2-2003

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Original Citation

Lee, K., Kim, M., Chanson, S.T., Yu, C.S., & Lee, J. (2003). CORP - A Method of Concatenation and Optimization for Resource Reservation Path in Mobile Internet. IEICE Transactions on Communications E86B, 479-489.

PAPER *Special Section/Issue on Communications*

CORP – A Method of Concatenation and Optimization for Resource Reservation Path in Mobile Internet

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Summary
Existing research related to RSVP with mobility support has mainly focused on maintaining reservation state along the routing path, which changes continuously with the movements of mobile host (MH), without much overhead and delay. However, problems such as deepening RSVP's inherent scalability problem and requiring significant changes in the existing network infrastructure have not been adequately addressed.
In this paper, we propose a new approach, known as *Concatenation and Optimization for Reservation Path* (CORP), which addresses these issues. In CORP, each BS pre-establishes *pseudo reservations* to its neighboring BSs in anticipation of the MH's movement. When the MH moves into another wireless cell, the associated pseudo reservation is activated and concatenated to the existing RSVP session to guarantee continuous QoS support. Because a pseudo reservation is recognized as a normal RSVP session by intermediate routers, little change is required in the current Internet environment to support both movements within a single routing domain and between two different routing domains. CORP also dynamically optimizes the extended reservation path to avoid the *infinite path extension* problem. Multicast addressing is used to further reduce resource consumption in the optimization process.
The experimental results of the CORP implementation demonstrate that it significantly reduces the delay and overhead caused by handoffs compared to the case of establishing a new RSVP session. The improvement increases as the distance between the MH and its correspondent host (CH) grows.

Key words:
QoS guarantee, mobile Internet, RSVP with mobility support, reservation path extension and optimization

1. Introduction

Internet applications tend to include more and more traffic types requiring different quality of service (e.g., transfer rate, delay and jitter). In particular, support for real-time services is being more important since delivering time-sensitive multimedia contents is getting popular. In order to satisfy these requirements, several transport mechanisms have been proposed for QoS guarantees including Real-Time Protocol (RTP)[15], Resource Reservation Protocol (RSVP)[3] and Differentiated Service (Diffserv)[16].

However, most existing work on QoS guarantees for the Internet did not consider the mobile computing environment. There are some constraints in mobile networks that make QoS guarantees difficult. The communication environment in wireless networks is characterized by low bandwidth, high error rate, and low processing power of mobile devices. The mobility problem requires maintaining a traffic path when the mobile host (MH) and possibly its access point (AP) move around geographically.

In wireless networks based on Mobile IP, the MH's movement can incur changing its own IP address which is used to identify the MH's physical location[1, 2]. This characteristic of Mobile IP makes some useful existing techniques, such as Resource Reservation Protocol (RSVP), difficult to be accommodated successfully. In RSVP, a path is first established for traffic transport and QoS is guaranteed by reserving resources along the path[3]. If RSVP is used in the Mobile IP networks, a change in the location of the MH may make the existing reserved path useless. Thus resources along a new path have to be reserved again after each movement of the MH. This overhead results in inefficient use of network resources and also introduces additional delay. This is a major problem in applying RSVP to Mobile IP networks.

Some approaches[4, 8, 19, 22] have been proposed to solve the above problem. They focus on reducing the overhead and delay caused by handoffs. However, they require modifications to a considerable number of network components such as the intermediate routers and the mobility support stations (MSS). Later approaches[7, 24] avoid this limitation by restricting such requirements only in components within a single routing domain or an access network. However, it is a major reason why these approaches are difficult to be used for the movements of the MH between different routing domains or between two independent access networks.

In this paper, a new approach known as CORP (Concatenation and Optimization for Reservation Path) is proposed, which ensures QoS guarantees with RSVP in the mobile Internet. It can be easily applied to MH movements between different routing domains or two access networks as well as to the movement within a single routing domain. More importantly, with our approach, only minimal changes are required in the existing Internet components.

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CORP has three key features: *Pseudo Reservation Path* (PRP), activation of a PRP and *concatenation* of the activated PRP with an existing RSVP session, and *optimization* of the extended reservation path.

The rest of the paper is organized as follows: In Section 2, an overview of related work on QoS guarantees in mobile Internet based on Mobile IP and RSVP is presented. In Section 3, the concept of PRP and its concatenation with an existing RSVP session are discussed. In Section 4, the optimization mechanism for extended reservation paths is described. In Section 5, appropriate network architecture for the proposed idea is designed and our testbed configuration is presented. Some noteworthy experimental results are presented in Section 6. Finally, Section 7 concludes the paper.

2. Related Work

In the Bay Area Research Wireless Access Network (BARWAN) project[5] carried out in the University of California at Berkeley, a mechanism using multicast is proposed to reduce delays caused by handoffs of the MHs. All packets destined to an MH are delivered to the cell where the MH is currently located and also its neighboring cells using multicast. This mechanism trades-off network resources for smoother handoffs. *Header multicasting*, a method that multicasts only packet headers to the neighboring cells is also proposed to reduce network resource consumption.

