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An Efficient RSVP–Mobile IP Interworking Scheme

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Abstract. During the past years, several attempts have been made to develop functionality for mobility management support and QoS provision in the realm of the IP networks. Since IP was not designed to support such functionality, new protocols have been specified and implemented to tackle these issues. Mobile IP is currently the dominant protocol that allows users to retain connectivity while roaming in IP networks. RSVP (Resource reSerVation Protocol) is a well established protocol for reserving network resources to support QoS requirements. These protocols, when deployed separately, can work quite efficiently. However, if their functionality is combined, several inefficiencies arise in terms of QoS deterioration and misuse of the network resources. To minimize these inefficiencies, we propose a new approach that limits mobility and QoS related network modifications inside the domain, in which a user moves. The deployment of our scheme enhances the network resource usage efficiency, while minimizing the duration of the QoS deterioration experienced after a terminal movement. To quantify the advantages of our proposal, we have developed an analytical and a simulation model that we also present in this paper.

Keywords: RSVP, mobile IP, QoS, mobility management

1. Introduction

The wireless communication devices industry sector is experiencing an enormous growth in terms of units as well as capabilities for the embedded systems. People are getting accustomed to be productive while on the move, utilizing the capabilities those devices offer. The connectivity support, one of the most essential requirements, is likely to rely on the Internet Protocol architecture. It provides a simple, scalable 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 small, yet so powerful devices. Two major factors were not taken into account when designing this model some decades ago: mobility and guaranteed QoS.

Efforts have been underway worldwide to provide support for the missing links of mobility and QoS guarantee. Mobile IP [17] is the dominant protocol for mobility management support developed for IP. Mobile hosts (MHs) are uniquely identified by their Home Address, which corresponds to the address used when located in their home networks. When roaming in foreign networks, MHs request and acquire a new address, the Care-of Address (CoA). This new address is registered with their Home Agent (their mobility enhanced home router) and the MHs become accessible to other hosts through their home network. When route optimization [18] is used, or IPv6 and Mobile IPv6 [11] is deployed, then any host wishing to communicate with the MH uses the CoA for direct communication instead of going through the Home Agent.

Concerning QoS provision, two schools of thought have gained ground in the Internet community: the Integrated Services architecture [5] and the Differentiated Services architecture [3]. RSVP [4] is the signaling protocol for Integrated Services architecture support. It provides a well defined means to specify data flows and to reserve resources in the communication path of the flow. It is designed to deal with end-to-end unidirectional flows, facilitating QoS requests throughout the communication route. In this paper we assume the use of the Fixed Filter reservation style (defined in [4]), suitable for unicast applications.

It is argued in the literature [1] that 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 [2].

The aforementioned efforts to provide mobility support and QoS guarantees in the Internet began – and mostly continued – independently, leading to inefficiencies and/or incompatibilities between the approaches. Only recently was the

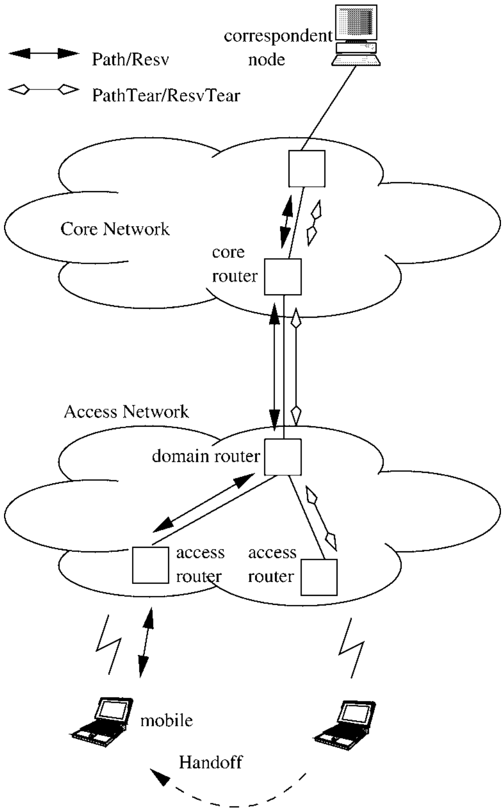

Figure 1. Network topology.

need for their integration identified. Our proposal builds on the already established schemes for mobility and QoS guarantees and provides the necessary functionality for their seamless integration.

The rest of the paper is organized as follows. Section 2 presents 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 functionality of our proposed solution, and, in section 4, we analyze its performance, using an analytical and a simulation model, and compare it to that under plain RSVP operation. Section 5 concludes the paper and points to possible future research.

2. Problem formulation

A MH changing points of attachment to the network during an active call is performing a handoff. Two different types of handoffs can be identified: handoffs between access points that are linked to the same access router and handoffs between access points that are linked to different routers. In the former case, the handoff is handled exclusively at the link layer and no modification in the IP address of the MH is performed. In the latter case, however, a new IP address (CoA) is assigned to the mobile. In this paper, we assume an access network large enough to accommodate network layer handoffs, where special Mobile IP–RSVP interworking is required. The topology of such a network is illustrated in figure 1. The existence of Mobile IPv4 with route optimization [18] or Mobile IPv6 [11] is also assumed.

