

An Efficient QoS Scheme for Mobile Hosts

Sarantis Paskalis

Dept. of Informatics and Telecommunications,
University of Athens, Greece
paskalis@di.uoa.gr

Alexandros Kaloxylos

Dept. of Informatics and Telecommunications,
University of Athens, Greece
agk@di.uoa.gr

Evangelos Zervas

Department of Electronics,
TEI-Athens, Greece,
zervas@ee.teiath.gr

Abstract

Mobile hosts utilize Mobile IP to retain connectivity while roaming in various networks, and acquire new IP addresses through the mechanisms Mobile IP supports. Today, one of the most demanding application requirements is QoS support. RSVP, the protocol implementation of the IETF Integrated Services Architecture, cannot handle hosts that change their IP addresses amidst a connection lifetime, and thus, must re-establish any given reservation states.

To overcome this limitation, we propose the adoption of a mobility management scheme, that maintains a single contact IP address throughout the mobility session. Furthermore, we introduce RSVP Mobility Proxy, an enhanced RSVP enabled border router to deal with QoS signaling at any mobility related network topology modification.

1 Introduction

Wireless devices are expected to increase in number and capabilities in the following years. The most important capability, though, for the next generation mobile devices is the inherent connectivity they should possess. One should be able to use them for any kind of communication, regardless of location or even movement.

The platform of choice for the interconnection of all the next generation devices tends to become the architecture of the Internet Protocol suite. It provides a simple, extensible and robust framework for building data communication applications. However, IP still lacks some of the necessary qualities for the full deployment of applications suitable for those appliances. Two major factors were not taken into account when designing this model some decades ago: mobility and guaranteed Quality of Service.

Efforts have been underway worldwide to provide support for the missing links of mobility and Quality of Service guarantees. These efforts began—and mostly continued— independently, leading to inefficiencies and/or incompatibilities between the approaches. Only during the recent past, was the need for their integration identified. Our proposal builds on the already established schemes for mobility and QoS guarantees and provides a necessary component for their seamless integration.

The rest of the paper is organized as follows: In section 2, we present the problem arising from the interworking of Mobile IP and RSVP in detail, as well as previous attempts to solve it. In section 3, we describe the mechanism of our proposed solution, while section 4 illustrates the application of this new mechanism in a more complex network topology. In section 5, a short discussion about the performance assessment is presented, and section 6 concludes the paper and points to possible future research activity.

2 Problem Identification

2.1 Quality of Service

Quality of Service is an ambiguous concept with different interpretations. In the Internet community, two schools of thought have gained ground for the provision of QoS: the Integrated Services Architecture [3] and the Differentiated Services Architecture [2]. The common aspect in both architectures is the effort undertaken to treat certain packets preferentially, so as to “guarantee” their on-time delivery. They are mainly targeted to real-time applications such as Voice-over-IP or streaming video.

RSVP [5] is a protocol implementation of the Integrated Services Architecture. It provides a well defined means to

specify a data flow and to reserve resources in the communication path of the flow. It is designed to deal end-to-end with unidirectional flows, facilitating QoS requests throughout the communication route. Its flexibility stems from the fact that it does not deal directly with QoS service details or flow specification, but merely interacts with the respective “packet scheduler” and “packet classifier” at each node to ensure provision of the necessary QoS and flow identification. In our study, we will use the Fixed Filter reservation style, suitable for unicast applications.

The Integrated Services architecture is best applied to access networks due to its fine-grained classification, whereas core networks can scale better when the Differentiated Services architecture is applied. In our study, we assume that QoS reservations are performed with RSVP in the access network. The core network can support either kind of QoS architecture. If it only supports Differentiated Services, then some interworking scheme can be employed [1]. If the core network supports RSVP, then no extra components need to be added.

2.2 Mobility Support

The mobility in the Internet world is dealt with Mobile IP [13]. Mobile hosts are uniquely identified by their Home Address, which is either preconfigured or assigned by their Home Agent. When they roam in a foreign network, they request a new address, the Care-of Address (CoA). They register afterward this new address to their Home Agent and can have a directly routable IP address. When route optimization [14] or Mobile IPv6 [10] is used, then any correspondent host uses the CoA to contact the mobile host instead of going through the Home Agent.

