LETTER

Seamless Switching of RSVP Branch Path for Soft Handoff in All-IP Wireless Networks

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SUMMARY This letter addresses the QoS issue of a RSVP flow during handoff events. For the QoS guarantee of real-time applications with RSVP reservation in All-IP wireless networks, mechanisms are required to minimize the resource reservation path changes and the packet loss resulting from handoff events. If the new RSVP reservation is made along the path via a new base station (BS) in advance for soft handoff, on-going RSVP flow session can be kept with the guaranteed QoS. Therefore, we propose a seamless switching scheme of RSVP branch path for soft handoff. We also show that this scheme could provide the QoS guarantee by adaptively adjusting the pilot signal threshold values for soft handoff.

key words: *RSVP, soft handoff, advance reservation, QoS, seamless switching*

1. Introduction

In All-IP wireless network, IP-based wireless base stations (BSs) connect radio system to an IP radio access network. These BSs use IP protocols for data transport and/or signaling in either wireless LANs or 3G cellular systems, but wireless cells may be arranged in any arbitrary configuration [1]. IPv6, next-generation IP protocol, allows DiffServ-style QoS to be applied, but some applications such as streaming audio and video would be much better served under the RSVP/IntServ model as they have a relatively constant bandwidth requirement for a known period of time.

Typically, when the amount of link bandwidth required for a real-time application is rather large, packet loss time due to handoff can make a significant effect on the QoS of on-going flow session. 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 is possible to provide good QoS guarantee to some real-time applications together with proper retransmission buffer size and well-measured beacon period. With RSVP session reservation, however, it may not possible to get enough short total handoff time to provide QoS guarantee due to the RSVP resource reservation delay during re-establishment of a flow after handoff under RSVP. The longer the resource reservation delay due to RSVP signaling overheads in roaming environments, the greater the possibility for 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. 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 interactive services such as Internet telephony and teleconferencing since it would introduce additional delay. Furthermore, the buffering requires extra storage and operation complexity to manage the buffers. Mechanisms are thus needed to minimize the resource reservation delay and the packet loss resulting from handoffs under RSVP.

By rerouting RSVP branch path at a crossover router (CR) at every handoff event, handoff resource reservation delays and signaling overheads can be minimized which in turn minimizes the handoff service degradation [4], [5]. These schemes can considerably reduce the reservation latency; nevertheless, there is no guarantee for the QoS of on-going RSVP session at handoff event: The RSVP flow session may normally be disrupted until the new reservation is installed along the path via a new BS after handoff under RSVP. In hard handoff, the old reservation cannot also be explicitly removed, and thus the utilization of network resources will decrease. However, soft handoff can provide a reliable way for RSVP resource reservations when considered with more intelligent receiver than that used in IS-95. That is, from the changes in pilot signal strength, the receiver is able to select one candidate (for handoff) of all the possible BSs involved. Eventually, a new RSVP reservation path to the candidate BS can be established while the existing reservation path is maintained. Even though there are two problems to be solved in order to support soft handoff: data distribution and selection, and data content synchronization [1], soft handoff can be a key challenge in providing Quality of Service (QoS) with RSVP in All-IP wireless networks.

In this letter, therefore, we consider a mechanism for the QoS guarantee of on-going RSVP session. First, resource reservation delays and signaling overheads can be minimized by rerouting RSVP branch path at a crossover router (CR) at every handoff event, and in turn the handoff service degradation can be minimized. Second, the new RSVP reservation can be made between the crossover node and a new BS in advance,

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and thus the on-going flow can be kept with the guaranteed QoS. Hence, we propose a seamless switching scheme of RSVP branch path for soft handoff. Figure 1 shows RSVP branch-path rerouting at crossover router (CR) and the switching of branch path for soft handoff where GW means the gateway router in IP micro mobility scenario.

2. Proposed Scheme

Soft handoff allows an MN to communicate with multiple BSs at the same time. For a soft handoff, an MN must make a conditional decision, which depends on the changes in signal strength from the two or more BSs involved. That is, it performs actual handoff after making sure that the signal received from one BS is considerably stronger than those from the others. Thus, an MN eventually communicates with only one BS [3]. In the interim period, the MN communicates with all candidate BSs at the same time. Hence, soft handoff can guarantee that the mobile is indeed linked at all times to the BS from which it receives the strongest signal, whereas hard handoff cannot guarantee this.