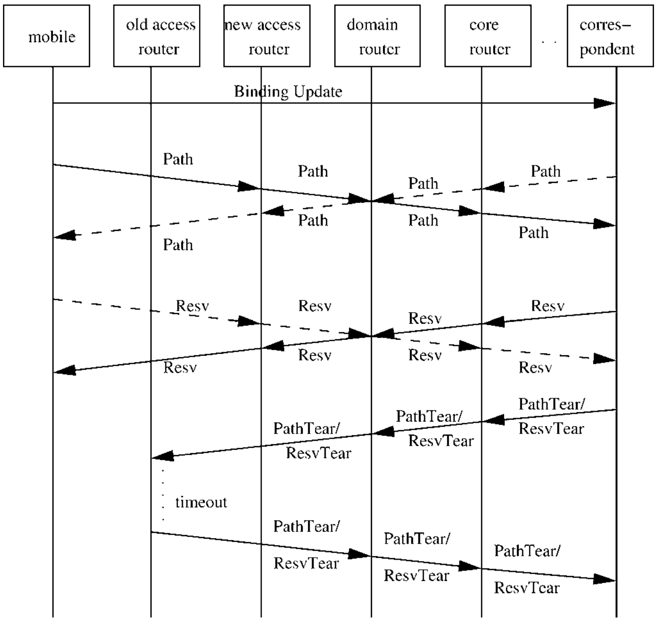

Figure 2. Analytical RSVP signaling after a handoff.

If a MH, with established RSVP data flows, performs a network layer handoff, its IP address changes, and a new round of RSVP signaling exchanges must be triggered. RSVP creates soft session states in every intermediate router of the traffic flow. Each session is uniquely identified by the Session object, which is constructed by the triplet ⟨DestAddress, DestPort, [ProtocolId]⟩. Thus, the downlink reservation (the packet flow toward the mobile) becomes invalid, since the DestAddress parameter has been changed. The new uplink re-establishment is also affected, since the Path messages sent from the MH contain its new IP address. These messages are considered to correspond to a new session and generate a new Path state, according to [6].

With the existing RSVP functionality, independent RSVP sessions are established between the correspondent host and the MH, after the execution of a network layer handoff. The RSVP message exchange is illustrated in figure 2. In this signaling exchange, it is assumed that the MH is handed off to the "new" access router, whereas the "old" access router has no way to be informed about the MH's migration. The MH has already acquired a new CoA and has informed its correspondent host (and its Home Agent) about its new location. The MH and the correspondent host begin independently a re-establishment of the resources necessary for a QoS supported session by exchanging Path and Resv messages. These messages contain the new CoA of the mobile and act as new reservation requests.

This scheme is obviously slow, inefficient, and bandwidth consuming. Some of the major problems identified with this approach are the following:

- *Long delay for reservation re-establishment.* RSVP messages must traverse twice the network end-to-end to re-establish a session, resulting in a major deterioration in the quality of active flows.

- *Duplicate reservation of resources for a non-negligible time period.* After the execution of a handoff, network resources are allocated twice for the same session, toward the old and the new location of the MH. This duplication exists until resources on the old path are explicitly released or timed out.
- *Increased blocking probability of new session requests.* The duplication of resource requirements in high mobility environments or in networks that support a large number of MHs, can affect the overall efficiency of the network. In such environments a new reservation request will experience a higher possibility of getting rejected.
- *Increased cost for providing QoS enabled services.* It is safe to assume that the service provider of the access network will have a prearranged Service Level Agreement (SLA) with an upstream Internet Service Provider (ISP, core network provider). Duplication of reserved resources on the access-core link would lead to lower average resource utilization levels for the same cost.

2.1. Previous work

The interworking problems of Mobile IP and RSVP have been widely recognized and several methods have been 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 [22]. 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. A similar approach is suggest by Shen et al. [19], where the home address of a MH is used as the unique identifier of a session.

Talukdar et al. [21] proposed MRSVP, a solution in which reservations are pre-established in the neighboring Access Routers. 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 reestablishment with over-reservation, it has several disadvantages. 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 MH to supply its mobility specification (i.e., a list of CoAs in the foreign subnets it may visit). Das et al. [8] attempt 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. [23], in attempt to ameliorate the excessive resource reservations of MRSVP, proposed the Hierarchical MRSVP. According to HMRSVP, resources are reserved only when a MH 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 and Ko [13], 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 by extensively modifying the RSVP protocol.

Chen and Huang [7] proposed 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 MH 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. [10] 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 to existing protocols and network components. In the following section we describe a new approach that minimizes the delay in reestablishing 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

As proposed in [19,22], we think that using a unique and permanent identifier for every RSVP flow should be the basic concept to achieve efficient interworking between RSVP and Mobile IP. Our goal, however, is to affect as less as possible the existing infrastructure and protocols. The key idea of our proposal is to minimize any modifications (i.e., RSVP flows re-establishments) inside the access network where a MH moves. To achieve this, we propose that a MH may acquire different CoAs (Local Care-of Addresses, LCoAs) while moving inside an access 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 [9,20].

In the rest of the paper the existence of such a mobility management functionality is assumed, i.e., the use of a unique DCoA. Note that it is only mandatory to keep the same DCoA for as long as there are ongoing connections to/from the MH. The MH may change DCoA when no active connections are in place as proposed in [15]. This could be a useful flexibility when designing the routing functionality.