Mobile hosts may change CoAs when they change points of attachment. Two different types of handoff can be identified: A handoff between Access Points that are linked to the same Access router is handled exclusively at the link layer and no modification in the IP address of the mobile host is required. In case a mobile host moves between access points that are controlled by different access routers (network layer handoff) then a new CoA has to be assigned to it. In this paper we focus on network layer handoffs, since handoffs involving lower-level only signaling does not require any IP interaction, and hence no special Mobile IP-RSVP interworking.

2.3 Network Topology

We assume an access network large enough to accommodate network layer handoffs. The topology of such a network is illustrated in Fig. 1, where it is implied that Mobile IPv4 with route optimization [14] or Mobile IPv6 [10] is supported. In case a mobile host with established

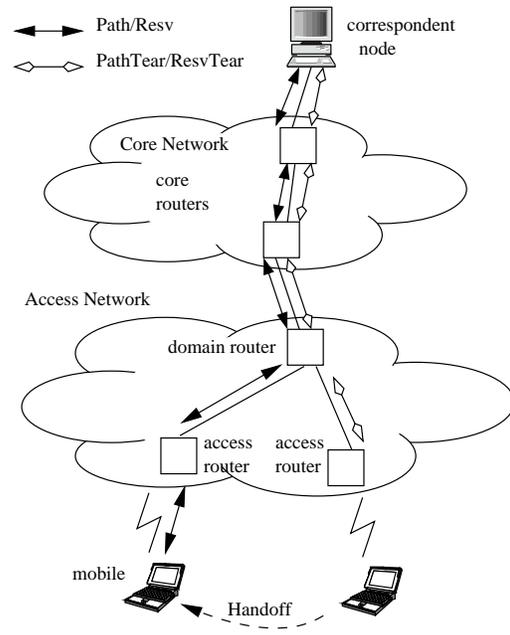


Figure 1. Network topology

RSVP data flows performs a network layer handoff, then a new round of RSVP signaling exchanges must be triggered. This happens because the resource reservation for the flow to the mobile is uniquely identified by the Session object, which is constructed by the triplet $\langle \text{DestAddress}, \text{DestPort}, [\text{ProtocolId}] \rangle$, and the IP DestAddress is modified. Moreover, the Path messages from a new IP address are treated as messages of a new session, originating a new Path state according to [4], since they stem from a different IP address. The Path messages contain a different Sender_Template object, and thus cannot match the Path State Block (PSB) established for the flow using the previous CoA.

The end-to-end RSVP signaling exchange needs to establish new RSVP soft states in every intermediate router between the mobile host and the correspondent host. Path and Resv messages have to be exchanged in both directions and new, independent reservations to be made. During the execution of this process, the mobile faces a serious deterioration of the supported QoS for its flows. The overhead increases when the connection endpoints are located far away from each other and the round trip time is large.

Resources have to be allocated twice for a period of time, until the previous reservation either times out or is released by the appropriate PathTear/ResvTear messages. In a high mobility environment or in networks that support a large number of mobile hosts this problem will result in a large waste of network resources. The Path/Resv, PathTear/ResvTear message exchanges are merged in Fig. 1 for brevity.

The RSVP message exchange is illustrated analytically

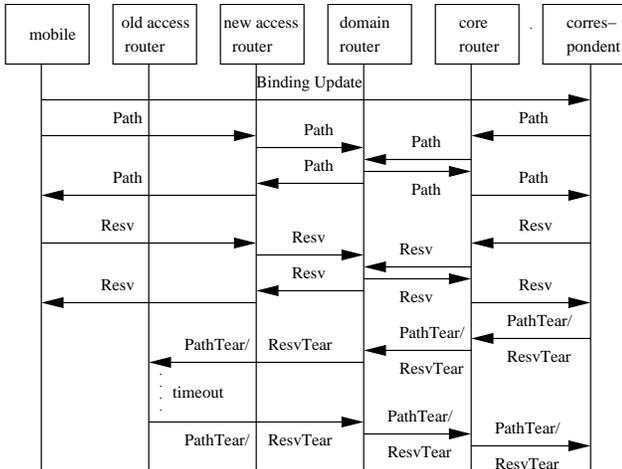


Figure 2. RSVP signaling after a handoff

in Fig. 2. In this signaling exchange, it is assumed that the mobile is handed over to the “new” access router, whereas the “old” access router has no way to be informed about the mobile migration. The mobile has already acquired a new CoA and has informed its correspondent host (and its Home Agent) about its new location.

