RSVP Extensions for Real-Time Services in Wireless Mobile Networks

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ABSTRACT

Currently, the RSVP model, which is efficient resource reservation in the fixed endpoints, becomes invalid under host mobility. In this article, we investigate the problems of standard RSVP in providing real-time services in wireless mobile networks. We also observe carefully how to interoperate IntServ services over DiffServ networks, and how to map IntServ QoS parameters into a wireless link. We then identify the advantages and drawbacks of the existing RSVP proposals to support QoS under both micromobility and macromobility. We finally propose a dynamic resource allocation scheme for reducing service disruption of real-time applications due to frequent mobility of a host.

INTRODUCTION

As many real-time applications have been developed in the Internet, the best effort delivery model became inadequate for these new applications. TCP, used widely in the current Internet, is not well suited to real-time applications. Instead, Real-Time Transport Protocol (RTP) is usually implemented on top of UDP, which is better adapted to real-time applications. However, this protocol mechanism is not enough to guarantee a specific quality of service (QoS) for a session between a sender and a receiver.

Two different models are proposed to guarantee QoS in the Internet by the Internet Engineering Task Force (IETF): the integrated services (IntServ) and differentiated services (DiffServ) models. In the IntServ model, network resources are explicitly identified and reserved. Network nodes classify incoming packets and use reservations to provide QoS. Meanwhile, in the DiffServ model, resources are not explicitly reserved. Instead, traffic is differentiated into a set of classes, and network nodes provide priority-based treatment according to these classes. IPv6, which is a new version of the most successful protocol, IPv4, allows DiffServ-style QoS to be applied. However, some applications, such as streaming audio and video, would be much better served under the IntServ model since they have a relatively constant bandwidth requirement for a known period of time.

Resource Reservation Protocol (RSVP) is an attempt to provide real-time service through the use of virtual circuits. It is a resource reservation setup protocol designed for the IntServ model. RSVP is not a routing protocol but a control protocol, which allows Internet real-time applications to reserve resources before they start transmitting data. That is, when an application invokes RSVP to request a specific end-to-end QoS for a data stream, RSVP selects a data path relying on underlying routing protocols, and then reserves resources along the path. Since RSVP is also receiver-oriented, each receiver is responsible for reserving resources to guarantee requested QoS along its data path. Hence, the receiver sends an RESV message to reserve resources along all the nodes on the delivery path to the sender.

Recently, as it becomes much easier to access the Internet from a mobile host, mobile users are demanding the same real-time service available to fixed hosts. However, for a wireless network where hosts are likely to be mobile, the semantics of QoS are more difficult to achieve due to host mobility and the nature of the wireless medium. Mobility of hosts has a significant impact on the QoS parameters of a real-time application. It also introduces new QoS parameters at the connection and system levels. Currently, Mobile IP is based on the best effort delivery model and has no consideration of QoS. Furthermore, the RSVP model, which is efficient resource reservation in the fixed endpoints, becomes invalid under host mobility. In this article we investigate how to interoperate IntServ services over DiffServ networks, how to map IntServ QoS parameters into a wireless link, and the problems of RSVP in wireless mobile environments. We then identify the advantages and drawbacks of the existing proposals under both micro- and macromobility.

INTEGRATED SERVICES OVER DIFFSERV NETWORKS

Within the IntServ network, the processing of per-flow states in IntServ-capable routers leads to the scalability problems when deployed to large networks. Meanwhile, DiffServ networks classify packets into one of a small number of classes based on the DiffServ code point (DSCP) in the packet's IP header. DiffServ eliminates the need for processing per-flow states, and therefore scales well to large networks. In the network with IntServ operation over DiffServ, IntServ architecture is used to deliver end-to-end QoS to applications. RSVP signaling messages travel end to end between sending and receiving hosts to support RSVP reservations outside the DiffServ network region. From the perspective of IntServ, DiffServ regions of the network can be treated as virtual links connecting IntServ-capable routers or hosts. Therefore, this network includes some combination of IntServ-capable nodes and DiffServ regions. Individual routers may or may not participate in RSVP signaling regardless of where they reside in the network. This network includes DiffServ regions in the middle of a larger network supporting IntServ end to end. The DiffServ region contains a mesh of routers, at least some of which provide aggregate traffic control. The regions outside the DiffServ region (non-DiffServ regions) contain meshes of routers and attached hosts, at least some of which support the IntServ architecture. IntServ service requests specify an IntServ service type and a set of quantitative parameters known as a flowspec. These requests for IntServ services must be mapped onto the underlying capabilities of the DiffServ network region. In RFC 2998, this kind of mapping includes selecting an appropriate per-hop behavior (PHB), or set of PHBs, for the requested IntServ services, performing appropriate policing at the edges of the DiffServ region, exporting IntServ parameters from the DiffServ region, and finally performing admission control on the IntServ requests that takes into account the resource availability in the DiffServ region [1].