Furthermore, we assume a mobility management authority component such as the Mobility Anchor Point (MAP) [20] or the Gateway Foreign Agent (GFA) [9], which can supply authoritative answers about the MH's Home Address, location or current CoA.

3.2. Basic functionality

Based on the aforementioned assumptions, we propose the introduction of the RSVP-MP (RSVP Mobility Proxy). RSVP-MP is actually the router responsible for the RSVP message handling at the edge of the access network and in addition capable of:

- keeping track of the correspondence between the DCoAs and the LCoAs and recording any modification of it by communicating with the mobility controlling authority of the access network (e.g., MAP or GFA),
- performing dynamic address translation of DCOA to LCOA and vice versa, when necessary.

RSVP reservations are made based on the (unique for each MH) DCoA. This means that the IP address of the MH is always represented in the RSVP internal State Blocks (Path State Block PSB, Resv State Block RSB, etc.) in its DCoA format. The address translation is performed only at the packet header level at the edge of the network, usually by means of en- or decapsulation. 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).

The RSVP messages are translated into their "DCoA" format before PSB, RSB updating takes place. Some functions in the RSVP message processing though require knowledge of the DCoA-LCoA binding to operate correctly. These 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 in comparison to [6]. The important factors are the type of the message and the incoming interface. The internal interfaces are those interacting with the access network, whereas the external interfaces are those interacting with the upstream ISP.

1. Path message from an internal interface (LCoA):
    - Swap LCoA in the source header of the packet with DCoA.
    - Swap LCoA in the Sender_Template object with DCoA.
    - Update PSB.
    - Forward Path to the respective external interface.
2. Resv message from an external interface (DCoA):
    - Swap DCoA in the Sender_Template object with LCoA. This object 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 (resources, policy).
    - Update RSB.
    - Send Resv to next (internal) hop.
3. Path message from an external interface (DCoA):
    - Update PSB. The update_PSB function contains a route query routine, which must be enhanced to return the correct interface that points to the LCoA; DCoA is a "virtual" address.
    - Swap DCoA in the destination header of the packet with LCoA.
    - Swap DCoA in the Session object with LCoA.
    - Forward Path to the respective internal interface.
4. Resv message from an internal interface (LCoA):
    - Swap LCoA in the Session object with DCoA.
    - Determine outgoing interface; this function must be enhanced, since the correct interface should be the interface toward the LCoA.
    - Check if reservation is possible (resources, policy).
    - Update RSB.
    - Send Resv to next (external) hop.

A message sequence chart for a bidirectional QoS reservation with the use of our scheme is presented in figure 4. The reservation states outside the access network are configured for the stable DCoA. Only the reservations inside the access network are LCoA dependent. This establishes the necessary infrastructure to accommodate mobility events inside the access network, without the need to propagate the topology modification outside of it (figure 3).

3.3. Mobility related functionality

In case of a handoff, we assume that the mobility control authority (MAP/GFA) is either in control or immediately notified about it. An asynchronous notification about the handoff must be delivered to the RSVP-MP by, e.g., MAP. The two entities may be co-located at the edge domain router. By the reception of the handoff notification, the RSVP-MP examines its internal Binding Cache, which contains the MHs' ⟨DCoA, LCoA⟩ binding and finds out whether a reservation for the MH that changed its point of attachment was already in place. An analytical RSVP signaling exchange after a handoff is illustrated in figure 5.

In figure 5, it is assumed that a MH has acquired a new LCoA and wishes to re-establish the reservation for the information flow between itself and the correspondent host, and

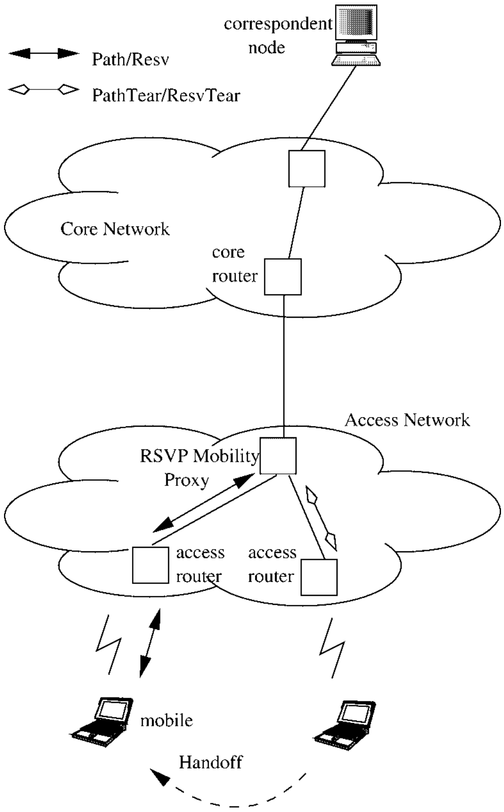

Figure 3. Network topology with the RSVP-MP.

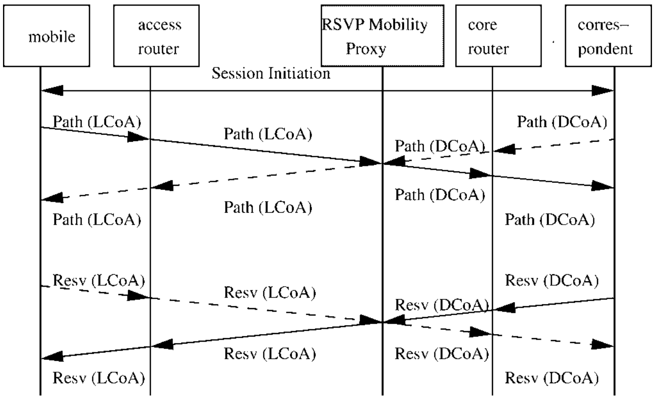

Figure 4. RSVP signaling through the RSVP Mobility Proxy.

