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HMRSVP: A Hierarchical Mobile RSVP Protocol

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Abstract. In this paper, we propose a hierarchical Mobile RSVP (HMRSVP) that can achieve mobility independent QoS-guaranteed services in mobile computing environments. The HMRSVP integrates RSVP with Mobile IP regional registration and makes advance resource reservations only when an inter-region movement may possibly occur. We first show that, by NS simulator, our HMRSVP can achieve the same QoS guarantees as MRSVP does with fewer resource reservations. Then, we show that HMRSVP outperforms MRSVP in terms of reservation blocking, forced termination and session completion probabilities.

Keywords: mobile IP, RSVP, MRSVP, quality of services

1. Introduction

ReSource reserVation Protocol (RSVP) [2,11] is a protocol that can provide QoS guarantees for integrated services on the Internet. However, RSVP cannot be used directly in a mobile computing environment for the following two reasons. First, RSVP messages are invisible to the intermediate routers of the IP tunnel used in Mobile IP [7] because the IP tunnel is implemented using an IP-in-IP encapsulation scheme. Second, after a mobile host moves to a new location, the previously allocated resources are no longer available.

Some schemes have been proposed to resolve the mobility impact on RSVP in mobile computing environments. The RSVP Tunnel [11] was proposed to resolve the RSVP signaling invisibility problem. The RSVP Tunnel does not support seamless handoffs for QoS guarantees due to the lack of advance reservations in a neighborhood. Mobile RSVP (MRSVP) [9,10] overcomes the handoff impact of mobility on RSVP by making advance resource reservations in all neighboring subnets. However, these excessive resource reservations may demand too much bandwidth and degrade the network performance. In this paper, we propose a new Mobile RSVP Protocol – a hierarchical Mobile RSVP (HMRSVP) that can achieve the same QoS-guaranteed seamless handoff as MRSVP does but makes fewer advance resource reservations. HMRSVP adopts the hierarchical concept of Mobile IP regional registration [5] and makes advance resource reservations for a mobile host only when the mobile host resides in the overlapped area of the boundary cells between two regions. To measure the performance of our proposal, we compare the HMRSVP performance with that of MRSVP in terms of data transmission rate, reservation blocking, forced termination and session completion probabilities using simulations. Numerical results show that HMRSVP, compared with MRSVP, reduces the reservation blocking and forced termination probabilities by 50% and 27%, respectively, when the offered load is 0.6. They also show that HMRSVP improves the session completion probability by more than 8% if the load is larger than 0.6.

The rest of this paper is organized as follows. In section 2, we discuss the mobility impact on RSVP in mobile environments. In section 3, we introduce the related research: RSVP Tunnel and MRSVP. The HMRSVP scheme is proposed in section 4. Section 5 presents our simulation models and results. Finally, we make some conclusions in section 6.

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2. Mobility impacts on RSVP

RSVP is a signaling protocol for Internet resource reservations. Two types of messages, PATH and RESV, are used in RSVP to setup resource reservation states on the nodes along the path between a sender and a recipient. Initially, the sender learns the IP address of the recipient using some out-of-band mechanism and sends a PATH message to the recipient to find a path all the way from the sender to the recipient for a specific flow. When a router receives a PATH message, it will record which upstream router the PATH message was received from and forwards the PATH message to a downstream router. The PATH message is then passed from one to another downstream router and finally received by the recipient. The recipient will respond with a RESV message to make a resource reservation for the specific flow. The RESV message will be transmitted in reverse along the same path as the PATH message was originally transmitted. Upon receiving a RESV message, each router or host on the path will reserve resources for the specific flow if sufficient resources are available. However, two mobility impacts occur on the original RSVP signaling protocol.

First, RSVP is not aware of mobility. According to the original RSVP signaling protocol, the resource reservation path cannot be dynamically adapted along with the movement of a mobile host. In other words, once a mobile host (MH) handoffs to a new region, its prior reserved resources are no longer available and the service quality of the MH may degrade significantly due to the lack of resources reserved for the MH in the new region. Second, IP-in-IP makes RSVP messages invisible. Mobile IP uses an IP-in-IP encapsulation technique [6] to route IP packets correctly to an MH that is away from its home network. If the RSVP protocol is applied, RSVP messages, PATH and RESV, will be encapsulated in an IP-in-IP encapsulated packet with a protocol number as integer 4 in the outer IP header, concealing the original RSVP protocol number 46 in the inner IP header. As a consequence, the routers on the path of an IP tunnel cannot correctly recognize RSVP signals to provide the required QoS.

3. Related research

In this section, we address two important technologies, RSVP Tunnel and MRSVP, proposed to resolve the mobility impact on RSVP in mobile environments.

3.1. RSVP Tunnel

Terzis et al. [12] proposed RSVP Tunnel to resolve the RSVP message invisibility problem. The underlying principle of RSVP Tunnel is to establish nested RSVP sessions between the tunnel end-points, namely entry and exit points. That is, an extra pair of tunnel PATH and RESV messages, without encapsulating IP headers, is sent to establish a QoS-guaranteed communication path between the tunnel entry and exit points.