In the Dataman project, Talukdar proposed the Mobile RSVP (MRSVP)[4, 6] where RSVP is extended to work on wireless networks. The major feature of MRSVP is *passive reservation*. These special RSVP sessions are pre-established between a source and the current cell's neighbors along a multicast tree to prepare for the MH's possible movement. No data is passed on a passive reservation until activated. In MRSVP, each MH must maintain its own *mobility specification* that includes information on all locations where the MH is expected to visit during the lifetime of a connection. This information is used to construct a multicast routing tree including an active reservation and one or more passive reservations. MRSVP requires special hosts, called *proxy agent*, to make active/passive reservations on behalf of the MH.

The major drawback in this approach is that the intermediate routers must manage all state information in the passive reservation. If passive reservations are made to all the neighboring cells, the overhead of maintaining state information can be several times higher than that for an active reservation. This deepens the limitation in scalability of RSVP. Also the architecture requires all routers to equip additional functions to support passive reservation and an MH to have prior knowledge of its mobility.

Tseng proposed the Hierarchical MRSVP (HMRSVP)[22] where MRSVP is enhanced to reduce the overhead and network performance degradation due to excessive resource reservations in [4, 6]. In HMRSVP, mobility support with maintaining reservation path is performed with the RSVP tunneling mechanism and Mobile IP regional registration scheme[23]. Resources are saved by making advanced reservations only when an MH resides in the overlapping area of the two wireless cells. However, this approach does not sufficiently consider the inherent disadvantages introduced by MRSVP. In the case of inter-region handoff (usually between two routing domains), the number of RSVP sessions required for a data flow can increase excessively due to RSVP tunneling. Also the delay time for inter-region handoff will be long as it includes times for Mobile IP registration, passive reservations and new RSVP tunnel establishment, which are sequentially performed.

Chen described a similar method to MRSVP, which employs a *predictive reservation* and *temporary reservation* scheme[19]. With this mechanism, an MH makes predictive resource reservation in advance at the locations where it may visit during the lifetime of the connection. These locations become the leaves of a multicast tree and the mobility of a host is modeled as transitions in the multicast group membership. To make more efficient use of wireless resources, temporary reservations can temporarily use the inactive bandwidth reserved by the predictive reservations. Simulation results were used to show the performance improvement over the approach of RSVP tunnel extension combined with Mobile IP[21]. However, since this mechanism is based on MRSVP and the multicasting method, the scalability problem of MRSVP still remains unsolved.

Mahadevan proposed a new network architecture that requires fewer passive reservation-capable routers than MRSVP[7, 20]. The main feature of the method is to extend RSVP path when an MH moves into another cell. In the architecture, a mobile access point (AP) with intelligence, i.e., Base Station (BS), is located in each wireless cell. A set of administratively grouped cells is defined as a *QoS domain*. If an MH participates in an RSVP session, passive reservations between the current BS and each BS in the neighboring cells within the same QoS domain are established in advance. In the case that a neighboring cell resides in a different QoS domain, a passive reservation is established between a gateway router and the neighboring BS instead. If an MH moves within a single QoS domain, the passive reservation between the current BS and the previous BS is activated and traffic is delivered along the activated passive reservation. If an MH moves from a QoS domain to another domain, a passive reservation between the current BS and a gateway router is activated and traffic is delivered along it. Therefore, only BSs and gateway routers are required to have passive reservation capability in this architecture. An MH does not need to participate in making passive reservations.

Mahadevan's approach solved the major limitations of MRSVP, but there are still some drawbacks. Under this mechanism, a reservation path may be extended too much if an MH keeps moving continuously within a QoS domain. It is due to the feature that an optimization process is performed only when an MH moves into a different QoS domain. Also, every gateway router needs to be able to do passive reservations. In practice, most routers also act as gateways for their own subnet. So the approach still requires a significant number of network components to be changed. Also there is no description on maintaining and extending an existing RSVP session when an MH moves into a different routing domain.

Pasklis introduced a mobility adaptation scheme with RSVP[24] where an RSVP mobility proxy (RSVP-MP) in the access network dynamically updates its own binding between an MH's Local Care-of Address (LCoA) and Domain Care-of Address (DCoA). Since an RSVP-MP performs dynamic address translation of RSVP messages and data packets for an MH according to this binding information, an MH's IP address can always be represented in the RSVP internal states by a single IP address (i.e., DCoA) while moving within an access network. The approach assumes the existence of a mechanism to maintain a single contact IP address inside a domain. Also the approach limits its functionality to inside a single access network with the assumption that the core network supports the other QoS architecture such as DiffServ.

