICROMOBILITY-BASED MPLS FRAMEWORK

A. *Radio Access Network*

We consider the multiple-domain network architecture shown in Figure 1, where each domain is a radio access network. A radio access network consists of two or more layers of label switched routers (LSRs). The routers at the edge of an MPLS network are called label edge routers (LER). In radio access networks these LERs provide connectivity to the mobile terminals through one, or more, radio base stations (BS). We refer to these routers as radio access routers (RAR). Several RARs are connected to intermediate LSRs, which in turn are interconnected to one or more edge gateways (EGW). Edge gateways provide access to outer (backbone) networks including other RANs. This architecture can also easily support MPLS traffic engineering based on DiffServ [10].

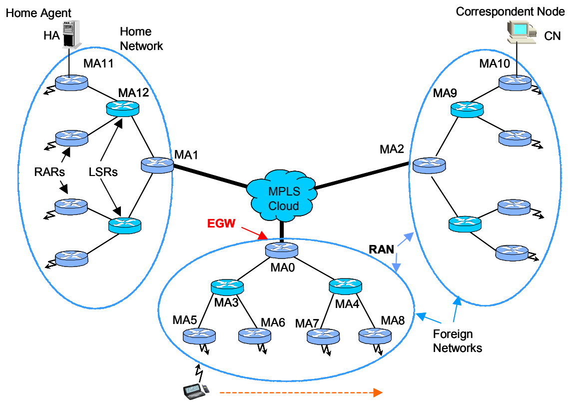

Figure 1. M-MPLS Radio Access Network

B. *Framework Assumptions*

The design of the M-MPLS radio access network is based on the following requirements and assumptions:

- All MPLS nodes in the RAN are mobility-enabled
- End nodes (MN and CN) have no MPLS related protocols in their stack
- FECs are defined based on both end-node addresses and QoS requirements.
- 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.
- No label merging: There is a unique label per LSP. If two packets for the same FEC arrive with different incoming labels they must be forwarded with different outgoing labels.
- No aggregation: Establishing more than one LSPs for the same FEC is acceptable based on QoS requirements.

C. *Overlay Framework*

We examine the overlay framework in two situations: when the correspondent node initiates communication, and when the mobile node initiates communication. In both situations, when a mobile node first powers up in a foreign network it goes through a MAP and HA registration procedure. The default MAP choice is the mobility agent the farthest away from the mobile node (i.e., the edge gateway of the RAN). If there is a

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[1] NHLFE and LFIB are used interchangeably in this paper

need the mobile node may also perform a home agent address discovery before initiating registration. These steps are numbered one through seven in Figure 2. The rest of the steps in Figure 2 outline the initial LSP setup process when the correspondent node initiates communication with the mobile node.

1) *CN Initiates communication*

When a correspondent node initiates communication toward a mobile node it first examines its binding cache for an entry of the mobile node's new CoA. If the correspondent node does not have an entry it sends its packets to the mobile node's home address. If the CN's RAR (MA10 in Figure 1) has an LSP for the packets' FEC it pushes the appropriate label on the outgoing packets and sends them to the mobile node. If no label is bound for that FEC, the RAR initiates an LSP setup for that FEC. The RAR on the mobile node's network (MA11 in Figure 1) will eventually respond with a label mapping and the LSP will terminate at it. At the end of this operation the correspondent node's RAR will have an outgoing label for sending packets to the mobile node and the mobile node's RAR (which also serves as the HA) an incoming label for receiving packets for the mobile node from the CN.

When a labeled packet arrives at the home agent, the router will use the incoming label value as an index to look up its label forwarding information base (LFIB). The out-label and out-port will be empty since the router is the edge router for that address. The RAR will then strip off the label and send 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 packet 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 HA will then create an encapsulation header, using as the destination address the CoA in the binding cache, and send the packet downstream.