Initially, a sender issues an *end-to-end PATH* message, which records the addresses of the sender and recipient in its IP header with the RSVP protocol number 46. When the end-to-end PATH message is delivered to the tunnel entry point, it is encapsulated with a new IP header, which records the addresses of the tunnel entry and exit points with the Mobile IP protocol number, 4. The tunnel entry point, after sending the encapsulated end-to-end PATH message, issues a new *tunnel PATH* message which records the addresses of the tunnel entry and exit points with the RSVP protocol number 46. On receiving the encapsulated end-to-end PATH message, each router on the path of the tunnel directly forwards the message downstream to the exit point. However, on receiving the tunnel PATH message, each router performs the path-finding function as described in the original RSVP protocol because the RSVP protocol number 46 is visible in this message. When these tunnel and encapsulated end-to-end PATH messages arrive at the exit point, the encapsulated end-to-end PATH message will be decapsulated and forwarded to the recipient, while the tunnel PATH message will be processed only by the exit point and need not be forwarded to the recipient. In response, the recipient, on receiving the end-to-end PATH message, replies an *end-to-end RESV* message to the sender. In a similar way, when the tunnel exit point receives the end-to-end RESV message, it will tunnel the message to the sender as described before. In addition, the tunnel exit point will also issue a *tunnel RESV* message to the tunnel entry point. Thus, all routers on the tunnel path, when receiving the tunnel RESV message, can reserve the desired resources for the recipient if sufficient resources are available.

Using the above nested RSVP session, RSVP Tunnel can actually resolve the RSVP signaling invisibility problem. However, it does not make advance resource reservations in its neighboring networks. Therefore, if an MH moves to a new foreign region, the MH's service may be terminated because of the lack of resources in the new region.

3.2. MRSVP

Mobile ReSource reserVation Protocol (MRSVP) was proposed by Talukdar [9,10] to achieve the desired mobility independent service guarantees in Integrated Services Packet Networks [3] with real-time multimedia applications. The MRSVP protocol makes advance resource reservations at multiple locations where an MH may possibly visit during the service time. The MH can thus achieve the required service quality when it moves to a new location where resources are reserved in advance. We describe the MRSVP protocol as follows.

Just as Mobile-IP protocol requires mobility agents to aid in routing, MRSVP requires *proxy agents* to make resource reservations for the MHs. A proxy agent is said to be a *local proxy agent* if it is collocated within the location where an MH currently visits, or a *remote proxy agent* if it is within the MH's neighboring subnetwork. The local and remote proxy agents are recorded in a Mobility Specification (MSPEC). The MSPEC indicates the set of locations where an MH may possibly visit in the near future. When a recipient MH moves to a new location, it needs to search all of the proxy agents in its neighborhood and then update MSPEC using a *Proxy Discovery Protocol* [10]. The updated MSPEC is sent as a *Receiver_MSPEC* message to the sender that initializes the flow to the recipient MH. By examining the *Receiver_MSPEC* message, the sender can obtain the locations where the recipient MH may possibly visit. In addition, the recipient MH sends a *Receiver_SPEC* message to all remote proxy agents recorded in MSPEC. These remote proxy agents can thus retrieve the QoS-guaranteed parameters for the recipient MH's services. Through the exchange of a pair of PATH and RESV messages between the sender and recipient, an *active resource reservation* can be built from the local proxy agent of the sender to the local proxy agent of the recipient. Several *passive resource reservation* paths are then built from the remote proxy agents of the sender to the remote proxy agents of the recipient.

An active reservation is the path on which packets are actually transmitted, whereas passive reservation paths are only reserved in advance without any actual packet flows. When the MH moves to a new location, MRSVP changes the passive reservation of the new visited location into an active state and the original active reservation is altered into a passive state at the same time. In this way, the needed resources for the

MH in the new region can be retrieved rapidly because the resources were preserved in the original passive reservation path. That is, a seamless handoff for QoS guarantees can be retained using the MRSVP protocol. However, MRSVP demands too much bandwidth in making advance resource reservations. This excessive resource waste may degrade system performance significantly.

4. Hierarchical MRSVP

The main idea behind our HMRSVP protocol is to integrate RSVP with a Mobile IP regional registration protocol and make advance resource reservations only when the handoff delay tends to be long.

In the base Mobile IP protocol, each time an MH moves, it must register with its home mobility agent (HA). In cases when the HA is far away, this registration process may become too expensive. The Mobile IP regional registration protocol localizes the registration process within a region when an MH makes an intra-region movement [5]. A region refers to a cluster of routers or subnets encompassed by an enterprise or campus network. Mobility Agents (MAs) in a region are arranged hierarchically according to its topology. Because of the hierarchical nature and IP-routing properties of the Internet, foreign MAs can perform the registration process with some degree of independence from the HA and registrations for MH intra-region movements can thus be isolated within the region. The setup time for the resource reservation path for an intra-region handoff is normally short. Therefore, HMRSVP adopts the hierarchical concept of Mobile IP regional registration and makes advance resource reservations for an MH only when the MH visits the overlapped area of the boundary cells between two regions.