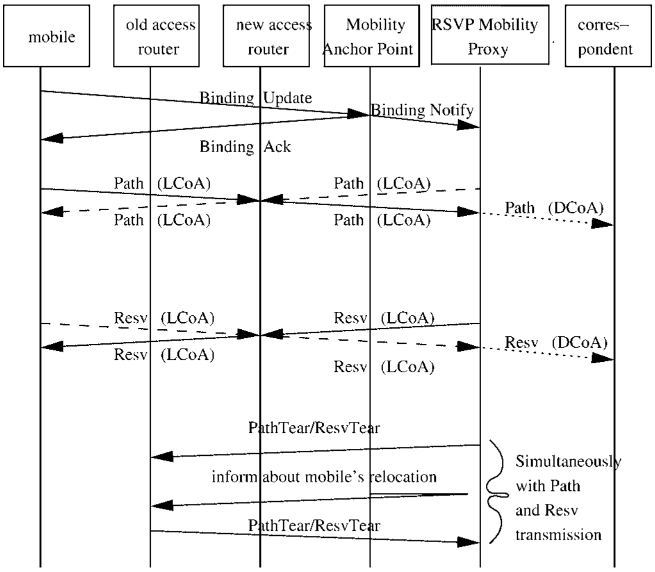

Figure 5. RSVP reservation signaling through the RSVP-MP after a handoff.

that resources must be reserved for both directions. The MH issues a Binding Update with its newly acquired LCoA, which reaches the mobility control authority of the mobile access network. The mobility control authority then issues an asynchronous notification to RSVP-MP.

The RSVP-MP checks for reservations in the downlink direction for Session objects regarding the MH's unchanged 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 MH responds with a Resv to the correspondent host. The Resv message is intercepted in the RSVP-MP and the LCoA is translated (or possibly decapsulated) into the DCoA both in the packet's headers and its contents. At the same time the MH issues in parallel a Path message to the correspondent host to re-establish the uplink QoS reservation. The RSVP-MP intercepts it, translates the LCoA into the DCoA before forwarding it to the core network and responds to it without waiting for any answer from the correspondent host.

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

A parallel activity, of equal importance, is the release of the downlink and uplink reservations corresponding to the MH's previous LCoA. The release of the downlink Path and Resv state is triggered by the RSVP-MP that sends a PathTear/ResvTear submission toward the old LCoA, i.e., toward the old Access Router. The reservation release from the old Access Router to the RSVP Mobility Proxy and any wireless reservation controlled by that Access Router 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 explicitly soon after the handoff completed and not after the RSVP soft states expired.

We should note here that our scheme is also applicable in more complex topologies, where more than one RSVP-MPs can exist in the edge of a network. As described in [16], this is achieved with no further modifications or requirements.

4. Performance evaluation

As mentioned in section 2, RSVP–Mobile IP interworking increases the blocking probability of RSVP sessions. RSVP-MP aims to improve this inefficiency. Furthermore, the reservation re-establishment delay will be likely much higher in the RSVP case, since the reservation signaling needs to travel twice end-to-end. Obviously, the re-establishment delay increases proportionally to the round-trip delay. In the RSVP-MP case, this delay depends only on the intra-access network delay.

The deployment of RSVP-MP eliminates the need for duplicate reservations through the access-core link for the same session. A consequence of the efficient resource handling is that there will be no duplicate reservation requests, that might be rejected due to lack of available resources in the access-core link, as is the case with plain RSVP operation.

In this section we provide an analytical model that estimates the blocking probability of requested sessions and compares the related performance of RSVP and RSVP-MP. We have also developed a simulation model that collects measurements including requests for QoS supported sessions as well as the success and failure ratio of new or handoffed sessions. Using the simulation model, we are also able to quantify the network utilization in terms of stale and active QoS supported sessions.

We focus our study on the link between the edge router in the access network and the core router in the upstream ISP, since we believe that this link is usually the bottleneck for access networks. Furthermore, it is expected that this link would be an expensive resource, and its optimum utilization is economically beneficial.

4.1. Analytical model

In our analytical model, an access network covering a geographical area by contiguous cells is considered. These cells are organized in clusters served by access routers as depicted in figure 6. This hierarchical pattern is considered throughout the access network up to the edge RSVP access router. The edge router directs its input traffic to the core network through a core router. All clusters at the same level are assumed statistically identical and of the same shape, which for analysis reasons is assumed to be circular with radius r_i (the subscript i denotes the level index).

Two levels are considered in the hierarchical model of the access network (figure 6). The clusters of the second level ($i = 1$) consist of N_0 clusters of the first level ($i = 0$). For simplicity reasons and analytical tractability, the following assumptions are made:

1. New traffic is generated at the lowest level according to a Poisson process with parameter λ_0.
2. The call durations are modeled as independent random variables, following the exponential distribution with parameter μ.
3. Mobile stations' cluster dwell times are modeled as exponentially distributed random variables with parameter n_i, depending on the cluster level.
4. A fluid flow mobility model is used to describe cluster boundary crossings and thus to find n_i.