QOS PROVISIONING OVER A WIRELESS LINK

With the third-generation (3G) all-IP networks, the wireless access network (WAN) provides radio access bearer services to support the layer 2 connection between the terminal (user) equipment (UE) and the WAN gateway node (GW). The characteristics of these bearer services are dependent on the wireless mechanisms, and can be markedly different from bearer services in traditional wired networks. In radio access bearer services, it is clear that different radio bearer services can be provided, resulting in quite different characteristics of QoS, service costs, and service behaviors. Consequently, sufficient detail about the applications' traffic and service requirements must be known in order to determine the appropriate parameter settings to enable service optimization. IntServ allows the network nodes to perform explicit resource management at the IP level by allowing applications to characterize their resource requirements. IntServ requests allow the nodes to exercise admission control and traffic control and thereby provide end-to-end QoS provisioning and resource allocation.

A traffic classifier in the UE and WAN GW has the capability and flexibility to classify a set of flows, or even an individual IP flow for each radio bearer. In order to achieve this, it can examine a range of packet header information including source and destination IP addresses, protocol, source and destination UDP/TCP port numbers, IPSec SPI, DSCP, and IPv6 flow label. When applications use an IntServ-based application programming interface (API) to request service, the radio management function, which is responsible for the establishment, modification, and release of the radio bearers, in the UE may utilize this information as a convenient means to identify the IP service requirements. In addition, by participating in the IntServ service, the UE can interact with the IP service. However, the wireless network offers a much larger set of parameters to control the characteristics of the radio bearers in order to optimize the offered services while maximizing the efficient use of the scarce radio resources. It is necessary to consider what information is important to provide to the radio management function from an application that wishes to operate efficiently over wireless networks. It is also necessary to consider how information can be provided by the application to aid in setting these parameters. Based on these considerations, Fodor *et al.* [2] proposed a small set of parameters that would help the wireless network configure its QoS and resource reservation parameters. This new set consists of an accurate description of the media for which the service is requested and some additional quantitative parameters on bit error ratio, packet loss ratio, maximum transfer delay, and packet handling priority.

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PROBLEMS OF RSVP UNDER THE MOBILE SCENARIO

For RSVP under wireless mobile networks, when a mobile node (MN) is a receiver and moves to another location, it must reestablish reservations along the new path from it to the source. In standard RSVP operation, since each data source issues PATH messages periodically to automatically reserve resources along a new path after a routing change occurs, the MN must wait for a PATH message at its new location before it can send an RESV message back along the new path to the source for reserva-