Figure 1 illustrates the resource reservation paths established in the HMRSVP scheme. The dark lines represent active resource reservation paths, while the dashed line represents a passive resource reservation path. As shown in figure 1(a), the MH is currently visiting a non-boundary cell MA_i and we can presume that the MH will make only intra-region handoffs in the near future. Therefore, the HMRSVP only establishes an active resource reservation along the path from the sender to the MH without making any advance resource reservations. In figure 1(b), when the MH enters the overlapped area of the boundary cells between two regions, the HMRSVP will establish an extra passive resource reservation along the path from the sender to the boundary cell MA_k of the MH's neighboring region. In this scenario, the HMRSVP establishes a passive reservation because the MH may make an inter-region movement into a new region. Unlike MRSVP, which establishes excessive passive reservations in all of the MH's surrounding cells regardless which cell the MH is currently visiting, HMRSVP only makes an advance resource reservation in the MH's neighboring boundary cell when the MH tends to perform an inter-region movement.

In the following subsections, we will explain our HMRSVP protocol in detail. For simplicity, we use a two-level hierarchical topology to illustrate the protocol flow of the HMRSVP.

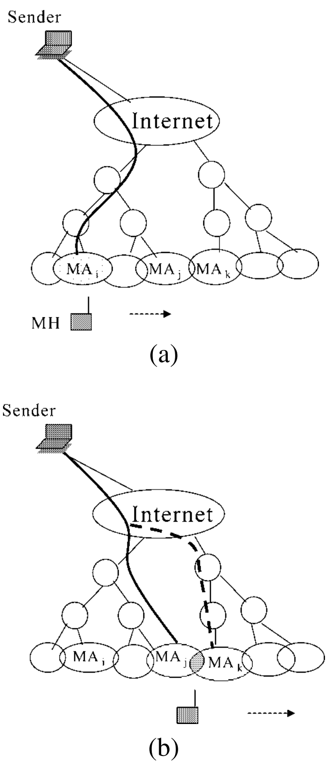

Figure 1. The hierarchical MRSVP scheme.

4.1. Receiver is a mobile

Figure 2 illustrates a two-level hierarchy of cooperating proxy agents that can provide Mobile IP regional registration and hierarchical mobile RSVP services to mobile hosts. P_{R0} to P_{R3} are the proxy agents of subnets C_{R0} to C_{R3}, respectively. GMA_{R1} and GMA_{R2} are the top-level gateway mobility agents of an enterprise region. We assume that a mobile receiver MR initially resides in the foreign subnet C_{R1} and a corresponding host CH is the data sender.

In our HMRSVP, two RSVP tunnels, one from CH to GMA_{R1} and another from GMA_{R1} to P_{R1}, will be established along the RSVP reservation path from CH to MR. Initially, MR will send a *Receiver_MSpec*{GMA_{R1}} message to inform CH that MR is visiting a subnet within the service area of GMA_{R1}. From the *Receiver_MSpec*{GMA_{R1}}, CH can learn that MR is currently away from the home region of MR. Therefore, the HMRSVP module[1] of CH will intercept the *end-to-end* Active PATH message issued by the RSVP software of CH, and tunnel the message to GMA_{R1}. In addition, the HMRSVP module of CH will also send a *tunnel* Active PATH to initiate the reservation of the RSVP tunnel CH–GMA_{R1}. On receiving the encapsulated end-to-end Active PATH message, GMA_{R1} will re-tunnel the original end-to-end message to P_{R1}. GMA_{R1} will also send a tunnel Active

[1] The HMRSVP module could also be situated at a proxy agent that provides HMRSVP service to CH. Without loss of generality, we assume that CH is equipped with the HMRSVP functions.

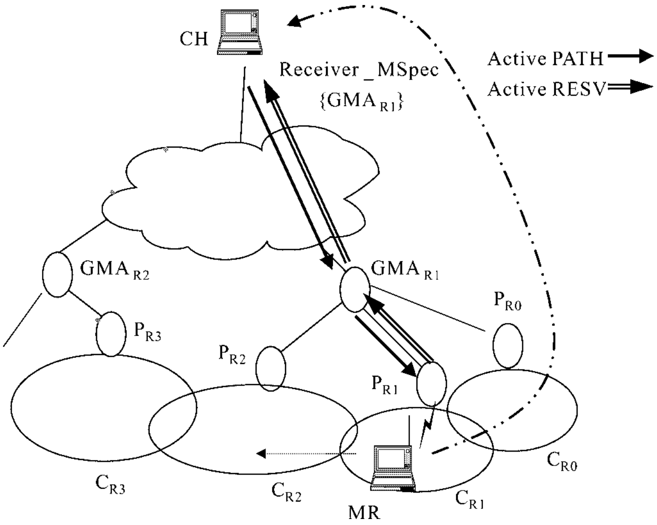

Figure 2. MR makes an intra-region handoff.