The mobile and the correspondent host begin independently a re-establishment of the resources necessary for a QoS connection by sending to each other Path messages and responding to the received Path messages with Resv messages. The exchanged Path/Resv messages contain the new CoA of the mobile and act as new reservation requests.

As it is already obvious, this scheme is inefficient, bandwidth consuming, and slow. Some of the major problems identified with this approach are the following:

- Duplicate resource reservation for the same flow for a non-negligible time period. It is quite possible that the old Access Router has no information about the mobile handoff and thus must wait until the soft state expires to tear down the mobile-to-correspondent reservation.
- Possibility of dropping the reservation altogether due to limitations in resources in the core or other transit networks. The mobile Service Provider may have a prearranged guaranteed bandwidth with peer networks and the extra reservation request be denied.
- Long delay for reservation re-establishment. RSVP messages must traverse the network twice for that task.

2.4 Previous Work

It is widely recognized that RSVP and Mobile IP interworking is problematic due to the modification of the IP

address at the mobile endpoint. This has been widely recognized and several methods were proposed to deal with this inconsistency.

The obvious modification would be to change the RSVP semantics to include a different unique identifier in the Session object (possibly a unique integer) instead of the IP Destination Address [17]. The message processing rules should also change respectively, so as to treat packets originating from different IP addresses containing the same Session identifier in the same manner. In any case, related solutions demand heavy modifications of the RSVP protocol and full redefinition of its semantics.

Talukdar et al [16] proposed MRSVP, a solution in which reservations are pre-established in the neighboring Access Routers and thus, the mobile does not need to re-establish them. To achieve this, proxy agents are introduced and a distinction is made between active and passive reservations. Although this proposal solves the timing delay for QoS re-establishment with over-reservation, several disadvantages are introduced. Firstly, RSVP has to be enhanced to support passive reservations. Furthermore, the introduction of several proxy agents together with their communication protocol augments the complexity of the network. Finally, a drawback of MRSVP is that it relies on the mobile host to supply its mobility specification (i.e., a list of CoAs in the foreign subnets it may visit). Das et al [7] attempts to tackle this last issue by introducing two new protocols called Neighbor Mobility Agent Discovery Protocol (NMADP) and Mobile Reservation Update Protocol (MRUP).

Tseng et al [18] in attempt to ameliorate the excessive resource reservations that waste bandwidth and degrade the network performance, have proposed a hierarchical MRSVP Protocol. Using this protocol, resources are reserved only when a mobile host resides in the overlapping area of the boundary cells of two regions. Although this proposal outperforms MRSVP in terms of reservation blocking, forced termination and session completion probabilities while achieving the same QoS, it does not cater for the other disadvantages introduced by MRSVP.

Another approach is presented by Kuo et al [11], where RSVP is extended with an appropriate resource clear and a resource re-reservation process in order not to release and re-establish resources in the intermediate routers that form a common segment between the old and the new path. This proposal tackles efficiently the interworking issue between Mobile IP and RSVP at a penalty of extensive alteration of the RSVP protocol.

Chen et al [6] proposes an extension of RSVP based on multicast IP. The mobility of a host is modeled as a transition in a multicast group membership. The multicast tree is modified dynamically every time a mobile host is roaming to a neighboring cell. In this approach service degradation

and packet delay are minimized and re-routing of flows is eliminated. However, background processing is introduced and network resources are poorly managed.

Hadjiefthymiades et al [9] proposed a Path extension scheme. The RSVP protocol is modified in such a way that the existing reservation is preserved and an “extension” to the reservation is performed locally from the old to the new Access Router. To deploy such a solution several modifications are required in the network components and the related protocols.

In summary, the aforementioned approaches, while solving the interworking problem between RSVP and mobility, exhibit some inefficiencies related to the network resource usage or the introduction of major modifications and/or enhancements to existing protocols and network components. In the following section we describe a new approach that minimizes the delay in re-establishing data flows, does not waste network resources, is scalable and compatible with other QoS related protocols, and requires modifications only in the RSVP router at the edge of the access network.