Dommety proposed a *route optimization* mechanism in mobile ATM networks described in [14]. The scheme optimizes a *sub-optimal connection*[1]. Most fast handoff schemes for mobile ATM networks, including *path extension* and *anchor switch*, reduce handoff latency by establishing only a necessary portion of the path and attaching it to the existing connection when an MH has moved. This may result in a sub-optimal connection between two endpoints. Dommety's mechanism finds a sub-path in the shortest path, which is not included in the current sub-optimal path, and generates an optimized connection. In principle, this approach can be applied to optimize the extended reservation path in Mahadevan's architecture[7, 20]. However, ATM networks are *connection-oriented*. Dommety's approach is based on the Private Network-to-Network Interface (PNNI) protocol and mobile ATM networks. Therefore, it needs to be modified to work on *packet-switching* networks using Mobile IP.

In the next two sections, we shall describe two key features of our scheme: *Concatenation of Resource Reservation Path* (CRP) and *Optimization for Resource Reservation Path* (ORP), to solve the problems stated above.

3. CRP using Pseudo Reservation

3.1 Pseudo Reservation Path (PRP)

In CORP, each BS takes charge of the RSVP process and also supports mobility of MHs. To support MH's movements including those that cross routing domains, we propose a special RSVP session, called a *pseudo reservation*, in place of the passive reservation in [4, 7]. A pseudo reservation is an advanced resource reservation session in order to prepare the possible movement of an MH. A BS pre-establishes pseudo reservations with neighboring BSs for each MH located in its own cell. If an MH moves to another cell, the PRP between the current cell and the previous cell is activated, and traffic is delivered through the activated PRP. The previous BS concatenates the original RSVP path with the activated PRP and forwards traffic on it.

A pseudo reservation session is established in the same way as a normal RSVP session but no traffic is delivered over the session until it is activated. It looks like a passive reservation but there is an important difference, namely, the routers in the networks do not need to know whether an RSVP session is a pseudo reservation or not. In our scheme, pseudo reservations are always established between two BSs. So, only the BSs need to know about the existence of PRPs. Since BSs never send traffic along the PRPs before they are activated, intermediate routers need not block traffic on the PRPs even when they are not activated. Because of this transparency of pseudo reservations, they can be applied to handoffs between two routing domains without any functional change and any extra overhead to keep pseudo reservations inactivated in the intermediate routers.

Each CORP BS takes charge of all the process related to PRPs, including establishment, maintaining and release. A PRP can be established and released with the same way as a normal RSVP session, using RSVP *path*, *resv*, and *path teardown* messages[3]. A CORP BS dynamically terminates useless PRPs after an MH leaves the current wireless cell.

In Figure 1, the MH participates in an RSVP session, which is illustrated by a double line. The current BS of the MH is A. A hexagon represents a wireless cell and each

[1] The path for a connection is considered sub-optimal if it is not the shortest path between the two endpoints of the connection.

point inside a cell represents a BS. A, B, C and D belong to the same routing domain with a gateway router R1. E belongs to another routing domain which is served by gateway router R2. A dotted line represents a PRP within a routing domain and a solid line represents a PRP between two routing domains.

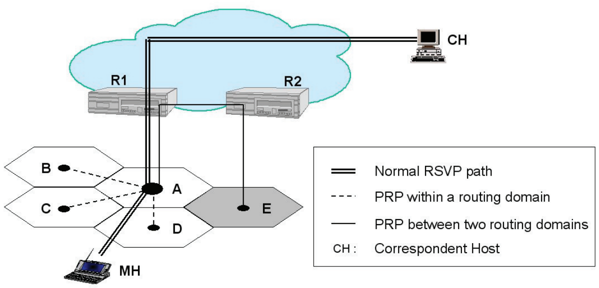


Fig. 1: Pseudo Reservation Path (PRP)

When an MH participating in an RSVP session enters cell A or when an MH in cell A requests a new RSVP session, BS A establishes pseudo reservations between neighboring BSs (B, C, D and E) and itself. R1 and R2 do not have to know whether a reservation session between A and E is pseudo or not. The pseudo reservation is treated as if it is an ordinary RSVP session.

3.2 Representative BS

A PRP between two different routing domains, called an *inter-routing-domain* PRP, generally requires more network resources than the one within a single routing domain. To reduce overhead for maintaining a lot of inter-routing-domain PRPs required, we propose a concept of *representative BS*.

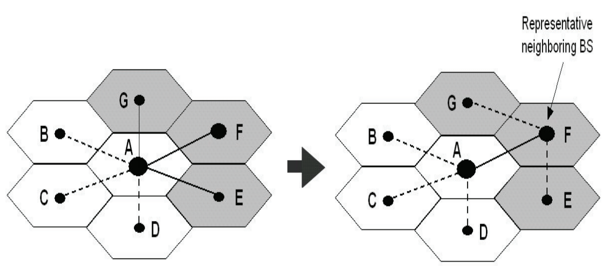


Fig. 2: Representative of neighboring BSs

In Figure 2, A, B, C and D belong to the same routing domain, and E, F and G belong to another routing domain. So, if an MH is currently served by BS A, three inter-routing-domain PRPs (between A and E, A and F, A and G) are required. However, in our example, BS F is selected as a representative of the neighboring BSs residing in another routing domain. Thus, only one *inter-routing-domain* PRP is established (between A and F). BS F in Figure 2 then establishes pseudo reservations from (to) E and G on behalf of A. The choice of the representative is arbitrary and can be predetermined for each BS along the boundary between two routing domains.