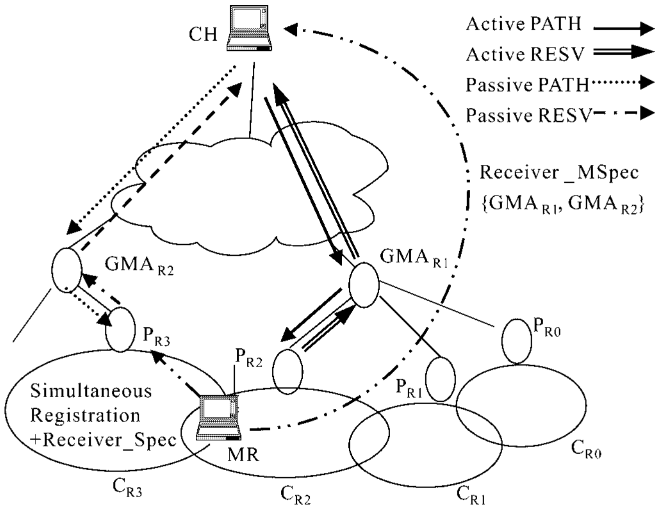

Figure 3. MR makes an inter-region handoff.

PATH to initiate the reservation of the RSVP tunnel GMA_{R1}–P_{R1}. P_{R1} will then decapsulate the end-to-end Active PATH message tunneled from GMA_{R1} and forward the end-to-end Active PATH message to MR. MR will reply an end-to-end Active RESV message to CH through the tunnels of GMA_{R1}–P_{R1} and GMA_{R1}–CH.

When MR moves from the subnet C_{R1} to the C_{R2}, an intra-region handoff occurs. The registration message sent by MR is transmitted only up to GMA_{R1}. On receiving the registration message, the Mobile IP module of GMA_{R1} informs the HMRSVP module of GMA_{R1} that MR is moving to the subnet C_{R2}. The HMRSVP modules of GMA_{R1} and P_{R2}, by exchanging an Active PATH and an Active RESV message, will establish a new RSVP tunnel between GMA_{R1} and P_{R2}. The original active reservation tunnel from GMA_{R1} to P_{R1} will be torn down after the new active RSVP tunnel, GMA_{R1}–P_{R2}, is established. The new reservation can be performed very quickly because P_{R1} and P_{R2} both reside within the same region served by GMA_{R1}.

If MR moves continuously from C_{R2} toward to C_{R3}, an inter-region handoff *may* occur as shown in figure 3. We assumed that MR can detect that it has moved into the overlapped area of two boundary cells by some means [10] as soon as it moves into this area. When MR moves into the overlapped area of the boundary cells C_{R2} and C_{R3}, it performs a home registration by sending a *Multiple Simultaneous Registration* to acquire a new care-of-address from P_{R3} [5,8]. P_{R3} will send this registration message to GMA_{R2}, which will then forward this message to MR's HA. The HA will add the GMA_{R2} care-of-address into the care-of-address list of MR and then return a *Registration Reply* message to GMA_{R2}. GMA_{R2} will send this reply message to MR through P_{R3}. MR then sends a *Reciever_Spec* message to inform P_{R3} of the original QoS parameters. In the meanwhile, MR also sends a *Receiver_MSpec*$\{GMA_{R1}, GMA_{R2}\}$ message to inform CH that MR is visiting an overlapped area of the boundary cells of GMA_{R1} and GMA_{R2}. On receiving the *Receiver_MSpec* message, CH tunnels an end-to-end Passive PATH to GMA_{R2} and GMA_{R2} in turn re-tunnel the end-to-end Passive message to P_{R3}. However, P_{R3} will not forward the original end-to-end Passive PATH to MR. Instead, P_{R3} itself will return an end-to-end Passive RESV to CH through the two RSVP tunnels GMA_{R2}–P_{R3} and GMA_{R2}–CH. These two RSVP tunnels constitute a passive resource reservation path from CH to P_{R3}. It should be noted that we could have reserved the passive reservation path between GMA_{R2} and P_{R3} at the time when the MR performs an inter-region handoff. However, we chose to make the passive reservation path GMA_{R2}–P_{R3} in advance because the CH–GMA_{R2} path is reserved over the Internet and is more involved compared with the GMA_{R2}–P_{R3} intra-region path reservation. Moreover, the passively reserved resources of the intra-region path GMA_{R2}–P_{R3} could be borrowed by other MHs currently visiting the region. The resource reservation borrowing policy will be explained later (section 5).

Assume that MR moves continuously toward subnet C_{R3} and MR changes its point of attachment to subnet C_{R3}. The passive reservation path from CH to P_{R3} will be changed to active, whereas the original active reservation path from CH to P_{R2} will be altered to passive. If MR moves further toward subnet C_{R3} and leaves the overlapped area of C_{R3} and C_{R2}, the passive reservation path on C_{R2} will then be torn down.

4.2. Data sender is also a mobile

In this subsection, the operation of our HMRSVP is explained using a case when the data sender is also a mobile host, denoted as MS in figure 4. As shown in figure 4, HMRSVP will establish three RSVP tunnels P_{S1}–GMA_{S1}, GMA_{S1}–GMA_{R1}, and GMA_{R1}–P_{R1} along the RSVP reservation path from MS to MR.