Figure 1 illustrates typical switching of RSVP branch path for soft handoff as an MN moves from one base station area to another area in the proposed scheme. When an MN is a sender, it then sends a RSVP PATH message (or the route update message including a PATH message) to the CR via the new BS before it performs an actual handoff. The crossover router then sends the MN a RESV message, and thus new RSVP branch path reservation is accomplished. When an MN is a receiver, it responds with a RSVP RESV message after receiving the PATH message (via the new BS) sent by the CR on the behalf of the correspondent node (CN). During this resource reservation phase, the packets are still delivered through the path reserved previously via the old BS. As soon as the MN receives the packets through the branch path reserved freshly via the new BS, it can explicitly remove the reservations along the old branch path, and eventually tunes its radio to the new BS. This scheme is very effective in the case that cells, if the hard handoff is considered, do not overlap enough to allow handoffs to complete before an MN loses connectivity with its previous base station. During this RSVP branch path-switching period, the double wireless resource is consumed through both the old and the new branch path. However, this period is very short because the old branch path is released soon.

We assume that an MN moves from a BS coverage area to the adjacent BS area. Whenever the pilot signal from either the old BS or the new BS drops below a predetermined threshold T_{DROP}, the MN starts a timer called "handoff drop timer." If the pilot strength goes back above T_{DROP}, the timer is reset; otherwise the timer is expired after the predetermined time, and the corresponding link is released. Soft handoff zone is the area that the MN can make potential soft handoff; it should large enough to capture all usable multipath signal components of a base station. 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. In addition, similar to the reservation mechanism by a threshold proposed in [3], 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, the MN asks the RSVP daemon on the associated BS to release the RSVP branch path reservation. On the other hand, if the pilot strength reaches T_{ADD}, then the MN initiates soft handoff. Eventually old RSVP branch path is switched to the newly reserved branch path and thus keeps the flow with the guaranteed QoS (see Fig. 2). The threshold T_{RSVP} is not an absolute value but is

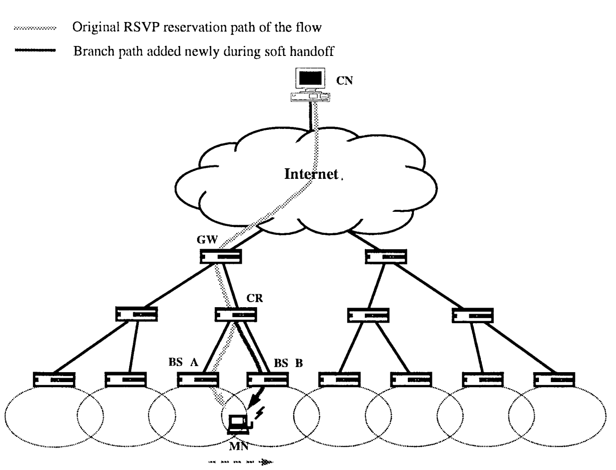

Fig. 1 An example of RSVP branch path switching for soft handoff.

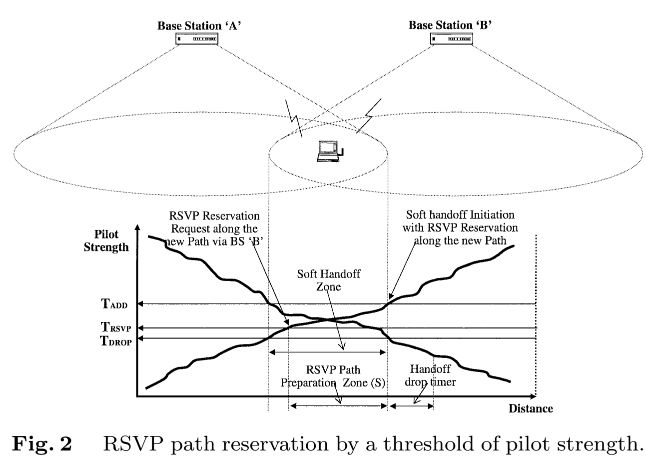

Fig. 2 RSVP path reservation by a threshold of pilot strength.

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.

3. Performance Measures

The signal received by an MN can be taken as a random variable with lognormal distribution, $f(x) = \frac{1}{\sqrt{2\pi}\sigma}e^{\frac{-(x-\mu)^2}{2\sigma^2}}$ 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. μ is average received signal levels due to the path loss from the neighboring BS, and can be given as $\mu(d) = K_1 - K_2\log(d)$ where K_1 depends on the transmitted power in the BS, 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 a 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 $(10^{\frac{K_1 - T_{RSVP}}{K_2}} - 10^{\frac{K_1 - T_{ADD}}{K_2}})$. 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}, ΔT, can thus be calculated by S/V. ΔT can actually be adjusted dynamically by changing T_{RSVP}, but too low T_{RSVP} value can cause excessive unnecessary RSVP reservations.