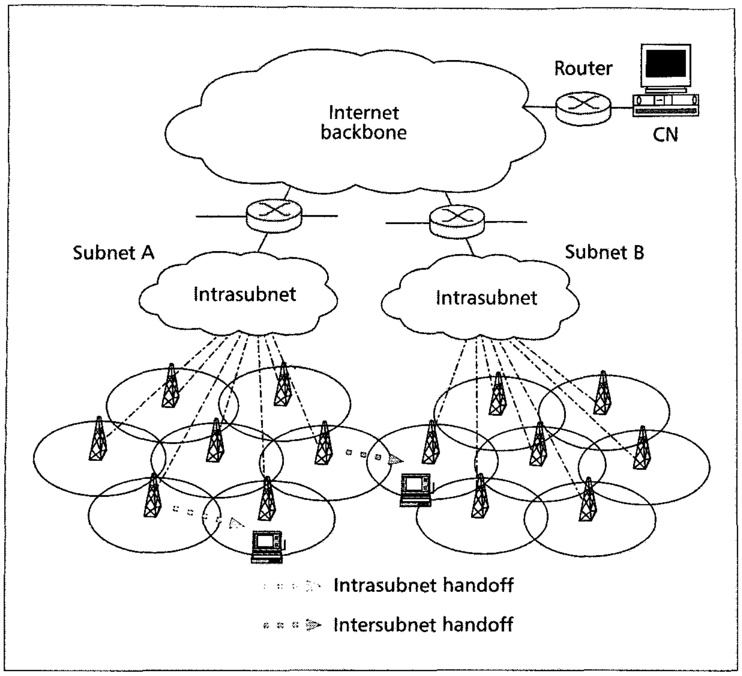

Figure 1. *Intrasubnet and intersubnet handoffs.*

tion of resources. In other words, whenever an MN performs a handoff that incurs a path change, the new path to the MN from the correspondent node (CN) is discovered by RSVP only after the soft state timers expire in network elements such as routers. However, consequently this mechanism is so slow that it may lead to large delays under a roaming environment with frequent host mobility. Hence, in order to reserve resources along the new path with support for both QoS and mobility, the RSVP signaling process must be invoked immediately, instead of waiting for the next periodic RSVP state update associated with the RSVP soft-state mechanism. Simply reducing the soft state timer may result in excessive signaling overhead when the host moves relatively slowly. This problem can be avoided by the mechanism that the CN triggers the transmission of a PATH message after receiving a binding update message from the MN.

For a guaranteed service, it is necessary for the network to offer tight delay bounds to applications. That is, it is required that network elements (e.g., routers) be able to estimate the maximum local queuing delay for a packet. Due to the long resource reservation delay during reestablishment of a flow after handoff under RSVP, service disruptions could occur in providing real-time services. The longer the resource reservation delay due to RSVP signaling overheads in roaming environments, the greater the possibility of a larger number of packets being sent along the previous reservation path to the MN's old location; hence, a greater number of lost packets. Mechanisms are thus needed to minimize the resource reservation delay and packet loss resulting from handoffs under RSVP. Simply buffering to reduce packet loss would violate the semantics of guaranteed QoS for real-time services since it would introduce additional delay. Furthermore, the buffering requires extra storage and operation complexity to manage the buffers.

In wireless networks, channel capacity, which is location-dependent, will most likely cause a mobile host's negotiated QoS to be compromised when it moves into a highly populated cell. The effect of this movement may cause the QoS of other mobiles, already in the cell, to degrade. A mobile host must additionally renegotiate its desired QoS (using RSVP messages) to set up a new reservation path each time it moves to a new location, which incurs additional delay. There is also no guarantee that the same level of resources will be available under a new point of attachment to which a MN moves. This implies that there may be service disruption with the mobility of the host. This problem can be solved with some information about how an MN is moving. In the 3G cellular systems, the European Telecommunications Standards Institute (ETSI) has already defined this functionality on GSM phase 2+ under the name of Support Of Localized Service Area (SOLSA). This new concept provides a cellular network operator to distinguish services offered to users or user groups depending on their location inside the network.

RSVP Extensions under Micro-Mobility

The term micromobility is defined as mobility within the same subnet. It often used interchangeably with intrasubnet mobility. An intrasubnet handoff occurs when an MN moves from one base station (BS) to another, and both base stations are connected to the same router. Figure 1 shows intrasubnet and intersubnet handoffs. Under micromobility, the IP address of the MN remains unchanged, and only link-layer connection need be rerouted. In other words, micromobility has the ability for an MN to move without notifying its home agent (HA). Hence, for a microcell or picocell system, where MNs change their points of attachment more frequently, Mobile IP that needs to update the HA could be the bottleneck for fast handoffs. Therefore, Mobile IP is not adequate in a cellular network, where mobile users could change serving BS very frequently during active data transfer. RSVP has been mainly considered with Mobile IP under macromobility, but network elements (NEs) or intermediate nodes under micromobility need to be RSVP-enabled to provide QoS guarantee for mobile users using real-time applications.

Indu *et al.* [3] proposed a resource reservation scheme with Class Based Queuing (CBQ) in a microcellular network (intrasubnet) architecture. This scheme distinguishes between the two kinds of reservations: one between the sender and various BSs in neighboring cells in the wired network, and another between the BS and the MN in the wireless region. In this scheme, the RSVP protocol is used, modified to recognize passive and active reservations. In addition to making active reservation between the BS and