If the MH moves from cell A to cell B, C, D or F, the PRP between the new BS and the previous BS is activated. Then BS A forwards traffic between the activated PRP and the existing reservation path. If the MH moves to cell E, a PRP between BS E and F and a PRP between F and A are activated. The reservation path is extended to BS E via BS F. In this case, not only BS A but also BS F forwards traffic between the two PRPs. This increased number of activated PRPs in an extended reservation path can incur much overhead and performance degradation in the network. To minimize such overhead and deterioration, CORP immediately performs an ORP process to optimize the reservation path when it is extended using an inter-routing-domain PRP. The ORP process is described in detail in Section 4.

3.3 CRP Process: Before a Handoff

A network architecture that supports CORP is presented below. The major features of this architecture are:

- Each cell in the mobile network has a BS which is a mobile access point (AP) with certain intelligence.
- Every BS knows about their neighboring BSs including their IP addresses.
- Each BS has capability to establish a pseudo reservation and to activate it when needed.
- Each BS can forward traffic from one reservation path to another.

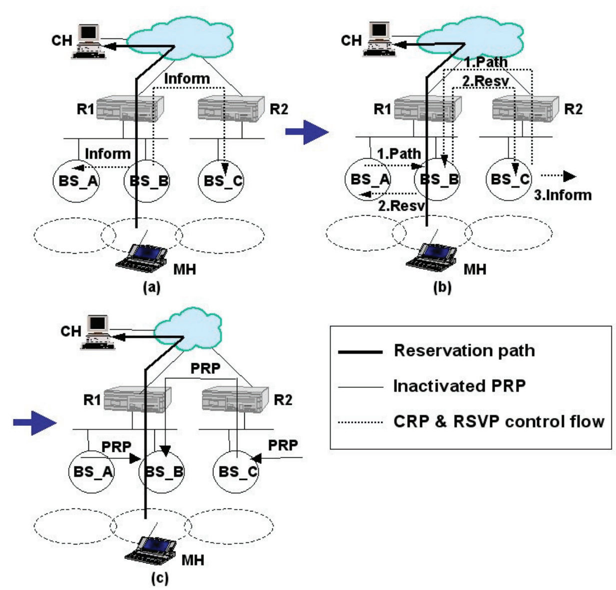


Fig. 3: CRP process before a handoff when an MH is a sender

Figure 3 shows the process of establishing pseudo reservations before a handoff when the MH is a sender in an RSVP session. A thick solid line represents an ordinary RSVP path, and a dotted line represents a control message flow for the RSVP and CRP processes. Each thin solid line represents a PRP between two BSs. To show that the proposed mechanism supports the movements between two different routing domains successfully, we describe an example that an inter-routing-domain PRP is used to extend the original RSVP session.

In Figure 3(a), The MH currently resides in cell B and participates in an RSVP session as a sender. The current BS is BS_B. First, BS_B passes CRP *inform* messages (which notify the MH's entrance or establishment of a new RSVP session) to its neighboring BSs (BS_A and BS_C). An *inform* message includes *Tspec*, which defines the traffic characteristics of the data flow that the MH will generate. In this example, BS_A and BS_B are in the same routing domain while BS_C resides in a different routing domain.

As shown in Figure 3(b), when BS_A receives an *inform* message, it sends an RSVP *path* message to BS_B in order to establish a PRP from itself to BS_B. This RSVP *path* message includes *Tspec* and BS_B replies to the message with an RSVP *resv* message. Then a PRP between BS_A and BS_B is established. Since BS_C resides in another routing domain, the *inform* message delivered to BS_C should include not only *Tspec* but also IP addresses of BS_B's neighboring BSs. In other words, BS_C should establish a PRP from itself to BS_B using RSVP *path* and *resv* messages, and also should play a role of BS_B in Figure 3(a) as the *representative* of neighboring BSs in another routing domain. Thus, as shown in Figure 3(c), all required PRPs are successfully established to prepare all possible movements of the MH.

The CRP process when an MH is a receiver in the RSVP session is similar to the procedure when an MH is a sender. But there are some minor differences because RSVP is a *receiver-initiated* setup protocol. In this case, RSVP *path* messages including *Tspec* are delivered from the current BS to its neighboring BSs to establish PRPs. So a CRP *inform* message does not have to include *Tspec*. The *inform* message delivered to BS_C should include only IP addresses of BS_B's neighboring BSs. Subsequently, BS_B performs the PRP establishment process by exchanging RSVP *path* and *resv* messages with its neighbors in the reverse direction to the case in Figure 3. BS_C acts as a *representative* of the neighboring BSs by sending RSVP *path* messages to BS_B's neighbors which reside in BS_C's routing domain. Finally, all required PRPs are successfully established to prepare all possible movements of the MH.