When MS moves from C_{S1} to C_{S2}, an intra-region handoff occurs. The registration message sent by MS is only transmitted through P_{S2} to GMA_{S1}. Again, only a new RSVP tunnel will be established from P_{S2} to GMA_{S1}, and the original reservation path from P_{S1} to GMA_{S1} will be torn down after the new P_{S2}–GMA_{S1} RSVP tunnel has been established.

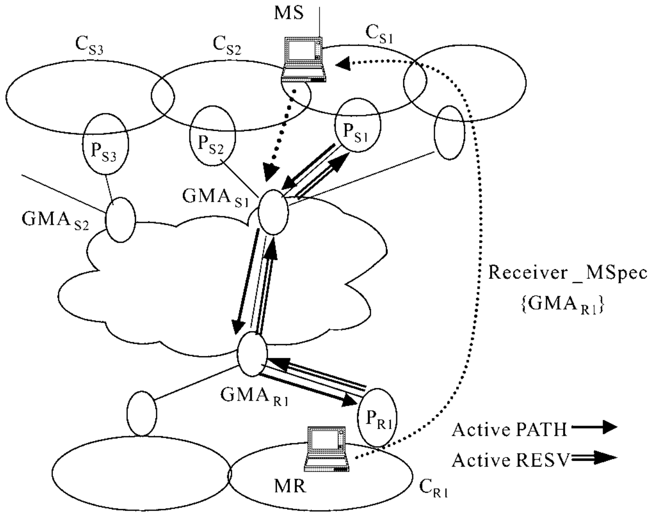

Figure 4. MS makes an intra-region handoff.

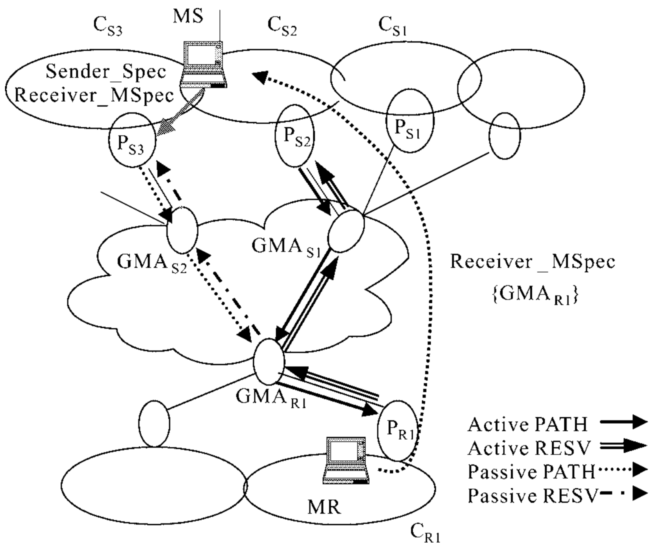

Figure 5. MS makes an inter-region handoff.

If MS moves continuously from C_{S2} toward to C_{S3}, an inter-region handoff may occur, as shown in figure 5. When MS visits the overlapped area of the boundary cells C_{S2} and C_{S3} of the regions GMA_{S1} and GMA_{S2}, respectively, it performs a home registration by sending a Multiple Simultaneous Registration to HA through P_{S3} and GMA_{S2}. Upon receiving a successful registration from MS's HA, MS issues a *Sender_Spec* message and a *Receiver_MSpec* message to inform P_{S3} of the original QoS parameters and the proxy agent of MR, respectively. P_{S3} then tunnels an end-to-end Passive PATH to GMA_{S2} and GMA_{S2} in turn re-tunnel the end-to-end Passive message to GMA_{R1}. In this case, GMA_{R1} is the end point of a passive RSVP tunnel because the resources on the path from GMA_{R1} to P_{R1} are already reserved in advance by the active reservation. In other words, the end-to-end Passive PATH is only tunneled to GMA_{R1}, which will then return an end-to-end Passive RESV message to P_{S3} through the two RSVP tunnels GMA_{S2}–GMA_{R1} and GMA_{S2}–P_{S3}. Therefore, only two new RSVP tunnels, P_{S3}–GMA_{S2} and GMA_{S2}–GMA_{R1}, will be established and these two RSVP tunnels constitute a new passive resource reservation path from P_{S3} to GMA_{R1}.

Assume that MS moves continuously toward subnet C_{S3} and MS changes its point of attachment to subnet C_{S3}. The passive reservation path from P_{S3} to GMA_{R1} will be changed to active, whereas the original active reservation path from P_{S2} to GMA_{R1} will be altered to passive. If MS moves further toward subnet C_{S3} and leaves the overlapped area of C_{S3} and C_{S2}, the passive reservation path on C_{S2} will be torn down.