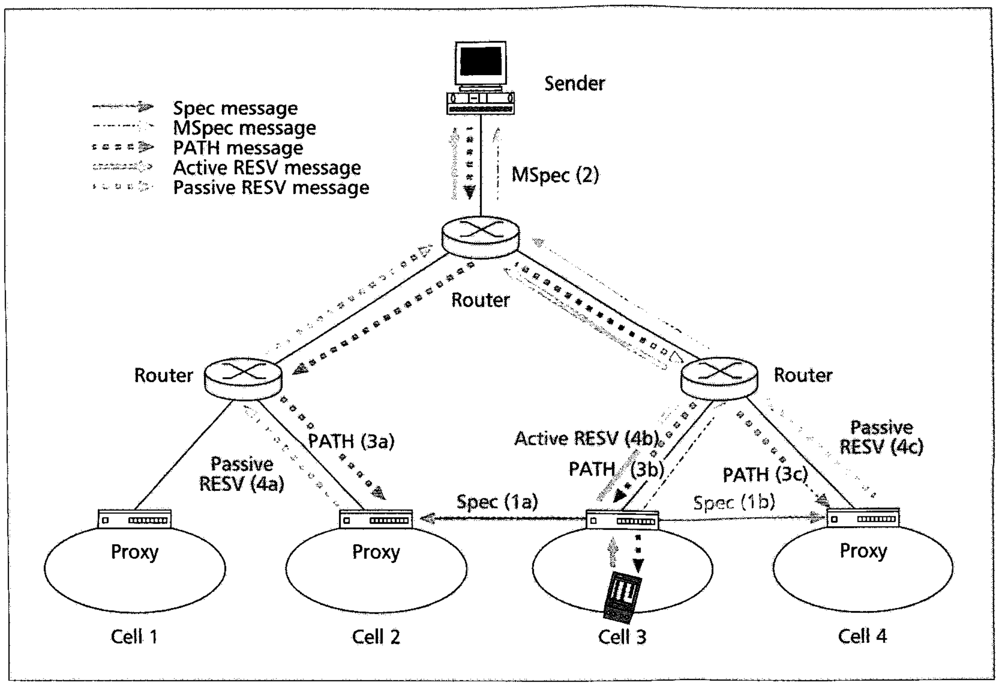

Figure 2. *Reservation routes for MRSVP.*

The resource reservations delay over only two-hop link will be very short, and guaranteed QoS in the newly modified portion of the path can be obtained easily. Admission control and resource allocation mechanism can be used to help provide bandwidth required for a MN in the neighboring cells.

the MN, the BS has to make passive reservations with all the BSs in the neighboring cells when the BS accepts the call. Once the MN moves to the neighboring cell, both the MN and BS know that a handoff occurred. At this point, PATH and RESV messages denoting an active reservation are exchanged between the old and new BSs, and the new BS and the MN. If the RSVP process has a reservation successfully along the path through the end-to-end QoS negotiation, the data sent from an application can use CBQ for packet scheduling and classification. CBQ makes forwarding decisions on the outgoing interface, which uses the particular link-layer medium.

An alternative approach involves changing the RSVP implementation at the NEs to which BSs are connected. In this scheme, whenever the MN moves into the neighboring cell, resource reservations are made newly over a two-hop link between the NE and the MN. Once the BS detects the MN's handoff, it notifies the NE, and thus PATH and RESV messages are exchanged to make a new reservation between the NE and the MN. Therefore, the resource reservations delay over only a two-hop link will be very short, and guaranteed QoS in the newly modified portion of the path can be obtained easily. Admission control and resource allocation mechanism can be used to help provide the bandwidth required for an MN in the neighboring cells.

For more general approaches under micromobility including various topologies (e.g., Cellular IP, HAWAII, HMIP), a new path needs to be set up during a handover. In setting up a new path, the remaining circuits need to be reused because only a partial path is changed. This kind of path reestablishment scheme requires discovery and setup of the new partial path between the crossover NE and the MN during handoff. While the signaling overhead depends on the connection setup protocol, the number of hops required to set up the partial path during a handover is crossover-NE-dependent; end-to-end latency is a function of the route length. Hence, an efficient partial path discovery mechanism is required so that the RSVP resource reservation delay is reduced, resulting in being able to get guaranteed QoS for real-time services.

RSVP Extensions under Macromobility

The term macromobility is defined as mobility between different subnets. It is often used interchangeably with intersubnet mobility. An intersubnet handoff occurs when the MN moves to another BS that is connected to another router. In Mobile IP, an MN registers with its HA each time it changes its point of attachment. When the HA is distant from the MN, the delay to complete an update could be significantly high. Mobile IP has been optimized for macromobility and relatively slow-moving mobile hosts. It causes disruption during handoff, and high signaling overhead due to frequent notification to the MN's HA. Therefore, Mobile IP does not scale well to serve a large number of mobile users moving frequently between small cells.