3.4 CRP Process: After a Handoff

After an MH's handoff, there is little difference in the CRP process depending on whether the MH is a sender or a receiver in the RSVP session. Only difference is the direction of the traffic delivered with QoS guarantees between the MH and the CH. Figure 4 shows the CRP process after a handoff. A thick solid line represents an ordinary RSVP path or an activated PRP attached to the original RSVP path. Since there is no meaning in the direction of delivered traffic, we describe all reservation paths in the figure as arrows with both directions.

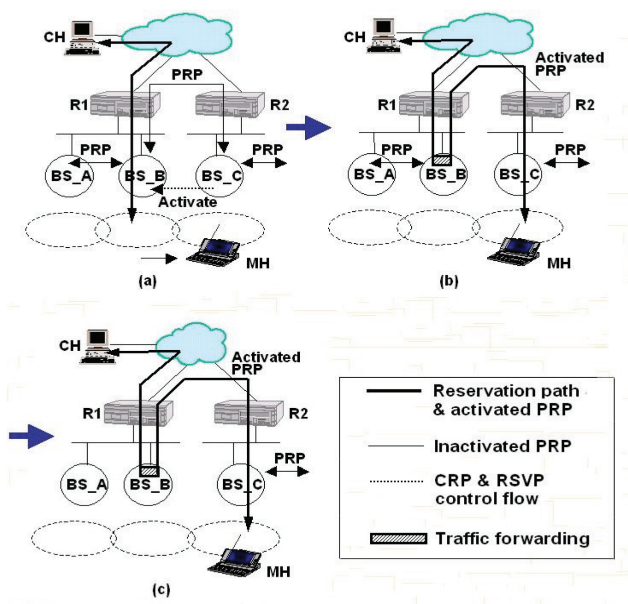


Fig. 4: CRP process after a handoff

PRP activation can be performed by either the current BS or the previous BS, depending on which BS currently acts as the sender of the PRP. When an MH enters into a new wireless cell, it tries to perform a Mobile IP registration process with its Home Agent (HA)[1]. By relaying a Mobile IP *registration request* packet from the MH to the HA, the current BS knows that a corresponding PRP between the previous BS and itself should be activated. Then the current BS sends a CRP *activate* message to the previous BS to inform the movement of the MH. Finally, one of the two end BSs of the PRP, whichever is currently the sender, activates the PRP by starting to send traffic along the PRP.

In Figure 4(a), when the MH moves into the cell in which BS_C resides, the current BS, BS_C sends a CRP *activate* message to BS_B to notify this movement and the PRP between BS_B and BS_C is activated by a sender of the PRP. Then, by concatenating the activated PRP to the original RSVP session, the reservation path is successfully extended to guarantee seamless QoS to the MH. To do that, BS_B forwards the traffic between the activated PRP and the original RSVP session as shown in Figure 4(b). It is not necessary to maintain the PRP between BS_A and BS_B any more. Thus BS_B terminates the PRP as shown in Figure 4(c). Finally, BS_C plays the role of BS_B in Section 3.3 to prepare for future movement of the MH.

In this section, we have proposed the concept of CRP to maintain a reservation path when an MH moves in the wireless network. The proposed mechanism supports *inter-routing-domain* handoffs and requires little change to the existing Internet. However, this mechanism does not address the *infinite reservation path extension* issue. In the next section, a new mechanism, called ORP, is proposed to solve this problem.

4. Optimization for the Extended Reservation Path (ORP)

4.1 Considerations on ORP Process

The CRP mechanism is built on RSVP and uses a “path extension” technique to guarantee seamless QoS in mobile Internet. To do this, each BS along the MH’s movement extends a reservation path by activating a prepared PRP and forwarding traffic between the existing reservation path and the extended one. One problem in this mechanism, is that a reservation path can be extended infinitely if an MH moves continuously in the wireless network. In [7], to avoid infinite extension of the reservation path, an optimized sub-path is made between a gateway and the current BS when an MH moves from one QoS domain to another. However, as described in Section 2, this solution does not work when the MH moves continuously within one QoS domain.

To solve these problems, we propose a new solution, called *Optimization for Reservation Path* (ORP). In this mechanism, the current BS of an MH replaces the extended reservation path with the optimized one which is laid along the shortest routing path between a sender and a receiver. Two points should be considered when adopting this mechanism. The first issue is to determine when an optimization process needs to be performed. If a reservation path is extended using *inter-routing-domain* PRP or includes a loop, the reservation path necessarily needs to be optimized. An optimization process is also required when the cost of maintaining an extended reservation path is even higher than the cost of making new one. Thus a way of determining cost in each case should be studied. In our implementation, the ORP process is performed at every time that an MH’s handoff has occurred and the CRP process has been completed. This is due to that we intend to save network resources, especially bandwidth, rather than to reduce the overhead on BSs, which is required for ORP process. As an interval between two ORP processes increases, the overhead in each BS decreases, however, the bandwidth consumption in the network due to the extended reservation path increases significantly.