3 RSVP Mobility Proxy

3.1 Reasoning and necessary infrastructure

Mobility solutions are not standardized yet, and there is a lively discussion in the scientific research community about different schemes supporting various features. The single mobility protocol feature, with which RSVP can be seamlessly deployed in mobile access networks, is the maintenance of a single IP contact address inside a mobility access domain. This functionality is the one that enables the RSVP soft state maintenance outside the mobility domain. This means that the mobile host may acquire different CoAs (Local Care-of Addresses, LCoAs) while moving inside a domain, but it would always be reachable by a “global” CoA (Domain Care-of Address, DCoA) through tunneling, address translation, host routing or any other routing variety, as suggested in various hierarchical mobility management schemes [15] [8].

In the rest of the paper the existence of such a mobile routing functionality is assumed, i.e. the ability to maintain a single contact IP address inside a domain. Note that it is only mandatory to keep the same IP address for as long as there are on-going connections to/from the mobile. The mobile host may change “global” CoAs (DCoAs) when no active connections are in place as proposed in [12]. This could be a useful flexibility when designing the routing functionality.

Furthermore, we assume a contact point such as the Mobility Anchor Point (MAP) [15] or the Gateway Foreign Agent (GFA) [8], which can supply authoritative answers about the mobile Home Address, location or current CoA.

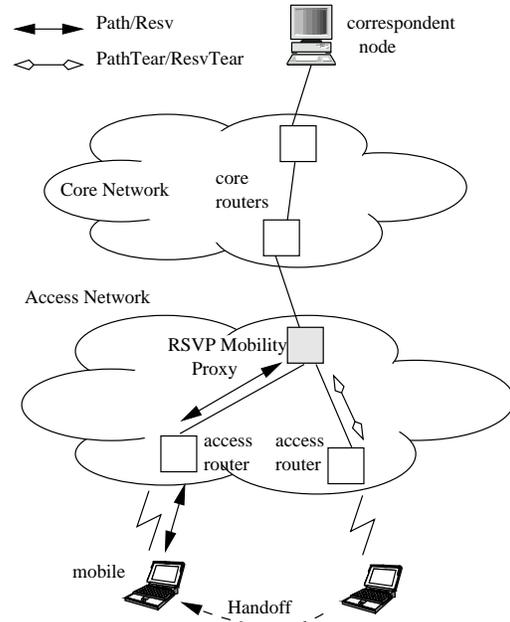


Figure 3. Network topology with RSVP-MP

Moreover, that border network entity possesses the ability to translate any LCoA to the unique across the mobile access network DCoA.

However, the address translation is performed only at the packet header level by the mobility routing functionality in the MAP/GFA entity, usually by means of en- or de-capsulation. RSVP messages contain the communicating addresses in their bodies, which must also be replaced by the respective LCoAs or DCoAs (depending whether the packet is forwarded inward or outward of the mobile access network).

3.2 Basic Functionality

RSVP Mobility Proxy (RSVP-MP) is the functional entity responsible for the RSVP message handling at the edge of the mobile network. It is essentially an RSVP-enabled router, which is also mobility aware. It keeps track of the valid bindings between the DCoAs and the LCoAs and records any modification of these bindings. The reservations are based on the (unique for each mobile host) DCoA. That means, that the IP address of the mobile host is always represented in the RSVP internal states by its DCoA format.

RSVP-MP performs dynamic address translation as necessary in any case. Specifically, RSVP-MP keeps only DCoAs in its internal State Blocks (Path State Block PSB, Resv State Block RSB, etc.). The RSVP messages are actually processed in their “DCOA” form when the PSB, RSB updating is taking place. Some functions though, require knowledge of the DCoA-LCoA binding to operate correctly.

Those functions are identified in the following analysis. The states for the other State Blocks must be updated accordingly.

We examine the processing of the four basic message cases in RSVP-MP and point out the implementation differences to [4]. The important factors are the type of the message and the incoming interface.

1. Path message from an internal interface (uses LCoA)
 - Swap LCoA in source header with DCoA.
 - Swap LCoA in Sender_Template with DCoA.
 - Update PSB.
 - Forward Path to the respective external interface.