There have been several studies on RSVP supporting macro- (intersubnet) mobility. The protocols under macromobility are Mobile RSVP [4], multicast-based model [5], RSVP tunnel model with Mobile IP [6], Mobile IP with location registers [7], Mobile IPv6 and RSVP integration model [8], and flow transparency-based model [9].

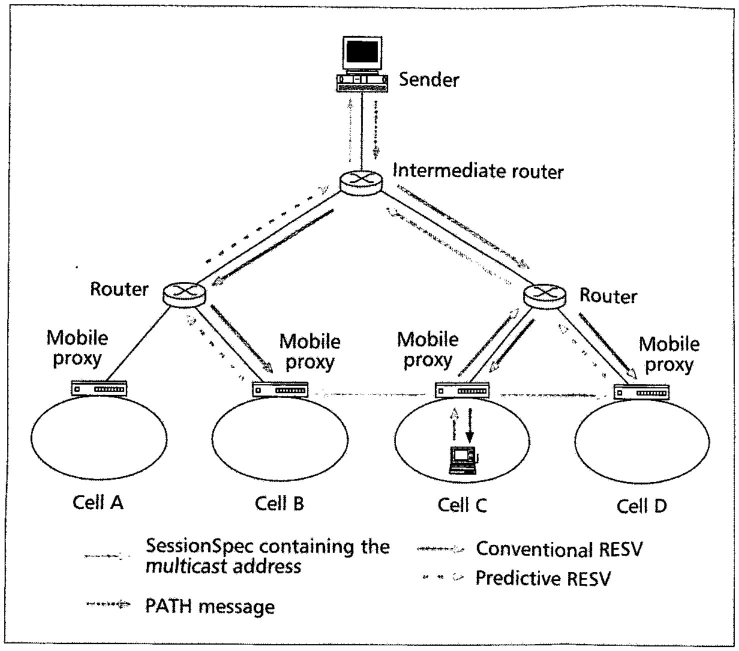

Figure 3. *Extended RSVP based on IP multicast.*

MOBILE RSVP

Talukdar *et al.* [4] proposed Mobile RSVP (MRSVP), as an extension to conventional RSVP, for the provision of QoS guarantees to MNs independent of their movement throughout the access network. Figure 2 shows the reservation route of MRSVP when an MN is a receiver. In MRSVP, a mobile host can make advance resource reservations. For making advance reservations, it is necessary to specify the set of locations, called Mspec, the mobile host may visit in future. The mobile node thus establishes paths with sufficient resources to a possibly large set of attachment points the mobile host may visit in future. When the node arrives at a particular point of attachment, the path to that attachment becomes active and the path to the previous one passive, so the data can still be delivered effectively. But this approach suffers from several drawbacks. It has the problem that many resources are reserved that may never be used even though they are available for other requests. It requires the BS to maintain a lot of state information regarding active and passive reservations during handoffs. Mobile node originating for real-time flows has to wait until all the necessary resources in a possibly large set of attachments become available. Therefore, eventually the blocking rate of the flows originating for real-time applications may become very high. It is also difficult to accurately determine the possibly large set of attachment points of a mobile host.