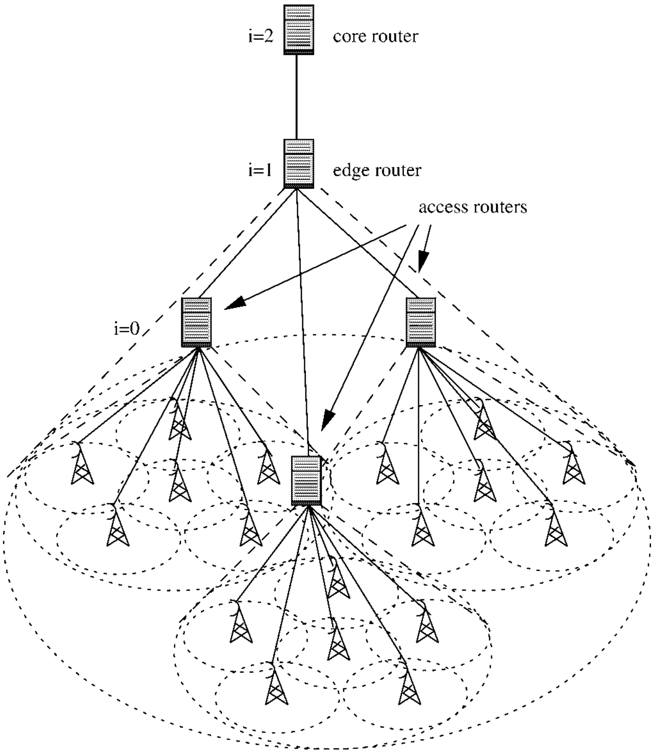

Figure 6. Access network topology.

Using the last assumption, the parameters n_i for the cluster dwell time are given by [12]

$$n_i = \frac{2v}{\pi r_i}, \tag{1}$$

where v denotes the mobile stations' velocity. The handoff probability $P_{h,i}$ is given by

$$P_{h,i} = \frac{n_i}{\mu + n_i}. \tag{2}$$

The session duration (minimum time of cluster dwell time and call duration) follows exponential distribution with parameter $\mu_i = \mu + n_i$.

The aim is to find the blocking probability at the link between the access and the core router, both for the RSVP and RSVP-MP method, given the rate of new arrivals, the mobility of the users and the number of shared channels (c_i) at each intermediate router of level i. An RSVP session is considered to occupy one channel, and since QoS is guaranteed and fixed, we can consider the network model as circuit-switched. We denote by $P_{b,i}$ the blocking probability at the routers of level i. The generation rate of handoffs at the lowest level, $\lambda_{h,0}$, satisfies the following equation:

$$\lambda_{h,0} = P_{h,0}(\lambda_0 + \lambda_{h,0})(1 - P_{b,0}), \tag{3}$$

where $P_{b,0}$ is calculated using the Erlang-B formula:

$$P_{b,0} = \frac{A_0^{c_0}/c_0!}{\sum_{i=0}^{c_0} A_0^i/i!}. \tag{4}$$

Equation (3) is justified as follows: $\lambda_0 + \lambda_{h,0}$ denotes the total traffic rate due to new arrivals and handoffs in the lowest level cluster. Multiplying by $(1 - P_{b,0})$, which is the probability of accepting the traffic, we obtain the "active" traffic rate in the cluster. Finally, multiplying the "active" rate by $P_{h,0}$, it yields the handoff rate in the neighboring cluster. In steady state, this rate is the same across all the clusters of the same level.

The offered traffic A_0 consists of the traffic due to new arrivals, $\lambda_0/(\mu + n_0)$, the traffic due to handoffs into the cluster, $\lambda_{h,0}/(\mu + n_0)$, and the traffic that stale connections create, $\lambda_{h,0}d$, where d is the RSVP flow reservation maintenance time without refreshes:

$$A_0 = \frac{(\lambda_0 + \lambda_{h,0})}{\mu + n_0} + \lambda_{h,0}d. \tag{5}$$

We should note that stale connections consume part of the resources and, thus, their negative effect on the blocking probability can be modeled as an additional source of traffic.

At the next level, the new traffic arriving at the router is $\lambda_1 = N_0 \cdot \lambda_0 \cdot (1 - P_{b,0})$. The handoff rate between edge routers is given by

$$\lambda_{h,1} = P_{h,1}(\lambda_1 + \lambda_{h,1})(1 - P_{b,1}) \tag{6}$$

with

$$\begin{aligned} P_{b,1} &= \frac{A_1^{c_1}/c_1!}{\sum_{i=0}^{c_1} A_1^i/i!}, \\ A_1 &= \frac{N_0\lambda_0(1 - P_{b,0})}{\mu + n_1} + N_0\lambda_{h,0}d. \end{aligned} \tag{7}$$

Using plain RSVP, the aggregate traffic that the edge router passes to the core router is

$$A_{\text{RSVP}} = \frac{N_0\lambda_0(1 - P_{b,0})}{\mu + n_1}(1 - P_{b,1}) + N_0\lambda_{h,0}d, \tag{8}$$

whereas in the case of RSVP-MP, the offered traffic is

$$A_{\text{RSVP-MP}} = \frac{N_0\lambda_0(1 - P_{b,0})}{\mu + n_1}(1 - P_{b,1}). \tag{9}$$