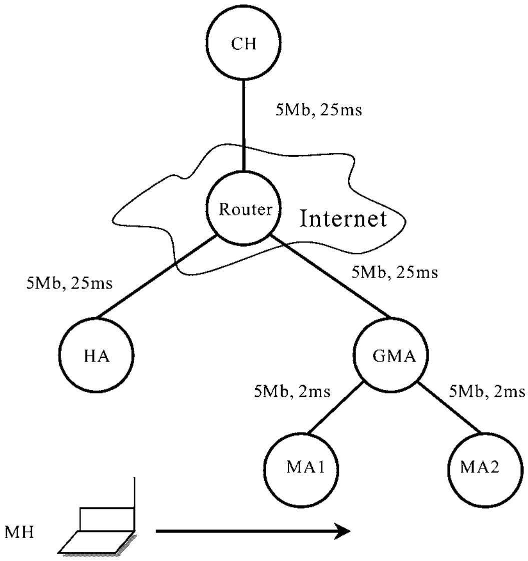

Figure 6. NS simulation topology.

5. Simulation models and numerical results

In this section, we present our simulation models and results. In our first experiments, the *NS* network simulator proposed by U.C. Berkeley [1,4] was used to estimate the data transmission rates for the HMRSVP, MRSVP and RSVP approaches. Figure 6 depicts the simulation topology used in the *NS* simulation. In this topology, we assume that the bandwidths of the links between all nodes are 5 Mbps and the transmission delays on the links from a CH, HA, or GMA to a router are all set to 25 ms. The link transmission delay between an MA and its parent GMA is 2 ms because GMA and MA1/MA2 are located in the same region.

Figure 7 shows the simulation results for the average data transmission rate using the HMRSVP, MRSVP and RSVP approaches over simulation time. In this simulation, an MH is initially located at its home network during the time from 0 to 30 seconds. After 30 seconds of simulation time, the MH handoffs to a foreign subnet served by a mobility agent MA1 with a parent GMA. Later the MH moves around the subnets served by MA1 and another mobility agent MA2 with the same parent GMA, during the time from 30 to 130 seconds, and finally the MH goes back to its home network after 130 seconds. In the figure, we can observe that the MH can maintain a stable data transmission rate at 64 Kbps when the

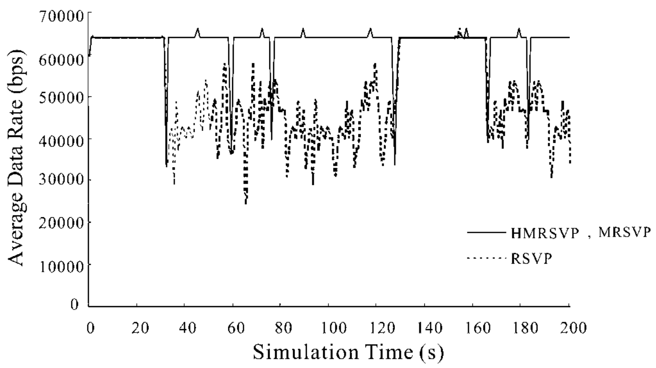

Figure 7. Average data transmission rate.

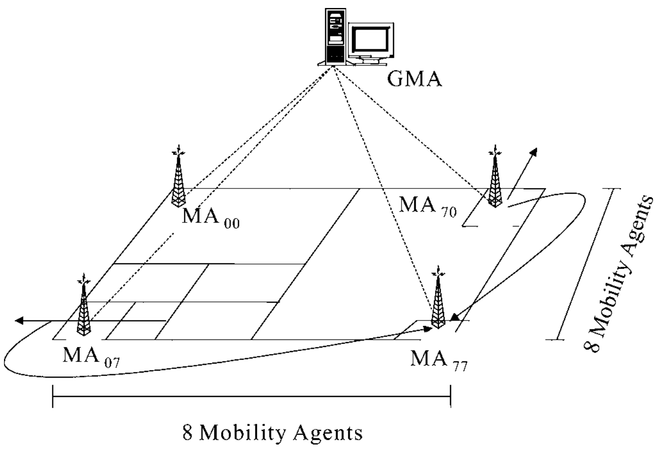

Figure 8. 8 × 8 mesh simulation model.

MH is at the home network regardless which approaches are applied. If the MH moves away from its home network and enters the foreign network served by the GMA, the average data transmission rate becomes unstable using the RSVP protocol. This is because the RSVP protocol does not reserve resources in advance at the foreign network, and thus the service quality of the MH cannot be guaranteed. On the other hand, if the HMRSVP or MRSVP is applied, the data rate is always stable at 64 Kbps except for the handoff time. This phenomenon shows that, although HMRSVP pre-reserves MH's needed resources in advance only at the overlapped area of the boundary cells, it can still maintain a high QoS guarantee for the service quality of the MH as MRSVP does.

To measure the performance of the HMRSVP protocol, we used an 8 × 8 wrapped-around mesh topology as shown in figure 8 to simulate a mobile computing environment with an unbounded number of regions. For simplicity, we only built a hierarchical infrastructure of two-tier agents. Each of the 8 × 8 cells is served by an MA, and all 64 MAs are served by a GMA. When the MH moves left and away from the cell served by MA_{07}, an inter-region handoff occurs and the MH will enter the cell served by MA_{77} in a new region. Similarly, when the MH moves up and away from the cell served by MA_{70}, an inter-region handoff occurs and the MH will enter the cell served by MA_{77} in a new region.