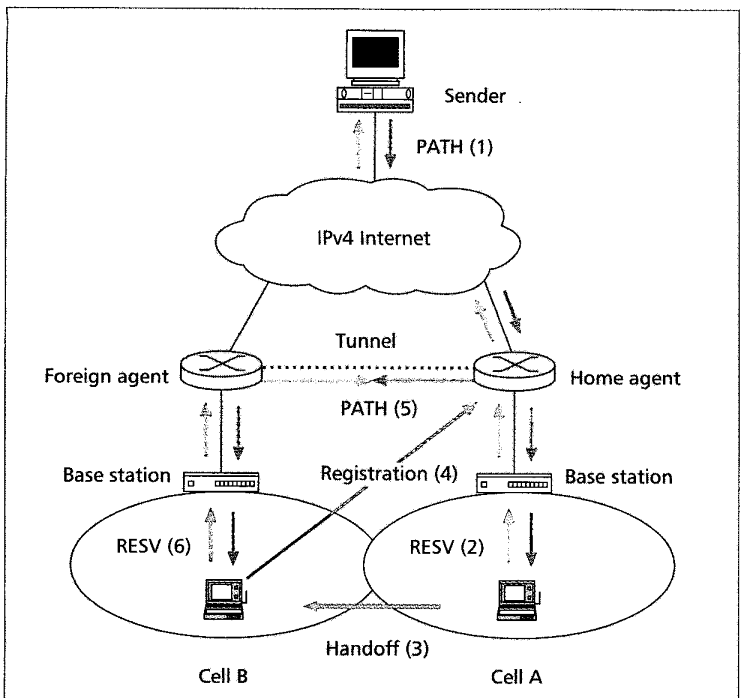

Figure 4. *RSVP tunnel with mobile IP.*

MOBILITY SUPPORT BASED ON IP MULTICAST

Chen *et al.* [5] proposed a new signaling protocol for mobile hosts to reserve resource in IntServ Internet. Under this approach, the RSVP model is extended based on IP multicast to support mobile hosts. RSVP messages and actual IP datagrams are delivered to a mobile host using IP multicast routing. The multicast tree, rooted at each source node, is modified dynamically every time a mobile host roams to a neighboring cell. Hence, the mobility of a host is modeled as a transition in multicast group membership. A new host joining a multicast group results in establishing a new branch in the multicast tree. A host leaving a multicast group may result in a branch in the multicast tree being pruned. Once these new branches have formed, path messages from the sender are forwarded to mobile proxies along the multicast tree. Upon receiving the path messages, a conventional reservation message from current mobile proxy and predictive reservation messages from neighbor mobile proxies are propagated toward the sender along the multicast tree. Figure 3 shows the extended RSVP based on IP multicast when an MN is a receiver. When the mobile receiver is moving from one location to another, the flow of data packets can be switched to the new route as quickly as possible. Even though this method can minimize service disruption due to rerouting the data path during handoffs, it has disadvantages such as overload to manage multicast tree dynamically and inefficiency due to resource reservation in advance.

SIMPLE QOS SIGNALING PROTOCOL

Terzis *et al.* [6] proposed a simple QoS signaling protocol by combining preprovisioned RSVP tunnels with Mobile IPv4. Figure 4 shows the RSVP tunnel model with Mobile IP when an MN is a receiver. When the MN moves to cell B, it informs its home agent of its new location. When the HA (home agent) is informed about the MN's new location, it does two things:

- It sets up a tunnel RSVP session between itself and the foreign agent (FA) if one does not exist between them.
- It encapsulates PATH messages from the sender and sends them through the tunnel toward the MN's new location.

When the FA receives a RESV message from the visiting mobile node, it sends a RESV message for the corresponding tunnel session between itself and the HA. After sending the reservation request, the FA waits for a confirmation from the HA that the reservation over the tunnel was successful. This approach can easily be implemented with minimal changes to other components of the Internet architecture. However, when a mobile host roams far away from the HA, the triangle routing problem occurs, but there is no consideration of the shortest path mechanism such as route optimization. In this protocol, there is also no solution for reducing service disruption due to frequent mobility of a host.

MOBILE IP WITH LOCATION REGISTERS

Jain *et al.* [7] proposed a scheme, called MIP-LR (Mobile IP with Location Registers), which may be more suitable for 3G cellular systems. This scheme uses a set of databases, called location registers, to maintain the current care-of address (CoA) of the mobile host. When an MN moves from one subnet to another, it registers its current CoA with a database called a home location register (HLR). When a correspondent node (CN) has a packet to send, it first queries the HLR to obtain the mobile host's CoA, and then sends packets directly to the mobile host; the CN caches the MN's CoA to avoid querying the HLR for every subsequent packet destined for the MN. MIP-LR not only eliminates the inefficiency of triangle routing in MIP, but also generally avoids tunneling and allows resource reservation using RSVP to provide QoS guarantees.

MOBILE IPV6 AND RSVP INTEGRATION MODEL

Chiruvolu *et al.* [8] proposed a Mobile IPv6 and RSVP integration model. The main idea of Mobile IPv6 and RSVP interworking is to use RSVP to reserve resources along the direct path between the CN and the MN without going through their HAs since Mobile IPv6 has route optimization. In this model, resources are initially reserved between the CN and the MN's original location. Whenever the MN performs a handoff, which incurs a path change, a new RSVP signaling process is invoked immediately to reserve resources along the new path. Figure 5 shows Mobile IPv6 and RSVP integration model when MN is a receiver. When the MN performs a handoff from subnet A to subnet B, it gets a new CoA and subsequently sends a binding update to the CN. The CN then sends a PATH message associated with the new flow from CN to MN. Upon receiving this PATH message, the MN replies with a RESV message immediately to reserve resources for the new flow. For each handoff, the MN as receiver has to wait for a new PATH message from the CN; only after getting the PATH message can it issue a new RESV message to the CN. However, all these RSVP renegotiations are conducted end to end even though the path change may only affect