2. Resv from an external interface (uses DCoA)
 - Swap DCoA in Sender_Template with LCoA. Sender_Template resides in the Resv message's Filter_Spec object, which is contained in the flow descriptor in the RSVP message.
 - Check if reservation is possible.
 - Update RSB.
 - Send Resv to next hop (in the internal network).

3. Path from an external interface (uses DCoA)
 - Update PSB. The update_PSB function contains a Route_Query routine. We must enhance that routine to return the correct interface that points to the LCoA; DCoA is a "virtual" address.
 - Swap DCoA in destination header with LCoA.
 - Swap DCoA in the Session object with LCoA.
 - Forward Path to the respective internal interface.

4. Resv from an internal interface (uses LCoA)
 - Swap LCoA in the Session object with DCoA.
 - Determine outgoing interface; this must be the interface pointing to the LCoA. This function needs to be enhanced.
 - Check if reservation is possible.
 - Update RSB.
 - Send Resv to next (external) hop.

A message diagram for a bidirectional QoS reservation is presented in Fig. 4. According to the detailed signaling exchange, the reservation states outside the access network are configured for the stable DCoA. Only the reservations inside the access network are LCoA dependent. This simplifies the reservation re-establishment task for the mobile host's new location and restricts the vital RSVP message exchange inside the access network (Fig. 3).

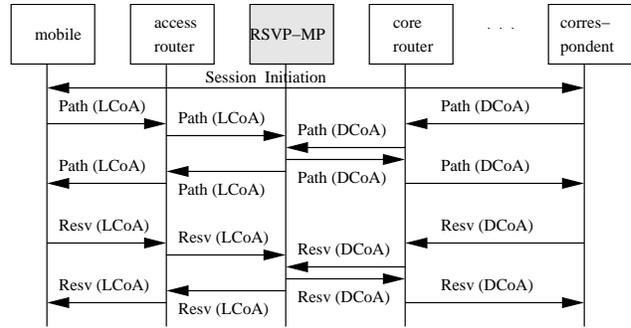


Figure 4. RSVP signaling through RSVP-MP

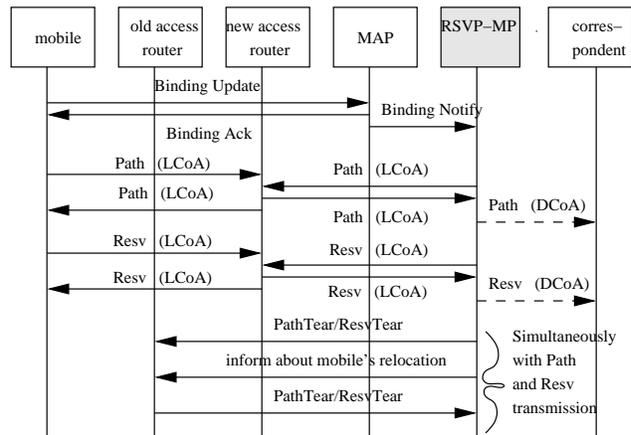


Figure 5. RSVP signaling through RSVP-MP after a handoff

3.3 Mobility Related Functionality

In the case of a handoff, an asynchronous notification must be delivered by the access network's mobility control authority (e.g. MAP), to the RSVP-MP. The two entities may be collocated at the border router, though they need not be. By reception of such a notification, RSVP-MP examines its internal database, which contains the mobile hosts' <DCoA, LCoA> mappings and finds out whether a reservation for that particular mobile host is already in place. An analytical RSVP signaling exchange after a handoff is illustrated in Fig. 5.

It is assumed that the mobile host has acquired a new LCoA and wishes to re-establish the reservation for the information flow between itself and the correspondent host. It is also assumed that resources are reserved both in the up-link and downlink direction. The mobile host issues a Binding Update with its newly acquired LCoA, which reaches the mobility control authority of the mobile access network. The mobility control authority issues an asynchronous notification to RSVP-MP.