Restricting the number of edge routers to one, we obtain $P_{h,1} = 0$, and therefore, $\lambda_{h,1} = 0$, and $n_1 = 0$. In this case equations (8) and (9) can be simplified as

$$A_{\text{RSVP}} = \frac{N_0\lambda_0(1 - P_{b,0})}{\mu}(1 - P_{b,1}) + N_0\lambda_{h,0}d, \tag{10}$$

$$A_{\text{RSVP-MP}} = \frac{N_0\lambda_0(1 - P_{b,0})}{\mu}(1 - P_{b,1}). \tag{11}$$

The blocking probability between the edge and the core router is

$$P_{b,\text{RSVP}} = \frac{A_{\text{RSVP}}^{c_2}/c_2!}{\sum_{i=0}^{c_2} A_{\text{RSVP}}^i/i!}, \tag{12}$$

$$P_{b,\text{RSVP-MP}} = \frac{A_{\text{RSVP-MP}}^{c_2}/c_2!}{\sum_{i=0}^{c_2} A_{\text{RSVP-MP}}^i/i!}. \tag{13}$$

4.2. Simulation model

We have built a simulation environment using the Octave tool [14] in a Linux PC. We used the access network topology of figure 6, Poisson traffic generation, exponentially distributed call duration and the fluid flow mobility model described in [12]. The general assumptions that we made were those of the analytical model. The simulation model allowed us to collect more realistic measurements and to obtain various other results other than the blocking probability, such as the percentage of active and stale reservations in various levels.

The simulation used 1-second time intervals as its time step-function. The decision for a handoff is taken at the end of a reservation time-period, and mobiles switch to another access router with probability $P_{h,0}$. We need to deal with all QoS supported session requests without prioritized treatment, hence, the allocation decisions for both new and handoff session requests must happen after the handoff decisions have been made.

Taking into account these constraints, the action sequence for every time slot is described using the following steps in the RSVP-MP case.

1. Find the reservations expirations for the current time slot.
2. Clear the stale reservation expirations.
3. For every expired reservation:
    (a) Find out whether the mobile will handoff to another cell according to the handoff probability.
    (b) If the mobile does not handoff (call end):
        i. Clear the reservations in the allocated channels.
    (b) If the mobile does handoff:
        i. Choose the next handoff cell randomly among the neighboring cells.
        ii. Reserve the currently allocated channels for a time period of d seconds, and mark the reservation as stale.
        iii. Do not clear the reservation in the access–core link.
        iv. Postpone the reservation request processing for the neighboring cell until the next step.
4. Deal with new arrivals and handoff reservation requests (try to allocate resources). The order or request processing is random.
5. If the request was a handoff request:
    (a) Clear the reservation in the access-core link.
    (b) Try to allocate the resources for the request.
    (c) If the allocation request fails:
        i. Reserve the channel at the access-core link for a period of d seconds and mark the reservation as stale.

In the plain RSVP case, steps 3(c)iii, 3(c)iv, and 5 are omitted.

The measurements we have collected from the simulation model include the reservation request rejections and successes as well as the average number of resources (channels) being reserved (active or stale) in the network. The active reservations represent the number of active mobile clients in the network at any time. Results from both models are presented in the following section.

4.3. Evaluation

In this section, we present results from the analytical and simulation models for the simple access network of figure 6. The cluster of level $i = 1$ consists of $N_0 = 10$ identical circular clusters of level $i = 0$ with radius $r_0 = 200$ m. We assume that the access routers are able to support $c_0 = 512$ and $c_1 = 1024$ channels, respectively, whereas the capacity of the core router is $c_2 = 256$ channels. These values have been chosen having in mind that the bottleneck in the various networks is almost always the link to the upstream ISP (core network), whereas the internal access network can support broadband communications at a fraction of the cost. The bandwidth is chosen so that no congestion occurs in the access network, but only in the edge-core router link.

The call holding time has mean value equal to $1/\mu = 120$ s and we assume the value of $d = 90$ s for the RSVP reservation maintenance time without any refresh as specified in [4]. The rate of new arrivals, λ_0, and the mobile stations' velocity, v, were left as parameters. We should note that the use of an asynchronous notification for stale resource releases triggered be RSVP-MP, which is described in section 3.3 is considered neither in the analytical nor the simulation model.

Figure 7 depicts the blocking probability at the link between the edge and the core router with variable arrival rates at the lowest level. The MHs' velocity is considered to be 1 m/s, which is a typical value for indoor environments. Both the analytical and the simulation curves have been drawn, and it can be observed that the blocking probability increases as expected for both RSVP and RSVP-MP as the arrival rate of new QoS sessions increases. The RSVP-MP case, however, exhibits much lower blocking probability for small values of λ, which is several orders of magnitude smaller compared to plain RSVP.

Similar results are also illustrated in figure 8, where the blocking probability for both schemes is plotted against the MHs' velocity. Note that for still users, the two schemes exhibit the same blocking probability. When mobility increases, RSVP shows a remarkable increase in $P_{b,2}$, whereas RSVP-MP retains the same blocking probability it had for no mobility. RSVP-MP is obviously not affected from user mobility at all. In the current scenario, for which $\lambda = 0.2$, the difference in performance scales to a tenfold increase in $P_{b,2}$, when velocity increases. If we consider smaller arrival rates, the difference in performance is even greater in favor of RSVP-MP.