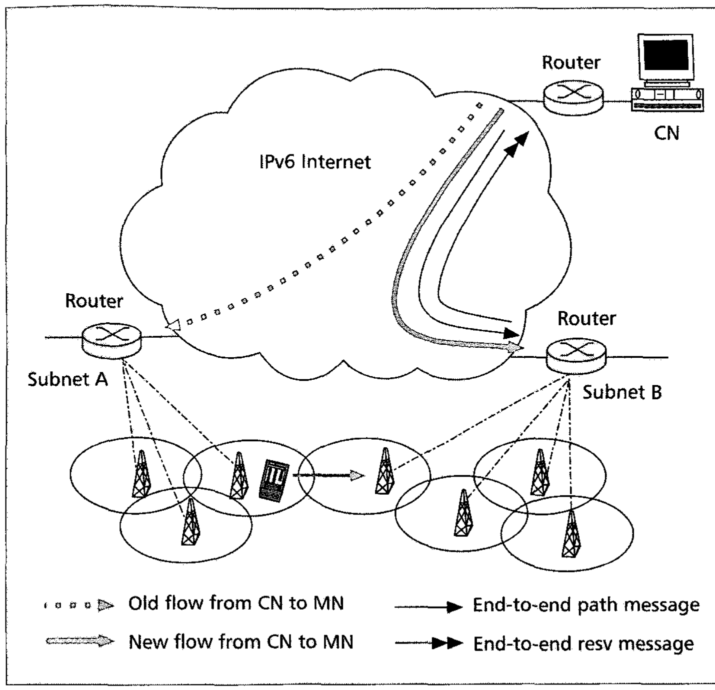

Figure 5. *Mobile IPv6 and RSVP integration model.*

a few routers within the whole path during a single handoff. Hence, the long handoff resource reservation delays and large signaling overheads caused by this end-to-end RSVP renegotiation process could lead to notable service degradation in providing real-time services. Furthermore, during this period there might not be enough resources in the newly added portion of the flow path between CN and MN.

MOBILITY SUPPORT BASED ON FLOW TRANSPARENCY

Shen *et al.* [9] proposed a method to solve the drawbacks in the existing IPv6 QoS with mobility support model, namely, long resource reservation delays and large signaling overheads. Node address is changed due to node mobility, and in turn flow identity is altered with the MN as source or destination. Consequently, the same application data flow may be perceived as a different flow at the network layer. Since a router needs to be processed based on flow, it is necessary to update the data in all intermediate routers along the flow path whenever a flow changes at the network layer. However, the routers that reside in the duplicated portion of the new and old flow paths should be prevented from performing handoff update; only those routers that are in the newly added portion of the flow path need be involved in the update process.

In this model, the RSVP session and flow identity at the network level should be constantly unique for the flow handling mechanism (e.g., the packet classifier) in the router regardless of node mobility. Figure 6 shows a mobility support model based on flow transparency when the MN is a receiver. When the MN is acting as a receiver, instead of the CN, the crossover router (CR)