The second issue is to minimize the optimization overhead. If a new RSVP session should be established to substitute for an extended reservation path, the two RSVP sessions for one flow is wasteful of network resources, even though it is temporary. Also, a new reservation request for optimization can be rejected by intermediate routers due to lack of network resources. To reduce the amount of extra network resources consumed by the ORP process, CORP can make use of *multicast* address for every RSVP session, even if it is a one-to-one flow. Thus optimization can be performed by joining in the multicast RSVP session instead of making a new RSVP session. This also can prevent effectively an optimization request from being rejected by intermediate routers. In the next section, we shall describe the ORP process using multicast IP address in detail.

4.2 ORP Process Using Multicast Address

Figure 5 shows an ORP process using a multicast address. In Figure 5, a thick solid line represents an ordinary RSVP path or an activated. For ease of illustration, Figure 5 describes the case where path extension is achieved using a PRP within one routing domain, but it can be applied directly to the case of *inter-routing-domain* PRP. We assume that an RSVP session with multicast address had been established between BS_A and the CH, and that a CRP process has been performed as described in Section 3.

As shown in Figure 5(a), BS_B first joins into the existing multicast RSVP session to open a direct reservation path along the shortest path between a CH and itself. There are some differences in this procedure according to whether an MH is a sender or a receiver in the existing RSVP session as following:

- When an MH is a sender, BS_B sends an RSVP *path* message destined to a multicast address of an existing RSVP session to join in the session. This message is delivered to the receiver and BS_A. BS_A discards the message because it knows that BS_B is on the extended path. However, the receiver (CH) is not aware of this, so it replies with an RSVP *resv* message. This allows BS_B to join in the existing RSVP session
- When an MH is a receiver, BS_B joins in the IP multicast group using the Internet Group Management Protocol (IGMP) *report* message [13]. It then waits for an RSVP *path* message which the sender (CH) generates periodically through the IP multicast session

to identify a flow for a new destination [3]. In this situation, BS_B can directly receive traffic from the router because it is a member of the IP multicast group, but the quality of service cannot be guaranteed. To support seamless QoS to the MH, BS_B should deliver traffic from the activated PRP to the MH and, at the same time, it should wait for an RSVP *path* message directly from the sender. When BS_B receives the *path* message, it replies with an RSVP *resv* message. This enables BS_B to join in the multicast RSVP session.

Consequently, BS_B is now able to send (receive) traffic from (toward) the MH through the new RSVP path as shown in Figure 5(b). Then it terminates the activated PRP between BS_A and itself using a CRP *release* message. After receiving a CRP release message, BS_A leaves the multicast group by sending an RSVP *path teardown* message to terminate the existing reservation path to the receiver. Finally, only an optimized path between BS_B and the receiver is left as shown in Figure 5(c). After finishing whole ORP process, the CRP process described in Section 3 is performed to prepare the next movement of the MH.

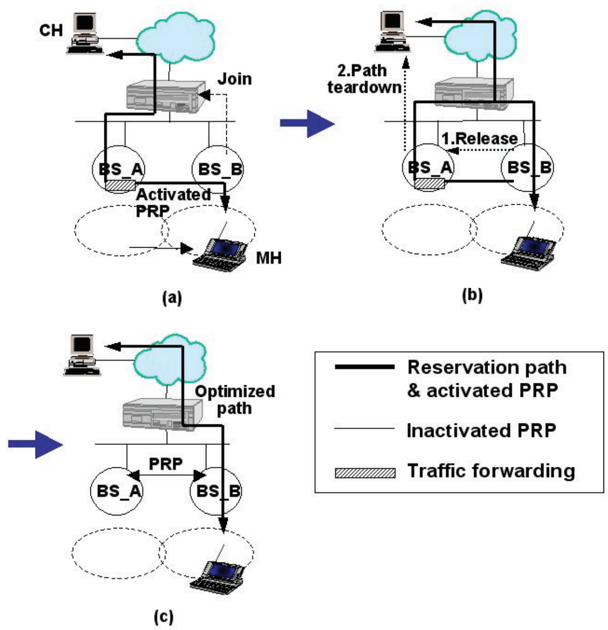


Fig. 5: ORP process

4.3 ORP Process Using Unicast Address

Although the ORP process using multicast address provides a more efficient and scalable way to optimize an extended reservation path, the ORP process using unicast address is still needed in some situations. For example, the underlying networks may not support IP multicasting, or an MH already participating in a unicast RSVP session may move into a cell. Therefore, a description of using unicast address is given below.

An ORP process using unicast address starts with establishing a new RSVP session between a CH and the current BS. To do this, first the current BS sends an ORP *initiate* message, which notifies a need for optimization of an extended reservation path, to the CH. Second, the current BS and the CH exchange RSVP *path* and *resv* messages with each other to establish a new RSVP session. When an MH is a sender, the current BS sends an RSVP path message first and the CH replies with an RSVP resv message, and vice versa. Third, the extended reservation path is replaced by the newly established RSVP session, which is used to deliver traffic. Fourth, the current BS terminates the activated PRP between the previous BS and itself using a CRP *release* message. Finally, the previous BS terminates the unnecessary RSVP session between the CH and itself by sending an RSVP *path teardown* message to the CH. After finishing the entire ORP process, the CRP process described in Section 3 is performed to prepare for the next movement of the MH.