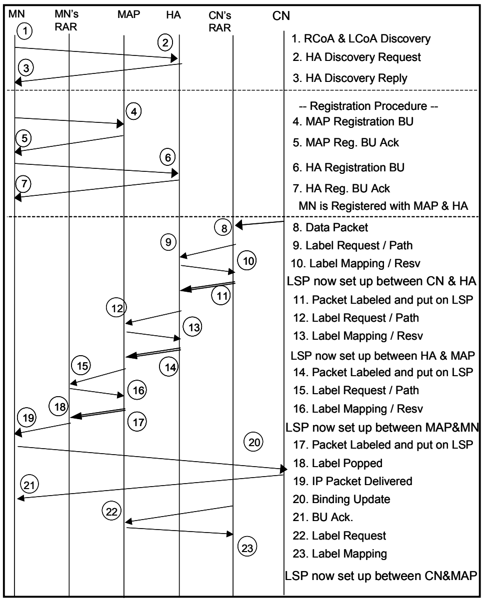

Figure 2. Initial LSP Setup in the Overlay framework

The home agent uses the CoA as a forwarding equivalence class to find an entry in its LFIB. The entry will initially have no outgoing label, meaning that no LSP has been setup between the home agent (MA11) and the EGW/MAP (MA0) for that mobile node. The home agent will initiate an LSP setup to the mobile node's CoA for this connection. The MAP also has a binding for the mobile node, but no label bound for it; therefore, before it can send a label mapping to the home agent, the MAP must get a label from the RAR serving the mobile node at its new location (MA5). 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 for the MAP-to-MN LSP (MA0 to MA5). The operations described above are summarized in steps 8 through 19 in Figure 2.

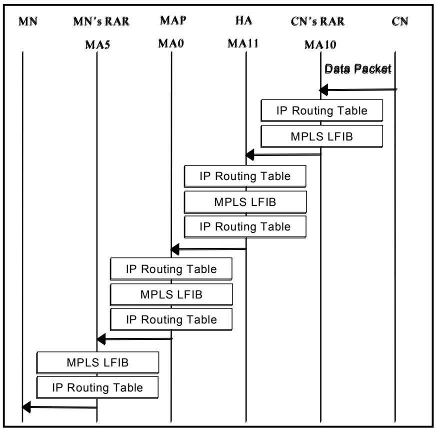

Figure 3. Overlay Datagram Delivery - CN initiated

Packets are delivered from HA to MAP along the recently set up LSP by label swapping at the intermediate LSRs. When a labeled packet arrives at the MAP, the router recognizes that it is the destination address of that LSP. Again, 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 Regional CoA will be related to the mobile node's Local-CoA. A new encapsulation header, having the LCoA as the destination address, is created by the MAP. The packet will be taken again by the MPLS protocol and a new label will be pushed on the packet 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. This datagram delivery process is illustrated in Figure 3.

After a mobile node receives encapsulated messages at its new location, it understands that the correspondent node does not have an updated binding of its location. It then sends a binding update directly to the correspondent node. The correspondent node's RAR (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 depends on the amount of data traffic in the downstream direction. The RAR will recognize if a persistent data stream exists and will initiate an LSP setup. The LSP setup request will create a shorter LSP directly from the CN's RAR and the MAP.

2) *Mobile Node Initiates Communication*

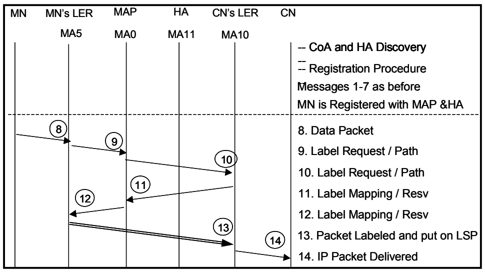

Figure 4. LSP setup after MN initiates communication

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 RAR (MA10) before it can forward any packets. Figure 4 shows the details for this scenario. 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 as shown in Figure 5.

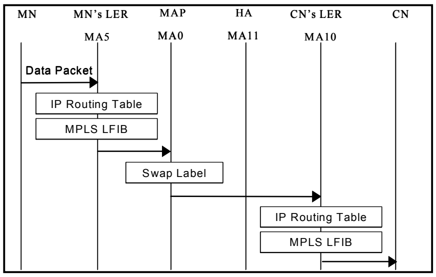

Figure 5. Overlay Datagram Delivery - MN Initiated

In the overlay framework, several LSPs (each covering a short span of the total path) are required to connect the CN to the MN. As a result, the HA and the MAP cannot directly swap one label for another toward a mobile node because their MPLS modules do not communicate directly with Mobile IP. For that reason, packets have to go through a label pop, a binding cache association, and a label push at each LSP egress node. Intermediate LSRs do not have to go through this procedure because they are not edge routers and do not deal with unlabeled packets. The inefficiency of changing layers in the software hierarchy, and the fragmentation of the total paths are examples of why an optimized integrated framework is needed in M-MPLS.

D. *Handoffs in the Overlay Framework*

1) *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 local binding update to its MAP (MA0) and any correspondent nodes inside the RAN. At the same time, the mobile node will send a binding update to MA5 with the new LCoA so that packets in transit toward the old RAR are redirected by MA5 toward MA6. After the handoff MA5 will initiate an LSP setup between itself and MA6. The LSP will be for the LCoA created at the new RAR (MA6). MA5 and MA6 will then update their tables accordingly.

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 RAR 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 returning to find the new path to the CoA is continued here. The MAP needs to perform an LSP setup for every entry it has in its table. To differentiate between entries, the FEC needs to contain the address of the sender node as well. That is why in our assumptions we included the requirement that FECs contain the addresses of end node pairs.