The simulation parameters used in our model are as follows.

- *Reservation inter arrival time* $(1/\lambda)$. The reservation inter arrival time represents the average inter arrival time for each RSVP session of an MH. We assume that the reservation inter arrival time of a RSVP session is an exponential distribution with mean $1/\lambda$.
- *Reservation holding time* $(1/\mu)$. The reservation holding time represents the average holding time for each RSVP session of an MH. We assume that the reservation holding time of a RSVP session is an exponential distribution with mean $1/\mu$.
- *Capacity* (C). The capacity C represents the average total number of available RSVP sessions supported by a cell.
- *Average number of MHs per FA* (N). N represents the average number of MHs visiting a cell.
- *Offered load* (ρ). ρ represents the system offered load for a cell, and thus it is equal to $N\lambda/C\mu$.
- *Reservation blocking probability* (P_b). P_b represents the probability that a failure occurred when an MH wishes to create a new active reservation for a RSVP session.
- *Forced termination probability* (P_f). P_f represents the probability that an active reservation can not be successfully made and the reservation is forced to terminate when an MH handoffs to a new cell.
- *Session completion probability* (P_c). P_c represents the probability that an MH can make an initial active reservation for a RSVP session and can complete the session successfully regardless how many cell-handoffs the MH makes during the connection time.

We present the performance results by comparing the reservation blocking, forced termination and session completion probabilities of the MRSVP and HMRSVP schemes with/without an enhanced management policy on the resources that have been reserved by a passive resource reservation. The underlying principles behind the resource management policy are illustrated as follows.

- The passively reserved resources, i.e., resources which are passively reserved by other MHs in the neighboring regions, of a region can be borrowed by the MHs visiting the region currently. The resources borrowed by an MH in a region should be returned when the original owner of the borrowed resources is about to handoff to the region.
- If an MH makes its active resource reservation by borrowing the passively reserved resources from some MH in a neighboring region, the MH cannot make a passive resource reservation since the active resource reservation may be terminated at anytime.

Figures 9–11 show our simulation results in terms of reservation blocking, forced termination and session completion probabilities, respectively. In the figures, the curves denoted by HMRSVP-R and MRSVP-R stand for numerical results for the HMRSVP and MRSVP schemes with the enhanced management policy on the passively reserved resources.

Figure 9 illustrates the reservation blocking probabilities for the four resource reservation schemes under discussion.

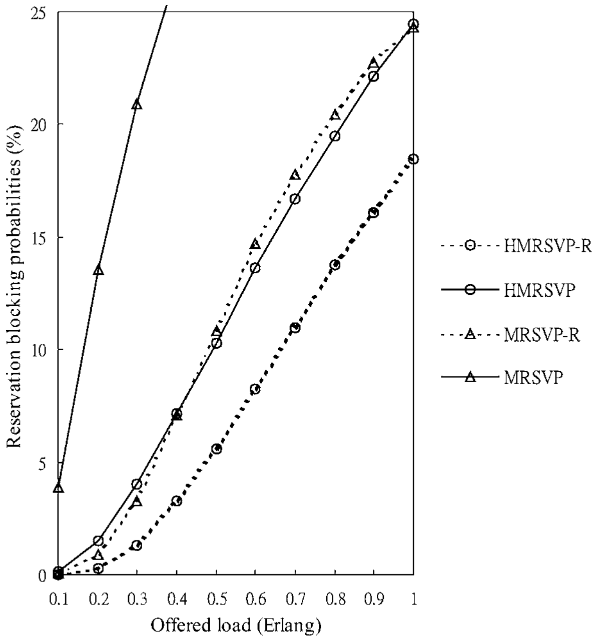

Figure 9. Reservation blocking probabilities.

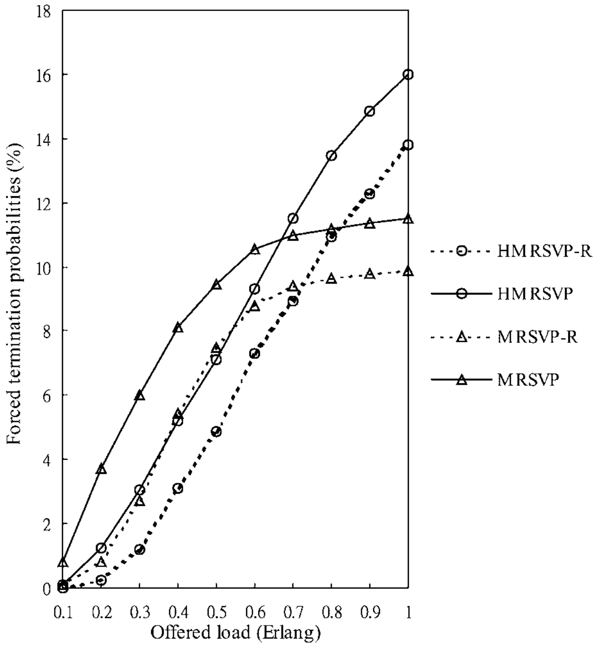

Figure 10. Forced termination probabilities.