In this section, we have described the ORP mechanism which optimizes an extended reservation path. The proposed mechanism has the advantage that it can avoid establishing a new RSVP session during the optimizing process by using multicast RSVP sessions. This can considerably reduce network resources consumption.

5. Experimental Testbed

The testbed architecture for implementing CORP is shown in Figure 6. A dotted line represents a flow for reserved traffic. In Figure 6, each BS consists of a *RA (Reservation Agent) module*, a *HA/FA (Home/Foreign Agent) module*, a *routing module* and an *AP (Access Point) component*. The *RA module* performs all RSVP activities on behalf of an MH. It also establishes PRPs in preparation for the MH's motion and performs CRP and ORP processes. The *HA/FA module* enables a BS to act as a home agent or a foreign agent in Mobile IP. The *routing module* delivers traffic between wired and wireless networks and handles traffic control of reserved flows.

In the architecture shown in Figure 6, each BS has its own wireless interface. This feature enables a BS to have its own wireless subnet which is regarded as a cell, and to act as a gateway router for the subnet. Thus all traffic concerned with an MH passes through the BS that handles the MH. This feature makes the implementation of CORP mechanism easier and more efficient because each BS can monitor all traffic from/to MHs.

The experimental testbed consists of an RSVP router, two BSs supporting the CORP function, and an MH with

RSVP capability. The two BSs know each other's IP addresses. Each BS has two network interfaces: an Ethernet card and a WaveLAN I ISA card[9]. Also a WaveLAN I PCMCIA card is used for an MH. Each BS, router and MH runs FreeBSD 2.2.2. The Mobile IP software from Portland State University[10] is used to support mobility, and the RSVP package from Southern California University[11] is modified to implement the CORP mechanism. For traffic control, Alternate Queueing Package (ALTQ) [12] is used.

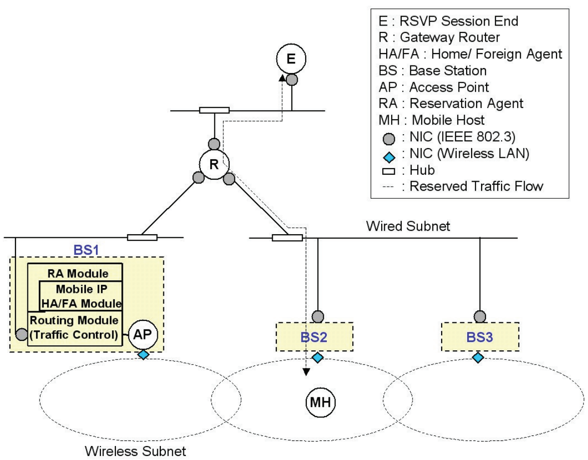


Fig. 6: The Testbed Architecture

The CRP module and the ORP module have been implemented in the testbed. The latest ORP module in the testbed has been implemented to perform an ORP process with unicast address only, which is described in Section 4.3. Also some applications were written using RSVP API (RAPI) to demonstrate the operability of the CORP module and to measure the performance.

6. Experimental Results

In this section, we present some experimental results measured while running our CORP implementation on the testbed described above. We evaluate the CORP performance in terms of processing delay, transfer rate observation, performance variation depending on the distance between a sender and a receiver, and so on.

6.1 CRP Performance Evaluation

Figure 7 shows the elapsed times for resuming data transfer when an MH moves into another cell. The estimated Mobile IP handoff time appears about 112 ms. This delay represents the interval from the time the MH crossing a cell boundary to completion of registration with a new mobile agent. It needs approximately 9 ms delay for resuming data reception through an existing TCP session after a Mobile IP handoff. An MH can receive QoS-guaranteed traffic through an extended reservation path 4 ms after the existing TCP session becomes available. The delay times presented are the average values of 50 experiments measured on the testbed. These results are dependent on how far the CH is from the MH. In this case, the MH is the receiver and the sender is 2 hops away.

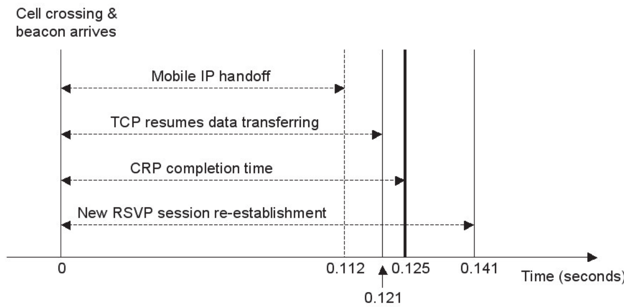


Fig. 7: Elapsed delays for resuming data transfer after a handoff

As shown in Figure 7, CORP significantly reduces the delay caused by handoffs compared to the case of establishing a new RSVP session which takes 141 ms. Also, as can be seen, the CRP process adds little delay (only 4 ms) to the Mobile IP handoff delay. The total CRP process takes around 125 ms. Most of the time is needed for Mobile IP handoff since a wireless LAN AP typically broadcasts a beacon signal at 100 ms intervals.