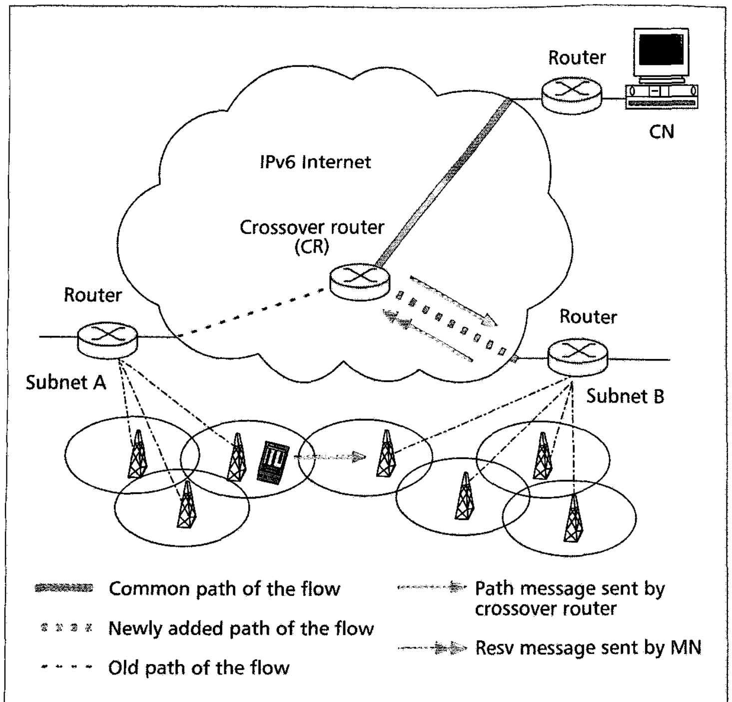

Figure 6. *Mobility support based on flow transparency.*

issues a PATH message to the mobile receiver because the required information already exists in the CR during the previous RSVP message exchanges. In order to detect the route change of the receiver and trigger local repair for the receiver, the receiver should be able to inform the CR of its handoff information, which contains the flow destination and the MN's current address.

This method automatically limits the handoff RSVP renegotiation process within the newly added portion of the path between CN and MN. Therefore, handoff resource reservation delays and signaling overheads can be minimized, which in turn minimizes the handoff service degradation. However, when the MN is acting as a sender, current Mobile IPv6 sets the source address (of packets originated from an MN) to the MN's CoA, and the MN's home address is moved into a home address option in a destination options header, which is not processed by intermediate routers during packet transmission. Only changing the flow source to be the MN's home address causes a problem for router packet classification. Hence, implementation of this model requires some modification to Mobile IPv6.

There is also no mechanism to guarantee the same level of resources in a new point of attachment to which the mobile host moves. This may cause service disruption with mobility of the host.

Resource Allocation under RSVP in Wireless Networks

The IntServ model specifies two service classes: guaranteed service (GS) and controlled-load service (CLS). In our proposed resource allocation model, a cell accepts GS, CLS, and best-effort service (BES) flows. This model provides infinite waiting queue for both CLS and BES handoff flows and guard channels for GS handoff flows. We also allow BES flows to overflow the region reserved for GS flows with the risk of being preempted by the newly arriving GS flows. When a mobile with GS flows attempts to reserve resources in a cell, the GS new (handoff) flows can use up to the given channel bandwidth limits with the preemptive priority over BES flows in any cell, and exclusive guard channels in the GS region are used to minimize the forced termination of GS handoff flows. If there is no idle bandwidth in a new cell after handoff in a heavily crowded area, the GS handoff request is just dropped. Hence, it is required to give a statistical guarantee on the GS handoff success in wireless environments. The remaining channel bandwidths except for the regions reserved for GS flows in a cell are dedicated to both CLS and BES flows. The BES flows preempted by the arriving GS flows in a cell are queued in the infinite queue to wait for service instead of being cleared, and CLS handoff flows have preemptive priority over BES flows existing in the dedicated region. Newly arriving CLS handoff flows are also queued after all existing BES flows are preempted and queued. If there is any flow waiting for service in the queue, both CLS and BES originating flows are blocked. We are currently developing this model; it will be published at a later date.

Conclusions

In this article we investigate the problems of existing RSVP in providing real-time services in wireless mobile networks. We also give short overviews on how to interoperate IntServ services over DiffServ networks, and how to map IntServ QoS parameters into a wireless link. We have then identified several schemes proposed for solving these problems under both micro- and macromobility. Even though they set up RSVP resource reservation paths efficiently, most of these solutions have no QoS mechanism enough to prevent service disruption at a new cell during handoff. Therefore, we propose a dynamic resource allocation scheme for reducing service disruption of real-time applications due to frequent mobility of a host.

Acknowledgments

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ADDITIONAL READING

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BIOGRAPHIES

BONGKYO MOON (bong-kyo.moon@kcl.ac.uk) was awarded a B.S. degree in computer science at Sogang University, Seoul, Korea, in 1992, and an M.S. degree in information and communications at Kwangju Institute of Science and Technology (K-JIST), Korea, in 1998. He has over five years of work experience in various fields of hardware/software technology, including telecommunications in both ETRI and Inex Technologies, Inc. He has been working toward a Ph.D. at the Centre for Telecommunications Research at King's College, University of London since 2000 in the field of QoS in wireless mobile Internet and supported by Mobile VCE, United Kingdom.

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