When the offered load increases, the reservation blocking probability increases in all schemes. It is obvious that the greater the offered load, the lesser the available resources and thus the higher the reservation blocking probabilities. On the other hand, we can observe that the reservation blocking probability of MRSVP is larger than that of HMRSVP. This is because MRSVP reserves much greater resources in neighboring regions than HMRSVP does, and thus the average number of remaining resources in the MRSVP decreases. As a consequence, the reservation blocking probability of a new RSVP session will increase. Furthermore, from the blocking

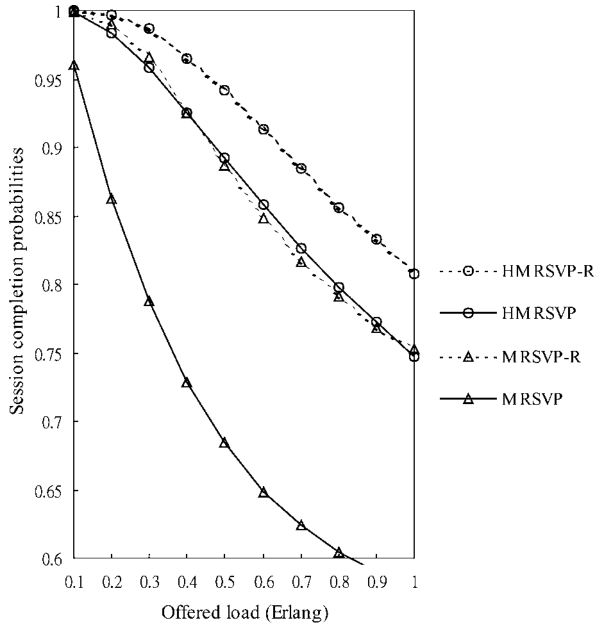

Figure 11. Session completion probabilities.

probabilities of MRSVP-R and HMRSVP-R, we can observe that the resource management policy can effectively improve the blocking probabilities of both the MRSVP and HMRSVP schemes.

Figure 10 depicts the forced termination probabilities for the four resource reservation schemes under discussion. In general, the greater the resources reserved in advance in the MH's neighboring regions, the higher the guaranteed QoS. However, the forced termination probability of the MRSVP is higher than that of the HMRSVP if the offered load is less than about 0.65 in our simulation. This is because if the offered load is small, the HMRSVP scheme, which does not reserve resources in every neighboring region, will retain more available resources than the MRSVP does. When the load is larger than 0.65, the benefit of excessive advance reservations for the MRSVP scheme will be obvious. A similar phenomenon can be also observed in that the forced termination probability will decrease when we apply the resource management policy in both schemes.

The session completion probability is a combinational effect of the reservation blocking probability and forced termination probability. Figure 11 shows the session completion probabilities for the four resource reservation schemes. It is obvious that when the offered load increases, the session completion probability decreases in all schemes. We can further observe that HMRSVP outperforms MRSVP in terms of session completion probability. If the offered load is larger than 0.8, the session completion probability of the MRSVP scheme is lower than 60%. However, if the load reaches to 1.0, the HMRSVP scheme can still retain about 75% session completion. The reason is that HMRSVP can reduce the reservation blocking probability with less increase in forced termination probability. Similarly, if the reserved resource management policy is applied, the session completion probability will also increase in both schemes. That is, even though the offered load reaches 1.0, the session completion probability of the MRSVP-R scheme can be maintained at about 75%.

From the phenomena mentioned above, we could conclude that HMRSVP outperforms MRSVP in terms of reservation blocking, forced termination and session completion probabilities. Only when the offered load is large, will the forced termination probability of HMRSVP be worse than that of MRSVP. Moreover, if the reserved resource management policy is applied, we can improve the performances of both the HMRSVP and MRSVP schemes.

6. Conclusions

We proposed an HMRSVP protocol that can achieve mobility independent QoS-guaranteed services to support real-time multimedia applications in mobile computing environments. Our HMRSVP integrates RSVP with the Mobile IP regional registration protocol and makes advance resource reservations only when an MH moves into the overlapped area of the boundary cells between two regions. The underlying idea behind the HMRSVP is to reserve in advance only those resources which are likely to be used in the near future. Moreover, we also proposed a resource management policy to improve the performances of the HMRSVP and MRSVP protocols. The numerical results show that our HMRSVP could achieve not only the same QoS guarantees as MRSVP but also could outperform MRSVP in terms of reservation blocking, forced termination and session completion probabilities. However, there exist other factors that may affect the HMRSVP performance, such as the mobility rate of the MHs, the size of an overlapped area, the end-points of a passive RSVP tunnel, the time to tear down a passive reservation path, etc. Therefore, we need to conduct more performance studies on the effectiveness of our HMRSVP scheme in the future.

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