We should note that the simulation curves represent blocking rates for new arrivals in both protocols. The handoff blocking probability is zero in the RSVP-MP case, whereas in the RSVP case, the handoff blocking probability is the same as the new arrival blocking probability.

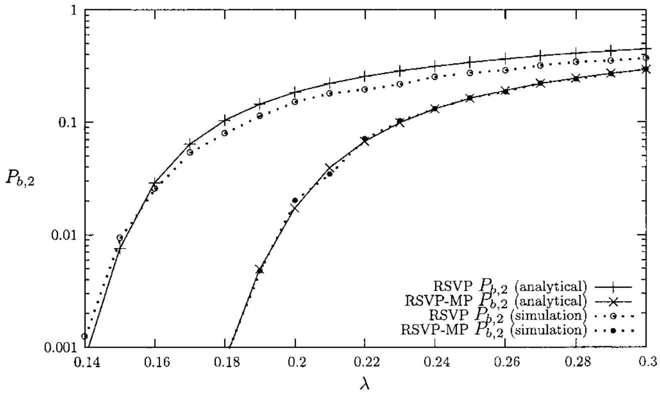

Figure 7. Blocking probability versus new arrival rate λ ($v = 1$ m/s).

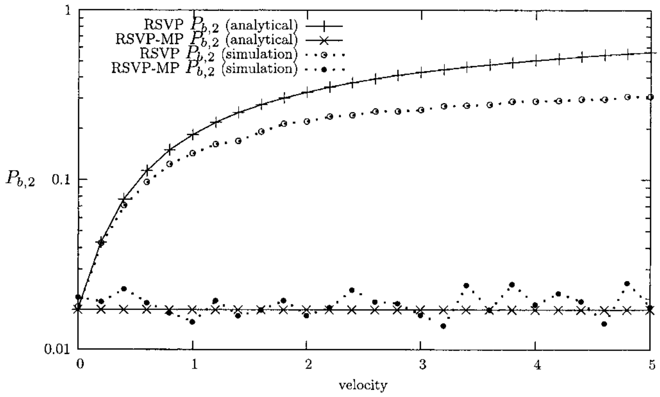

Figure 8. Blocking probability versus velocity ($\lambda = 0.2$).

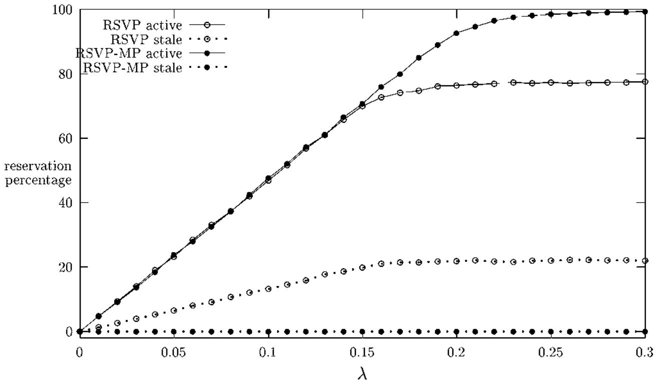

Figure 9. Active and stale reservations in the link between the edge and the core router versus new arrivals λ ($v = 1$ m/s).

In figure 8 we note a slight differentiation between the findings of the analytical model and the measurements from the simulations. This minor incompatibility between the models is due to the approximation used in the analytical model, where the stale reservations were regarded as Poisson-distributed traffic in the network.

In figure 9 the reservation occupancies at the link between the edge and the core router is illustrated as a fraction of the total bandwidth of the link. RSVP-MP does not create any

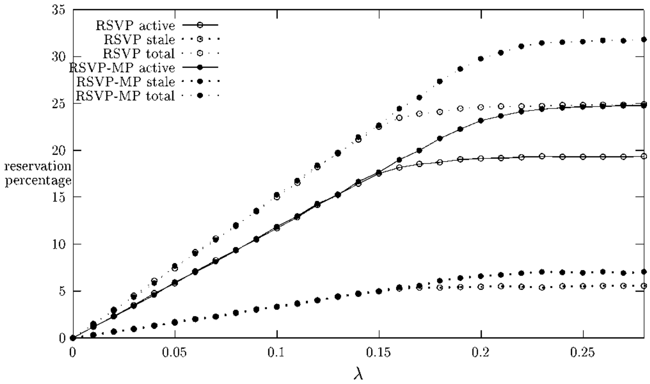

Figure 10. Active and stale reservations in the internal interfaces of the edge router versus new arrivals λ ($v = 1$ m/s).

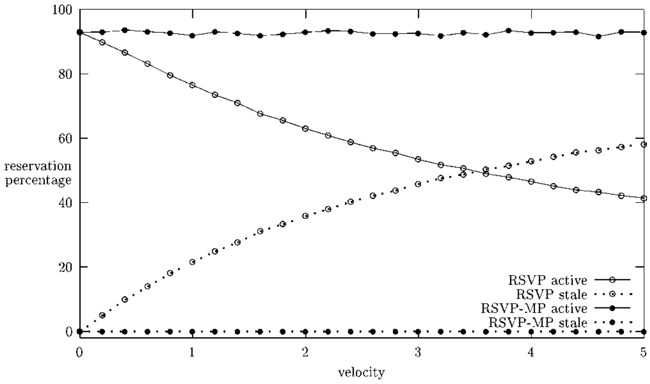

Figure 11. Active and stale reservations in the link between the edge and the core router versus velocity ($\lambda = 0.2$).