On the other hand, the RSVP packet processing delays, which are ΔP and ΔR 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 [2]. The setup time for RSVP branch path rerouting [4], $\Delta RSVP$, 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, ΔPR, 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 [2]. These delays do not depend on the amount of network bandwidth used. Instead, the number of the existing RSVP connections, (i.e. the amount of flow state information to be kept on routers) makes an effect on the type of loads; we can assume that they go by normal distributions with the parameters in Table 1,

Table 1 Average control packet latency (in ms) in three types of loads in the networks.

type of load	ΔP	ΔR	ΔPR
low load	2.00 (0.20)	3.07 (0.30)	1.72 (0.17)
medium load	3.90 (0.40)	5.41 (0.54)	2.14 (0.20)
high load	5.44 (0.54)	6.40 (0.64)	2.98 (0.30)

which is obtained from the results of the testbed in [2]. 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. 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 a crossover router and an MN in hierarchical tree topology for IP micro-mobility.

For the simplicity of simulation, we also assume that the time taken for an MN to attach to a new BS after it leaves the old BS, rendezvous time, is very small and thus ignored. Total handoff delay ΔT_RSVP of a real-time 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 ΔT and ΔT_RSVP then becomes an important parameter for measuring the QoS of a real-time flow with RSVP reservation path. When an MN moves into a new BS area under RSVP, the packets transmitted on the RSVP path reserved freshly via the new BS may be lost if ΔT_RSVP is greater than ΔT. Hence, the total handoff signaling process via new BS should be completed during the period ΔT.

When an MN is a sender, ΔT_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 ΔU to send the route update packet to the crossover router, and then also wait for $\Delta RSVP$ for RSVP branch path rerouting. ΔU depends on the size of route update packets, the processing delay of routing table on the CR and the number of links between an MN and a CR. In order to keep the flow with the same QoS after a handoff, it has to wait for the additional propagation delay ΔG from the crossover node to the 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 ΔG can be ignored under micro-mobility scenario. Thus, when an MN is a receiver, the total handoff delay ΔT_RSVP is $\Delta U + \Delta RSVP$. Hence, the total number of lost packets of a flow with RSVP resource reservation at soft handoff, N_L, is $B \times (\Delta T\_RSVP - \Delta T)$ where B is the amount of link bandwidth reserved for the flow. Consequently, if the value of ΔT_RSVP - ΔT 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 ΔT through threshold

$\Delta RSVP$. For our simulation, we assume that an MN is a sender and data transmission is uplink.

4. Results and Discussions

In an example of our simulation, we assume that All-IP wireless network with IP micro-mobility protocol has tree hierarchy structure. We also assume a full binary tree with a gateway node (GW) as a root (see Fig. 1). The depth k of a full binary tree with N nodes is $\lfloor \log_2 N \rfloor + 1$. 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. For the simplicity in this simulation, we also fixed the threshold values, T_{ADD} as -13.0 dB, and constants K_1 and K_2 in received signal level as 35.3 and 40.9, respectively.

Figure 3 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.

Figure 4 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 networks. In this figure, the faster MN's velocity is, the shorter the time that an MN spends in cell boundary area is. Even though the probability of service disruption is nearly zero only when the velocity is less than or equal to 6 m/s, it can be kept quite low when the number of levels in a tree is less than or equal to 3. For the practical system, therefore, this means that the seamless switching of RSVP branch path can be obtained with the proper limit of maximum tree level, and dynamic adjustment of threshold values, T_{ADD} and T_{RSVP} according to the various velocity of an MN.

Figure 5 shows that the mean number of lost packets with various threshold values of T_{RSVP} un-

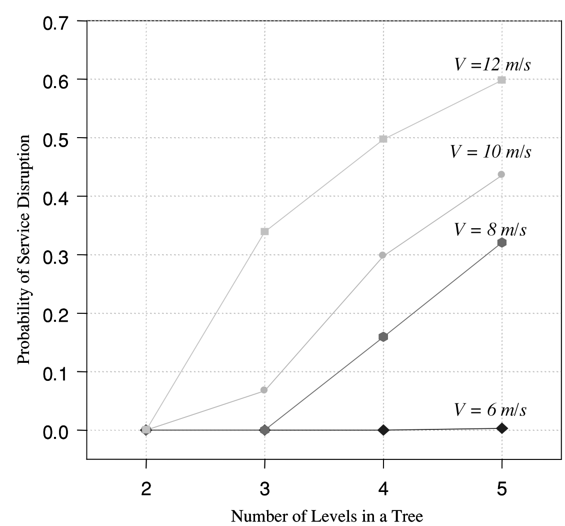

Fig. 4 Probability of service disruption with MN's various velocity under $T_{RSVP} = -13.4$ dB and high load.