2) *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 regional CoA (RCoA2) and will update its binding cache with the new value. 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 entry for the old RCoA (RCoA1) 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 MA0 will always be the correct downstream router for RCoA1 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 to which it has distributed that label. Label withdrawing is successful in the handoff framework only if there is a mechanism to inform MPLS that the binding is not needed anymore. This is another example why integrating the two protocols is beneficial.

E. *Integrated Framework*

The objective of an integrated framework is to enable faster and more optimized network operations, which will relate to better network utilization. Our optimization of the overlay framework involves two major components: node architecture and rerouting. The *architecture component* addresses the issues of enhancing MPLS nodes for the support of mobility. The *rerouting component* deals with the way handoffs and mobility-triggered MPLS events are handled. This subsection defines what changes need to be made in these components to evolve from the overlay to the integrated framework and presents the final operation of the framework after the changes are adopted.

A substantial improvement to the overlay framework would be a different database access and correlation, since in the previous section we showed that the overlay approach is not efficient. We propose to create a common control plane between MPLS and MIP and allow MPLS to have access to the binding cache of the mobility agents.

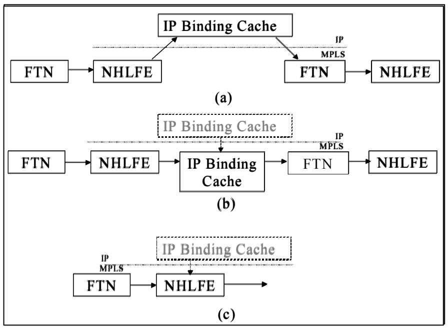

Figure 6. Database Access and Relation Methods

Section D identified the instances where multiple lookups are needed at LSP ingress or egress routers to transport a data packet between a mobile node and a correspondent node. The lack of interaction between the Mobile IP and MPLS control planes forces a change in the protocol layer every time a mobility enabled router gets a labeled packet for which it is the ingress or the egress router. The change requires MPLS headers to be stripped off and the packets sent to the IP layer for further processing. After the correct routes are determined, packets are re-introduced into the MPLS layer where they get re-labeled and forwarded. The tables taking part in this interaction are shown in Figure 6a.

If MPLS has direct access to the mobile IP binding cache, as shown in Figure 6b, the "layer-change" step is eliminated. The FEC of the next LSP is found after consulting the binding cache. The next label is "swapped" in the label field and the TTL value is updated in the new MPLS header without leaving the MPLS layer. The benefit from this action is a reduction in processing time since the MPLS header does not need to be destructed. However, the number of tables searched is the same as before. A better optimization choice is to enable the MPLS router to relate the relevant entries in the LFIB based on binding cache information. We propose a new field in LFIB containing a pointer to another entry in the same table. This new LFIB structure is shown in Table 1

TABLE I. MODIFIED LABEL FORWARDING INFORMATION BASE AT THE HA

#	Input I/F	Input Label	FEC	Operation	Out I/F	Out Label	LFIB ptr
1	1	10	MN1	Pop	--	--	~~2~~ 3
2	--	--	RCoA1	Push	1	20	
3	--	--	RCoA2	Push	1	60	

The LFIBptr field in the entry for the mobile node's home address (entry #1), initially points to the entry of the first MAP's RCoA (RCoA1 in entry #2). This operation is done after the binding cache changes. If the change in the cache relates the FEC with another RCoA, the LFIBptr entry should point to the entry of the new RCoA (RCoA2 in entry #3). This method of database access is illustrated in Figure 6c. In this case we may say that the binding cache "pushes" information to MPLS. This method not only avoids changing layers, but also saves processing time, and reduces the searching required, since the MPLS tables do not have to be searched again for the new FEC.

1) CN Initiates communication

The number and type of signaling messages required to setup an LSP for communication from the correspondent node to the mobile node when the mobile node is at a foreign network, are the same as in the overlay framework (messages 8 to 19). The difference in the integrated framework is their sequence and how they are acted upon. Figure 7 shows the relevant signaling messages for the integrated framework.