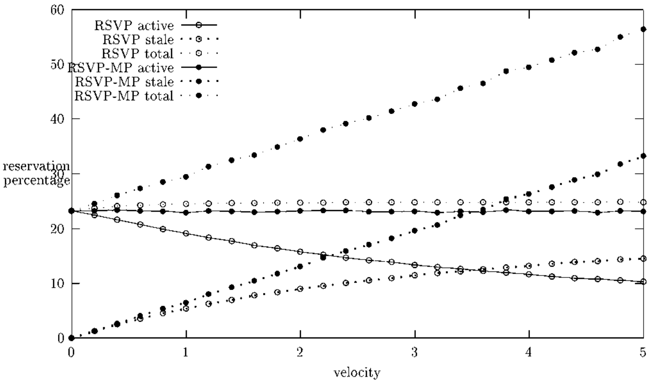

Figure 12. Active and stale reservations in the internal interfaces of the edge router versus velocity ($\lambda = 0.2$).

stale reservations on that link, while RSVP keeps approximately 20% of the link bandwidth unnecessarily occupied due to the stale sessions it maintains. One further note is that the stale-active ratio in the RSVP case does not seem to depend on the new traffic arrival rate. Both active and stale reservations increase linearly until their sum reaches the total bandwidth of the link. The stale reservations are due to handoffs and since the handoff probability remains constant in this scenario, the active-stale reservation ratio remains also constant. In the RSVP-MP case, the full bandwidth of the link is available to active connections.

Similar behavior can be observed in figure 10, where the reservation percentage at the internal routers of the access network is displayed. The actual number of active reservations is the same as in figure 9, but this time it represents a smaller fraction of the total bandwidth, since we assumed a network topology with a large bandwidth in the access network. RSVP-MP does show stale reservations in the internal network, and in fact in greater numbers than plain RSVP. The ratio between active and stale reservations remains constant when the MHs' velocity is kept constant. Since RSVP-MP allows for more active reservations, it will have to maintain more stale connections in the internal network.

In figure 11, the reservations at the link between the edge and the core router are displayed in a relation to MHs' velocity. The total number of reservation (active + stale) remains constant and constrained by the link's bandwidth in the RSVP case. This leads to the phenomenon that the percentage of stale reservations increases as the users' velocity increases, whereas the active reservations face a continuous deterioration. In the RSVP-MP case, on the other hand, the full bandwidth in the link is utilized by active connections, while the stale reservations percentage is kept to zero.

The internal access network utilization when the MHs' velocity increases is shown in figure 12. The under-utilization of the internal network is a first observation, since both protocols occupy only a fraction of the available bandwidth. In the RSVP case, a quarter of the total bandwidth for both types of reservations is occupied. In the RSVP-MP case, the number of active reservations is a constant quantity and constrained by the bandwidth limitation on the access-core link. Stale reservations inside the access network are allowed by the RSVP-MP architecture and their number increases linearly with the MHs velocity increase. Using the RSVP-MP architecture, the access-core link is always occupied only with active reservations, while letting the stale reservations in the internal access network increase, since enough bandwidth can be allocated there.

The increased complexity of the edge router in the RSVP-MP is the main important drawback for our proposed QoS solution. However, the edge router is the only network component affected by. 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 [4].

The most important benefit from the introduction of the RSVP-MP is the QoS signaling exchange reduction outside the access network. The advantages of signaling reduction can be observed both at the core network as well as at the end-user. The core network does not have to re-establish essentially the same session and lets the previous reservation time out, avoiding resource waste in terms of bandwidth. The minimized RSVP signaling in the core network also reduces processing and bandwidth requirements in the core 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.

5. Conclusions and future work

In this paper we have presented a new scheme that tackles efficiently the inconsistencies arising from the interworking of Mobile IP with RSVP. Our main goal is to achieve this while keeping the required modifications on existing protocols and network components to a minimum.

Using an analytical and a simulation model we have demonstrated that with the introduction of RSVP-MP, the blocking probability in the link between the core and the access network is greatly reduced, and stale reservations are avoided. Thus, the network resource usage efficiency is greatly enhanced. Our scheme also reduces the period, during which, moving users experience QoS deterioration. This is achieved by keeping the required signaling for the re-establishment of an end-to-end QoS supported session inside the access network. Finally, our scheme works without any modifications to network components other than the edge RSVP router.

In the drawbacks of our proposal we acknowledge that RSVP Mobility Proxy should be developed in cooperation with any advances in hierarchical mobility management schemes. These schemes are still at a research stage, thus, major or minor modifications are expected. The enhanced functionality of RSVP-MP imposes also a complexity burden on the access network edge router.

Our future work includes a refinement of the analytical model, to take into account the deterministic nature of stale reservations. Furthermore, we will examine the possibility to introduce more RSVP-MP edge routers in an access network to minimize the load of a single access router. A hierarchy of RSVP-MPs and its applicability to current access networks will also be researched.

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