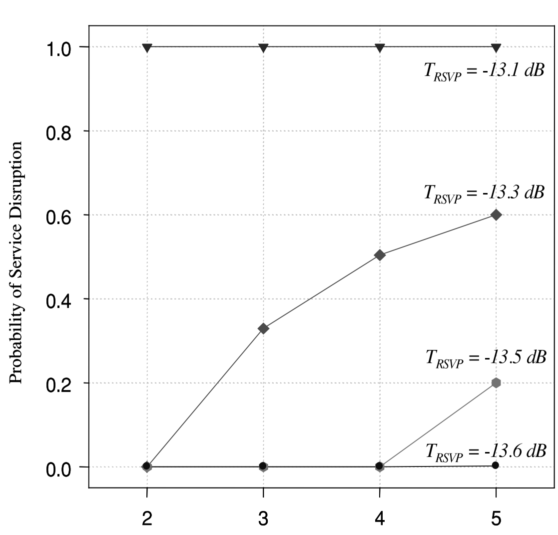

Fig. 3 Probability of service disruption with various T_{RSVP} under $V = 9.0$ m/s and high load.

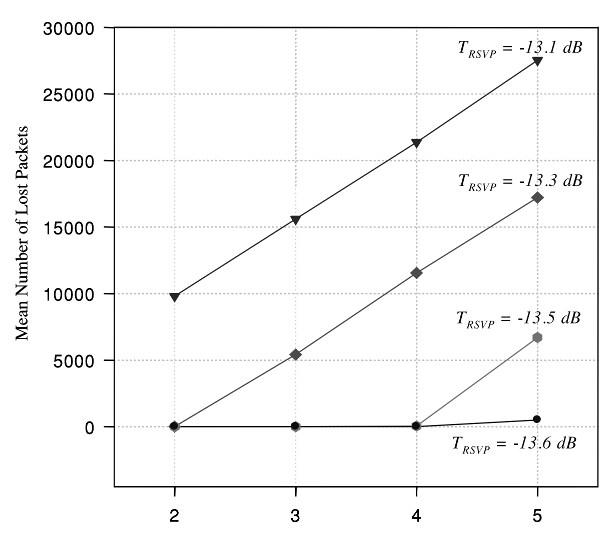

Fig. 5 Mean number of lost packets with various T_{RSVP} under $V = 9.0$ m/s, high load and 1 Mbps data rate.

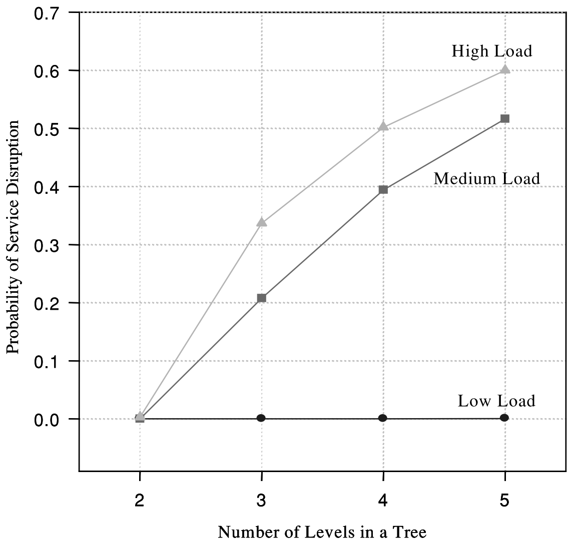

Fig. 6 Probability of service disruption with various load condition under $V = 10.0\,\mathrm{m/s}$ and $T_{RSVP} = -13.3\,\mathrm{dB}$.

der $V = 9.0\,\mathrm{m/s}$, high load of routers and application with 1 Mbps reserved bandwidth. In this figure, when T_{RSVP} is $-13.5\,\mathrm{dB}$ 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.

Figure 6 shows the probability of service disruption with various load condition (in Table 1) under $V = 10.0\,\mathrm{m/s}$ and $T_{RSVP} = -13.3\,\mathrm{dB}$. 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 letter, we considered the rerouting scheme 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 switching 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 the QoS guarantee by adjusting the pilot signal threshold T_{RSVP} and by well defining the number of levels in a tree in IP micro-mobility scenario. For the dynamic and adaptive modification of T_{RSVP} value, however, a mechanism is needed to measure the network condition and link status.

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