The RSVP-MP checks for reservations in the downlink direction for Session objects regarding the unchanged mobile DCoA. If such an entry exists, the RSVP-MP issues a Path message (containing the correspondent host's IP address as if it was issued by the correspondent host across the network). The mobile host responds with a Resv to the correspondent host. The Resv message is intercepted in the RSVP-MP and the LCoA is translated (or most possibly decapsulated) into the DCoA both in the packet's headers and its contents. At the same time, and for the uplink direction, the mobile host issues a Path message to the correspondent host to re-establish the QoS reservation. The RSVP-MP intercepts it, translates the LCoA into the DCoA before it lets it out of the access network and responds to it without waiting for any answer from the correspondent host.

The actual RSVP signaling is restricted inside the access network. Any Path or Resv messages transmitted to the core network merely serve as state refresh messages. No actual Path or Reservation state modifications are performed in routers outside the area controlled by the RSVP-MP.

A parallel activity, of equal importance, is the reservation release to, and from the previous LCoA inside the mobile access network. The release of the downlink reservation state is performed by a PathTear/ResvTear submission toward the old LCoA, i.e. toward the old Access Router. The uplink reservation release and any wireless reservation is trickier. An asynchronous notification (either by the mobility controlling authority or by the RSVP-MP) is necessary so that the uplink and the wireless reservations are released on time and not waiting for the RSVP soft state to expire.

4 Multiple RSVP-MP Support

The RSVP-MP concept can be extended to support more than one enhanced edge RSVP router. The only prerequisite (in terms of mobility routing infrastructure) is the linkage of the Mobility Anchor Point (MAP) to each of the edge RSVP-MPs and their continuous updating about network topology modifications (i.e. mobile handoffs). An example access network topology featuring three RSVP-MPs is presented in Fig. 6. For simplicity's sake, we have presented only one level of hierarchy in the access network. Multiple levels of hierarchy with multiple RSVP-MP levels can be implemented in the same manner.

In the multiple RSVP-MP case, the process for uplink and downlink resource reservation can be quite different since, the uplink and downlink streams may follow different routes and pass through different RSVP-MPs. For generality's sake, we assume that there is a duplex resource reservation established for the mobile host. The uplink reservation traverses RSVP-MP 1, whereas the downlink reservation traverses RSVP-MP 3.

The interesting part for the multiple RSVP-MP scheme

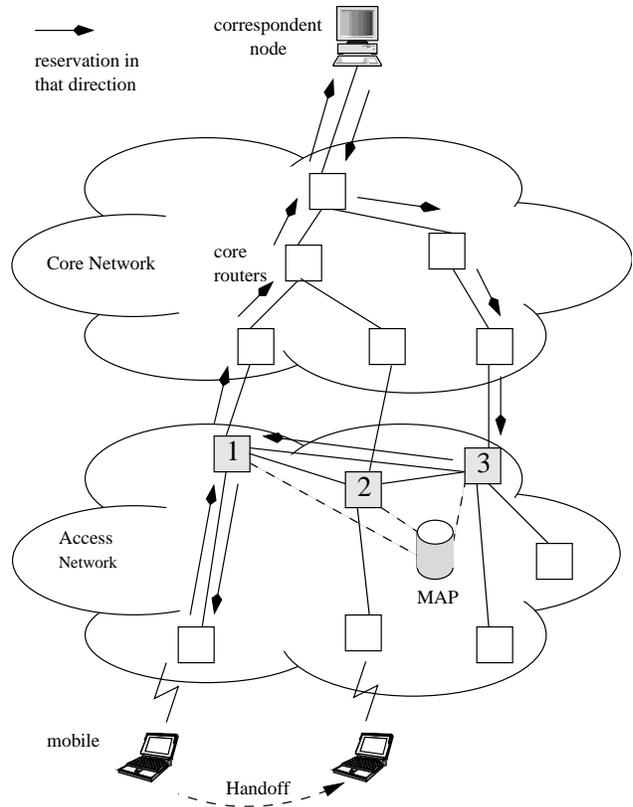


Figure 6. Support for multiple RSVP-MPs

arises after a handoff. In Fig. 7, the mobile was handed off to an access router connected to RSVP-MP 2. The MAP notifies immediately every RSVP-MP in the same level. If some RSVP-MP (RSVP-MP 1 in our case) services an uplink reservation for that mobile host, it broadcasts this information <Proxy IP address, mobile DCoA, session(s) serviced> to all of its neighboring RSVP-MPs. Thus, RSVP-MP 2 acquires the information that the mobile host already has an uplink reservation and it is currently handled by RSVP-MP 1. In order not to re-establish resources through the core network, RSVP-MP 2 has to route the respective QoS traffic through RSVP-MP 1.

