Quality of Service (QoS) Provisioning in IP-based Broadband Wireless Mobile Networks

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Abstract – In this paper, we propose the seamless switching scheme of RSVP (resource ReSerVation Protocol) branch path for soft handoff in IP micro-mobility domain. Typically, in order to minimize the handoff service disruption of RSVP flows, RSVP message delays and signaling overheads should be minimized. We firstly propose the rerouting scheme of RSVP branch path at a crossover router (CR) at every handoff event, and secondly propose the reservation scheme of new RSVP branch path between the CR and new BS in advance while the existing reservation path is maintained. Eventually, we show that this scheme could provide the QoS guarantee for RSVP flows during handoff with simulation and examples.

1. Introduction

Mobile-IP has been optimized for macro-mobility and relatively slow-moving mobile nodes (MNs). Due to the frequent notification to the MN’s home agent (HA), it increases signaling load experienced by the core network in support of mobility. However, micro-mobility has the ability for an MN to move without notifying its HA. Thus, this has the benefit of reducing delay and packet loss during handoff when MNs remain inside their micro mobility regions. Until now there have been several researches on RSVP (resource ReSerVation Protocol) [1] supporting Mobile IP, which are summarised in [7].

Meanwhile, the crossover switch discovery algorithms for path rerouting in wireless ATM LANs [2] have been evaluated on different network topologies. The work in [2] shows that the network topology can affect the performance of crossover node discovery algorithms. Micro-mobility networks with hierarchical topology such as Cellular IP [3] or HAWAII [6] is normally organized as a tree, and a single gateway node becomes the root of this tree. For efficient path rerouting in micro mobility networks, it is required to consider the discovery scheme of crossover router (CR), which depends on the tree topology and the interaction between micro-mobility protocol and RSVP daemon through RSRR interface [8].

Typically, handoff QoS signaling should be carried out very quickly. If the time required to restore the flow of traffic, after a mobile node (MN) receives the beacon that triggers a handoff, is very short, it might be possible to provide QoS guarantee to some real-time applications in aid of proper retransmission buffer size and well-measured beacon period. Under RSVP, however, it may not possible to get enough short total handoff time to provide QoS guarantee due to reservation delay and signaling overhead during path re-establishment at every handoff. Thereby, ongoing RSVP flow may be disrupted until the new reservation is installed along the path via new BS after handoff. Using retransmission buffers in BSs and MNs to recover from packet losses incurred during the transition between cells would violate the semantics of guaranteed QoS for the interactive services such as Internet telephony and teleconferencing, since it would introduce additional delay.

In section 2, we firstly investigate how to reroute the RSVP branch path at crossover router in tree topology, and secondly propose the reservation scheme of RSVP branch path in advance, and the seamless switching of RSVP branch path for soft handoff. We finally show that this scheme can provide the QoS guarantee through simulation and examples in section 3 and section 4.

2. Proposed Schemes

2.1 RSVP Path Rerouting at Crossover Router

In micro-mobility network protocol, when an MN performs a handoff and send a route update message towards the gateway router (GW), the intermediate nodes along the new path towards the GW are notified of the change of forwarding entries. One of the intermediate nodes on the new path then realizes that it becomes a CR by seeing the same IP address (of the source or the destination) in the new forwarding entry different from the one stored in the old forwarding entry. The CR then sends its RSVP daemon a PCN (path change notification) message in order for the RSVP to recognize the existence of the CR. Thereby, when an MN moves into new cell, the rerouting of RSVP branch path at CR can guarantee the minimum path change and the shortest path from the GW to the MN; in the worst case, the CR is the GW itself.
We now describe an RSVP branch-path rerouting at CR during handoff. In this scheme, only RSVP reservation path between the CR and an MN is re-established. Fig. 1 shows RSVP signaling for path rerouting at CR during handoff. In the case an MN is a sender (Fig. 1 a), an RSVP PATH message is sent by an MN after the route update is completed (or it can be implicitly sent as a route update message in order to reduce the RSVP PATH signaling overhead). When the RSVP daemon on the CR, which is determined by the route update message, receives an RSVP PATH message after a mobility event, it immediately sends an RSVP RESV message to an MN without delivering to the original receiver. In the case an MN is a receiver (Fig. 1 b), the RSVP daemon on the CR can trigger an RSVP PATH message immediately when detecting any changes to the stored PATH state or receiving a PCN message from the underlying routing daemon. This PATH message can be generated based on the path state stored for the flow during previous RSVP message exchanges. That is, after making sure that the ADSPEC and PHOP objects [1] for each outgoing interface are updated accordingly, the RSVP daemon on the CR then sends a PATH message along the forwarding path established freshly by route update message from an MN. When the MN receives this PATH message, it generates an RSVP RESV message after some receiver processing delay on RSVP daemon.