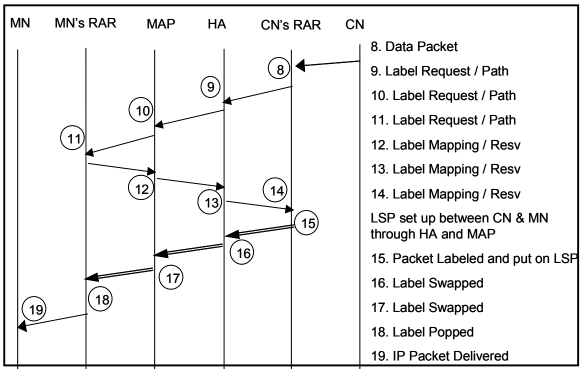

Figure 7. Initial LSP Setup in the Integrated Framework

As in the overlay framework, when a correspondent node initiates communication toward a mobile node it first examines its binding cache for an entry of the 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. If there is an LSP to the mobile node's home address, the CN's RAR pushes an appropriate label on the packets and sends them to the mobile node. If no label is bound for that FEC, the CN's RAR will have to set up an LSP to the mobile node's network with that FEC. The edge router on the mobile node's domain (MA11) will receive the request, but since it knows the mobile node's current care-of address it makes a label request toward the RCoA registered for the mobile node. The EGW/MAP (MA0) also has a binding for the mobile node, but no label bound for it. The MAP must get a label from the RAR serving the mobile node at its new location (MA5). After MA0 receives a label mapping for the LSP toward MA5 it can bind a label and send a mapping upstream to the home agent.

At the end of this operation the correspondent node's RAR will have an outgoing label for sending packets to the mobile node and the mobile node's RAR an incoming label for receiving packets for the mobile node from that particular CN.

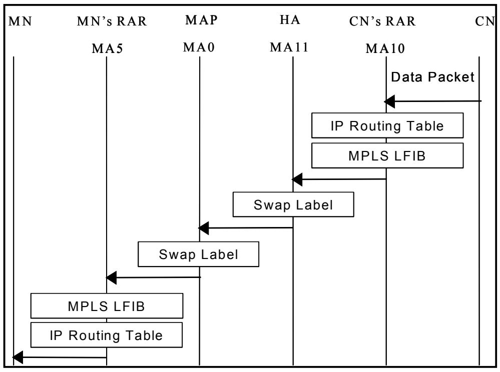

Figure 8. Integrated Datagram Delivery – CN Initiated

Figure 8 shows the datagram delivery process for the integrated framework. We observe that the multiple table lookups are reduced to label swaps because the path is comprised of only one LSP even though it transits the HA and the MAP as before. Communication initiated from the mobile node follows the same initial LSP setup process and has the same data delivery as in the overlay framework.

F. Handoffs in the Integrated Framework

In the integrated framework the handoff procedure is not based on the "extend and optimize" re-routing paradigm as in the overlay framework. Instead, since the LSP is un-interrupted from the CN to the MN we can take advantage of the LSP modification capabilities of MPLS during handoffs. Currently, both MPLS TE-enabled signaling protocols (CR-LDP and RSVP-TE) have established mechanisms dealing with LSP modifications [11][12]. The actual implementation details of the two signaling protocols are not important. More important is the fact that the use of LSP modification enables re-routing based on the partial re-establishment paradigm.

LSP modification in CR-LDP and RSVP-TE is initiated by the ingress routers and it is based on the "make-before-break" principle. The significance of this principle lies in the fact that services on the LSP are not disrupted and the resources are not double booked. The basic operation is that when the ingress node is informed that the path needs to be changed it sends out an LSP modification message and waits for a new label to return for use in the modified path. This information may be either mobility related (like a binding update), the result of a traffic-engineering algorithm, or even probed by a network node failure.

1) Intra-RAN Handoff

In an intra-RAN handoff, we expect that the MAP will be acting as an ingress router for LSPs originating from outside the RAN. After the mobile node registers its new LCoA with the MAP, the MAP sends out an LSP modification message. As the new path is resolved a new label will eventually be sent upstream to the MAP. The MAP will then update its LFIB table and use the new label for communication over the changed LSP. The old label should eventually be released by the ingress LSR after it receives a second label for the same LSP.

2) Inter-RAN Handoff

An inter-RAN handoff follows the same process as intra-RAN except that the home agent and the correspondent nodes outside the RAN are now the ingress routers changing their LSPs to the MAP. In both handoff cases the mobile node's RAR will have to initiate LSP modifications for all LSPs for which the mobile node is the sender (i.e., the RAR is the LSP ingress).

IV. CONCLUSIONS

In this paper we proposed a scheme that integrates MPLS and micro-mobility in a packet based radio access network. The resulting micromobility-based MPLS (M-MPLS) was defined for two modes of operation: *overlay* and *integrated*. The *overlay* framework is what we get if we just interconnect MPLS and HMIP without any special provisions. The resultant network does provide mobility support to MPLS, but in an in-efficient manner. When MPLS and HMIPv6 are *integrated* using common processes, tables, and signaling we can improve system performance. The uninterrupted path created using the integrated method is useful for better supporting traffic engineering based on DiffServ. It is also essential for the incorporation of end-to-end quality of service mechanisms.

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