The uplink reservation re-establishment process starts with a Path message from the mobile host using the new LCoA, which is intercepted at RSVP-MP 2. The DCoA corresponding to the Path message's LCoA is compared to the list of addresses serviced by other RSVP-MPs, and if it matches, is forwarded to the servicing RSVP-MP, namely to RSVP-MP 1. A host route entry must be configured for the particular session and remain valid until the end of the session. However, the uplink route traverses RSVP-MP 1 only for the aforementioned session. Any other traffic including best-effort traffic or a QoS session initiated at the new access router is routed through normal operations.

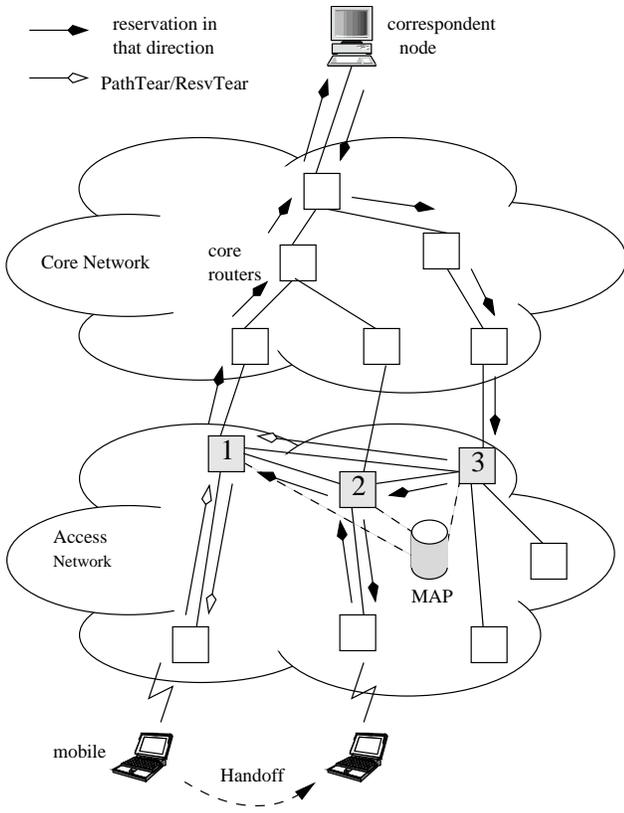


Figure 7. Reservations in a multiple-proxy network after a handoff

The downlink traffic continues to be serviced through RSVP-MP 3, since the DCoA of the mobile remains unchanged. MAP notifies RSVP-MP 3 about the mobile LCoA modification and the proxy issues a Path message toward the new LCoA to re-establish the reservation in the downlink direction to which the mobile responds with a Resv. The downlink signaling happens in parallel with the uplink signaling and keeps the reservation re-establishment time bound by the size of the access network. The reservations and traffic routes after the handoff are illustrated at Fig. 7. An added benefit of the MAP notifying the edge proxies is the minimized duplicate reservations interval. The PathTear/ResvTear resource cancellation messages should be signaled in parallel with the other RSVP resource reservation messages to avoid network resource waste.

5 Performance assessment

The most important benefit from the introduction of RSVP-MP is the QoS signaling reduction outside the access network. The advantages of signaling reduction can be observed both on the core network as well as on the end-

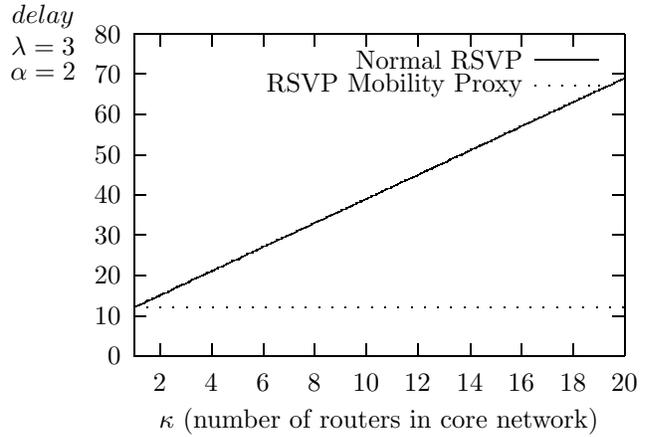


Figure 8. Reservation re-establishment delay

user service. Stale reservations are reduced at the core network, avoiding resource waste in terms of bandwidth. The minimized RSVP signaling in the core network also reduces processing and bandwidth requirements in the routers. The end-user operating the mobile device on the other hand will notice a tremendous improvement in reliable real-time service re-establishment after a handoff.