2.2 Reservation of RSVP Branch Path in Advance

In the hard handoff event, the QoS of an RSVP flow may be typically disrupted until the new reservation is installed along all the intermediate nodes on the fresh path toward the crossover router (CR) via a new AR. However, soft handoff can provide reliable RSVP reservations; from the changes in pilot signal strength, the receiver can select one candidate (for handoff) of all the possible ARs involved. Thus, new RSVP reservations along the new path via the candidate AR can be established while the existing reservation path is maintained.

Fig. 2 illustrates typical pilot strength variation as an MN moves from one base station area to another area. We assume that an MN moves from a BS coverage area to the adjacent BS area. If an MN finds a neighboring BS with a pilot signal higher than a predetermined threshold (T_ADD), then a new link to the BS is established while the existing link is maintained. If the pilot signal from either the old BS or the new BS drops below a predetermined threshold T_DROP, the corresponding link is released. In [4], authors proposed a mechanism for resource reservation on wireless link by a predetermined threshold in a BS coverage area. However, we here extend this reservation mechanism to all the links within IP micro-mobility network in aid of RSVP and CR discovery scheme. Thus, we define a new parameter T_RSVP, which is a threshold of RSVP reservation requests. This value is less than T_ADD. If an MN finds any neighboring BS with pilot strength exceeding T_RSVP, it sends a RSVP reservation request message to the RSVP daemon on the associated BS. Afterwards, if the pilot strength drops and stays below T_RSVP during a predetermined period, an MN asks the RSVP daemon on the associated BS to release the RSVP branch path. In Fig. 2, the threshold T_RSVP is not an absolute value but is rather a relative value to T_ADD. When T_ADD is dynamically determined according to the current wireless-link status and network load condition, T_RSVP can also be adaptively modified.

![Fig. 1 RSVP signaling for path rerouting at CR during handoff](image1)

![Fig. 2 RSVP path reservation by pilot strength thresholds](image2)
2.3 Switching of RSVP Branch Path for Soft Handoff

In Fig. 2, if the pilot strength reaches $T_{ADD}$, then an MN with a RSVP session switches old branch path to the newly reserved branch path by initiating soft handoff and keeps the flow with the guaranteed QoS. More specifically, when an MN is a sender, it sends an RSVP PATH message (or the route update message including a PATH message) via the new AR before an MN performs actual handoff. In order to minimize RSVP resource reservation delay, the new path reservation must be made between a crossover router (CR) and new AR. Thus, RSVP branch path can be successfully established after an MN receives an RESV message sent by the intended receiver (CR). When an MN is a receiver, it responds with an RSVP RESV after receiving a PATH message (via the new AR) sent by the CR. During this resource reservation phase, the packets are still delivered through the path reserved via the old AR (or BS). After starting to receive the packets through the path reserved freshly via the new AR, an MN can explicitly remove the reservation along the old path, and finally tunes its radio to the new AR. During this RSVP branch path rerouting period, the amount of bandwidth consumed through both the old and new reservation paths becomes double. However, this period becomes very short because the old path is released soon.

3. Performance Measures

The signal received by an MN can be taken as a random variable with lognormal distribution, $f(x) = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}$, where $x$ is the signal level in $dB$ received by the MN from the neighboring BS which has the strongest signal among all other neighboring BSs, assuming that Rayleigh fading can be averaged out. $\mu$ is average received signal levels due to the path loss from the neighboring BS, and can be given as $\mu(dB) = K_1 - K_2 \log(d)$ where $K_1$ depends on the transmitted power in the BS (or AR), $K_2$ is typically a constant due to path loss and $d$ is the distance from the neighboring BS. A handoff is required if the average signal level received from the current BS drops below that of the neighboring BS. In our simulation, we assume that the threshold values of $T_{ADD}$, $T_{DROP}$ and $T_{RSVP}$ are given within the range between $-31.5$ $dB$ and $0$ $dB$. Furthermore, we assume that an MN’s velocity $V$ is a constant and the power strength of each BS is identical. Thus, the distance that an MN moves within cell boundary area becomes proportional to the difference between two pilot signal strengths. Hence, from the above formula, “the RSVP path preparation zone” denoted by $S$ in Fig. 2 is equal to $\left(10^{\frac{\mu}{K_1}} - 10^{\frac{\mu}{K_2}}\right)$. As the MN moves to the neighboring BS, the time it takes for a pilot signal to be changed from $T_{RSVP}$ to $T_{ADD}$, $\Delta T$, can thus be calculated by $S/V$. $\Delta T$ can actually be adjusted dynamically by changing $T_{RSVP}$, but too low $T_{RSVP}$ value can cause excessive unnecessary RSVP reservations.

Now we need to define the terminology for the signaling protocol overhead and the number of hops. The RSVP packet processing delays, which are $\Delta P$ and $\Delta R$ for PATH and RESV messages, respectively, on a router are defined as the difference between the time stamps at which the packet appears on the input and output links [5]. The setup time for RSVP branch path rerouting, $\Delta RSVP$, is defined as the delay between the time when the first PATH message is appeared on the MN’s (or crossover router’s) interface and the time when the first RESV message is detected on the same interface. The receiver processing delay, $\Delta PR$, during this setup is the latency between the time the first PATH message is seen on the crossover router’s (or MN’s) interface and the time at which the first RESV message is seen on the same interface.

These delays depend on the load of routers and the number of the existing RSVP connections; we can assume that they go by normal distributions with the parameters in Table 1, which is obtained from the results in [5]. It shows the mean latency of RSVP control packets in the three types of loads when a certain number of real-time sessions already exist. The numbers in parentheses show the standard deviations.

<table>
<thead>
<tr>
<th>Type of load</th>
<th>$\Delta P$ (ms)</th>
<th>$\Delta R$ (ms)</th>
<th>$\Delta PR$ (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low load</td>
<td>2.00 (0.20)</td>
<td>3.07 (0.30)</td>
<td>1.72 (0.17)</td>
</tr>
<tr>
<td>Medium load</td>
<td>3.90 (0.40)</td>
<td>5.41 (0.54)</td>
<td>2.14 (0.20)</td>
</tr>
<tr>
<td>High load</td>
<td>5.44 (0.54)</td>
<td>6.40 (0.64)</td>
<td>2.99 (0.30)</td>
</tr>
</tbody>
</table>

Table 1: Average control packet latency (in ms) under three types of loads in the network

The setup time, $\Delta RSVP$ is thus given as $L \times \Delta P + L \times \Delta R + \Delta PR$ where $L$ is the number of links (routers) between the CR and an MN. Total handoff delay $\Delta T_{RSVP}$ of a flow with RSVP resource reservation is the time it takes for an MN to receive (or send) the first packet through the new RSVP reservation path when performing an actual handoff. Therefore, the time difference between $\Delta T$ and $\Delta T_{RSVP}$ then becomes an important parameter for measuring the QoS of a flow with RSVP reservation. When an MN moves into a new AR area under RSVP, the packets transmitted on the RSVP path reserved freshly via the new AR may be lost if $\Delta T_{RSVP}$ is greater than $\Delta T$. Hence, the total handoff signaling process via new AR should be completed during the period $\Delta T$.

When an MN is a sender, $\Delta T_{RSVP}$ is $\Delta RSVP$ if a PATH message is sent inserted in a route update message in order to reduce the signaling overhead. When an MN is a receiver, it has to wait for $\Delta U$ to send the route update packet to the CR, and then also wait for $\Delta RSVP$ for RSVP branch path rerouting. In order to keep the flow with the same QoS after a handoff, it has to wait for the additional propagation delay $\Delta G$ from the CR to an MN. That is, an MN has to perform an actual soft handoff after receiving the first packet.
through the new RSVP branch path. However, the propagation delay $\Delta T$ can be ignored under micro-mobility network. Thus, for a mobile receiver, the total handoff delay $\Delta T_{RSVP}$ is $\Delta U + ARSVP$. Hence, the total number of lost packets of a flow with RSVP resource reservation at soft handoff is $B (\Delta T_{RSVP} - \Delta T)$ where $B$ is the amount of link bandwidth reserved for the flow. Consequently, if the value of $\Delta T_{RSVP} - \Delta T$ is less than zero or equal to zero, service disruption does not occur. This means that this scheme can provide the QoS guarantee by dynamically adjusting the $\Delta T$ through threshold $T_{RSVP}$.