Analytically, let the access network consist of λ hops and the core network of κ hops. Let the processing delay for each RSVP message equal to 1 for the normal RSVP routers and $\alpha, \alpha > 1$ for the RSVP-MP, since the processing complexity will be somewhat larger for this router. Hence, the reservation re-establishment delay will be:

- for the normal RSVP case, we assume that the Binding Update reaches the correspondent host at the same time with the first Path message from the new CoA of the mobile host. Thus, the delay will consist of the time the original Path message spends reaching the correspondent host plus the time Resv and Path from the correspondent host spend to reach the mobile host plus the time the final Resv makes to reach the correspondent host. That is $3/2$ the round trip time, i.e. $delay = 3(\lambda + \kappa)$
- for the RSVP-MP case, under the same assumptions, the time will be $delay = 3(\lambda + \alpha - 1)$.

According to the aforementioned equations, the RSVP-MP approach is obviously better, if $\alpha < \kappa + 1$, i.e. if the processing delay of the RSVP-MP is less than $\kappa + 1$ times the processing delay of a normal RSVP router. As we can see in Fig. 8, the delay optimization increases when the distance to the correspondent host increases.

The default reservation re-establishment delay is expected to be even smaller for RSVP-MP if the asynchronous MAP notification to RSVP-MP feature is implemented. Using this optimization, we conclude that the time needed for

re-establishment is $delay = 2(\lambda + a - 1)$. With this feature implemented, the horizontal line describing the RSVP-MP delay in Fig. 8 will be shifted λ units downwards.

Moreover, there is no need for duplicate reservation in the core network for the same session. This leads to resource waste avoidance as well as economical benefits (the QoS guarantee always comes at some additional cost). A consequence of that efficient resource handling is the elimination of the risk that the (duplicate) reservation request will be rejected due to lack of available resources in the core network, as was the case with normal RSVP operation.

The complexity issues in the RSVP-MP are the most important drawback for our proposed QoS solution. It is the only network component though that is affected by our scheme. Every other network component, including core routers, correspondent nodes, internal access routers and, most importantly, the mobile terminal devices should only conform to the RSVP standard [5].

The multiple RSVP-MP extension introduces some more technical problems. It introduces a deviation from the RSVP semantics with the route enforcement, bypassing the RSVP approach of not enforcing routing policy and leaving it to other protocols. One other possible drawback emerges from the creation of a possible bottleneck in the lines connecting RSVP-MPs, due to the rerouting of uplink QoS traffic through the first serving RSVP-MP. We assume single RSVP-MP access networks in the following analysis.

6 Conclusions and Future Work

The signaling time for the reservation re-establishment is significantly reduced by the introduction of the proposed enhancements. The network resource usage efficiency is greatly enhanced. The request rejection probability due to over-reservations in the core network is also reduced and the compatibility requirements are kept to a minimum.

The asynchronous notification of the old point of attachment (Access Router) about the handoff is essential as we pointed out. While it is not a prerequisite for our solution, we estimate that it is of major importance for efficient network usage, and should be deployed regardless of any other optimization.

RSVP Mobility Proxy should be developed in cooperation with any advances in hierarchical mobility management schemes. However, hierarchical mobility management is still in the research stage, thus, major or minor modifications are expected.

A load distribution approach is of major importance, since the edge router of any access network is likely to become the bottleneck for the communication and especially for QoS sensitive flows. Several closely interworking RSVP Mobility Proxies would deal in an efficient manner with the scalability issue of seamless mobility while maintaining

the QoS reservations in place. A communication protocol between RSVP Mobility Proxies in the same or different mobile access networks should be deployed to facilitate the necessary information exchange.

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