![Diagram](image)

**Fig. 3 Flowchart of proposed QoS provisioning mechanism**

### 4. Examples and Discussions

Fig. 3 shows the overall flowchart for proposed QoS provisioning scheme. In our simulation, we just consider IP micro-mobility network, where the network has tree hierarchy topology. For the simplicity of the simulation, we also assume a full binary tree with a GW as a root. The depth $k$ of a full binary tree with $N$ nodes is $\lceil \log_2 N \rceil + 1$.

Hence, a full binary tree of depth $k$ has $2^k - 1$ nodes, $k \geq 1$ and the number of nodes (Base Stations, BS) at level $k$ is $2^{k-1}$. We take the mean latencies of RSVP control packets from Table 1. We also fixed the threshold values, $T_{ADD}$ as -13.0 dB, and constants $K1$ and $K2$ in received signal level as 35.3 and 40.9, respectively.

Fig. 4 shows the probability of service disruption with various threshold values of $T_{RSVP}$. RSVP control packet latency values are taken when the load of routers is high. Here, an MN’s velocity $V$ is 9.0 m/s. In this figure, service disruption always occurs with $T_{RSVP} = -13.1\ dB$, but there is no service disruption after $T_{RSVP} = -13.6\ dB$. That is, as the pilot signal difference between $T_{ADD}$ and $T_{RSVP}$ is bigger, the time that an MN spends in the RSVP path preparation zone in cell boundary area becomes longer. On the other hand, the mean number of links required to set up branch path at every handoff depends on the number of levels in a tree. Hence, the smaller the number of levels in a tree is, the less RSVP branch path setup time is. In this figure, the reasonable number of levels in a tree is within 5. Also, well-defined $T_{RSVP}$ value results in getting enough time to set up new RSVP branch path when an MN moves to the neighboring BS.

![Graph](image)

**Fig. 4 Probability of Service Disruption with various $T_{RSVP}$ under $V=9.0$ m/s and high load.**

![Graph](image)

**Fig. 5 Probability of Service Disruption with MN’s various velocity under $T_{RSVP} = -13.4\ dB$ and high load**

Fig. 5 shows the probability of service disruption with an MN’s various velocity under $T_{RSVP} = -13.4\ dB$ and high load of routers in the network. In this figure, the faster MN’s velocity is, the shorter the time that an MN spends in cell
boundary area is. Hence, seamless switching of RSVP branch path can be obtained when the velocity is less than or equal to 6 m/s. Fig. 6 shows that the mean number of lost packets with various threshold values of $T_{RSVP}$ under $V=9.0$ m/s, high load of routers and application with 1 Mbps reserved bandwidth. In this figure, when $T_{RSVP}$ is $-13.5 \, dB$ and the number of levels in a tree is less than 4, the on-going RSVP session can obtain seamless service despite the branch path rerouting at handoff. We can thus control the mean packet loss time by adjusting the threshold $T_{RSVP}$ in addition to the number of levels in a tree. In this case, the total number of lost packets of a flow with RSVP resource reservation depends on the amount of link bandwidth reserved for the flow.

Fig. 6 Mean Number of Lost Packets with various load condition under $V=10.0$ m/s and 1 Mbps data rate

Fig. 7 Probability of Service Disruption with various load condition under $V=10.0$ m/s and $T_{RSVP} = -13.3 \, dB$

Fig. 7 shows the probability of service disruption with various load condition (in Table 1) under $V=10.0$ m/s and $T_{RSVP} = -13.3 \, dB$. In this situation, under only low load condition of the routers in the network, packet loss can be minimized and QoS guarantee can be achieved. Hence, according to the current wireless-link status and network load condition, $T_{RSVP}$ should also be adaptively modified. For this kind of purpose, a mechanism is needed to measure the network condition and link status.

5. Conclusions
In this paper, we considered the rerouting of the RSVP branch path at a crossover router in order to minimize the resource reservation delay and the packet loss resulting from handoffs under RSVP. We proposed a seamless rerouting scheme of RSVP branch path for soft handoff in order to guarantee the QoS of on-going RSVP flows during handoff event. We also showed that this scheme could provide QoS guarantee for RSVP flows in IP micro-mobility network through simulation analysis and examples.

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References