Packet audio applications like vat (visual audio tool) [17] adopt a *playout delay* mechanism in which the receiver delays playback of the audio contents after packet arrival for some amount of time. Caceres et al. have measured the playout delay for particular Multicast Backbone (MBone) sessions that used vat[18]. The result shows that the tolerable playout delay is approximately 100 ms for a local conference and 4-5 seconds for a lecture from a distant host. Human factor studies have shown the maximum tolerable delay for interactive conversations is approximately 200 ms. These studies show that the proposed CRP mechanism is capable of supporting voice traffic in the mobile Internet.

Figure 8 shows the transfer rate variations of traffic during CRP, where 50 kilobytes of bandwidth have been reserved and a sender transmits 500 data packets per second with each packet size fixed at 100 bytes. We generated background traffic between a CH and an MH using a FTP application. The application generated background traffic at the highest rate possible. The total available bandwidth in the testbed was estimated to be about 150 kbytes/sec. We observe that the performance of CRP is not affected by the background traffic. The period of time identified as *CRP completion time* represents the delay during which an MH cannot receive any traffic after cell crossing. It includes a Mobile IP handoff delay, a TCP data re-transferring delay and a pure CRP delay as shown in Figure 9.

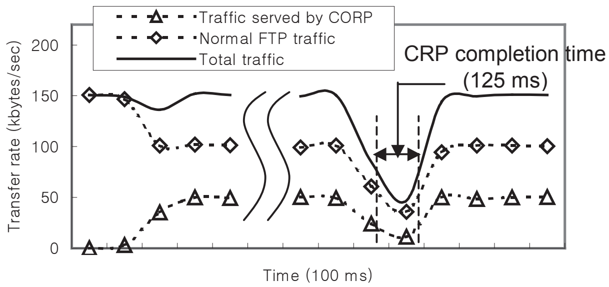
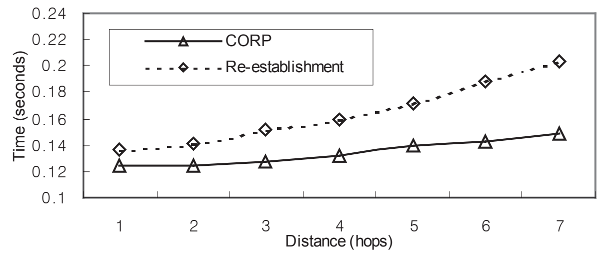


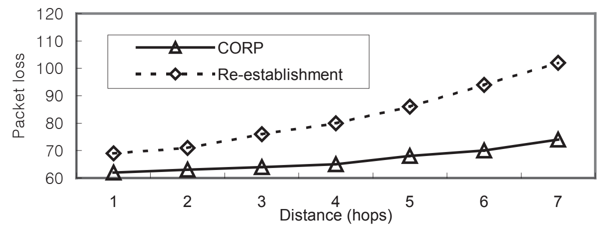
Fig. 8: Transfer rate variation when background traffic exists.

Figure 9 shows the CRP completion time and packet loss during this time as a function of the distance between the MH and CH. We measured the Round Trip Time (RTT) of a packet having the same size as an RSVP *path* message in each case that the distance between the sender and receiver was varied from 1 to 7 hops. The processing times of the RSVP *path* and *resv* messages at an intermediate router are also measured. With this data, we could estimate delays caused by the RSVP process for different number of hops. The CRP completion time does not depend very much on the distance between a sender and a receiver, but is more dependent on the distance between the current BS and the previous one. In this experiment, the current BS is always 2 hops away from the previous BS. So the CRP completion time is only dependent on the delay needed to resume traffic transfer after the reservation path has been extended. These delays could be estimated by measuring the packet delivery time between the previous BS (i.e., the one before the current BS) and the CH for different number of hops. So the packet delivery time is measured in each case that the distance between the sender and receiver was varied from 1 to 7 hops. In Figure 9(a), we see that the relative performance advantage of CORP increases as the CH is farther away from the MH. For example, the CRP completion time is approximately 125 ms and the new RSVP session establishment time is approximately 141 ms when the sender is 2 hops away from the receiver. The difference is only 16 ms. But the two values become 148 ms and 204 ms respectively when the sender is 7 hops away from the receiver. In the latter case, the difference is about 56 ms.

Figure 9(b) shows the number of dropped packets during handoff. We measured the number of packet lost during CRP completion time, where 50 kilobytes of bandwidth have been reserved for CORP traffic and the sender transmits 500 data packets per second with a fixed size of 100 bytes per packet. The result in Figure 11 confirms that the proposed mechanism provides better performance as the distance between the CH and MH increases.



(a) Delay with distance



(b) Packet loss with distance

Fig. 9: CRP performance with the distance between MH and CH

6.2 ORP Performance Evaluation

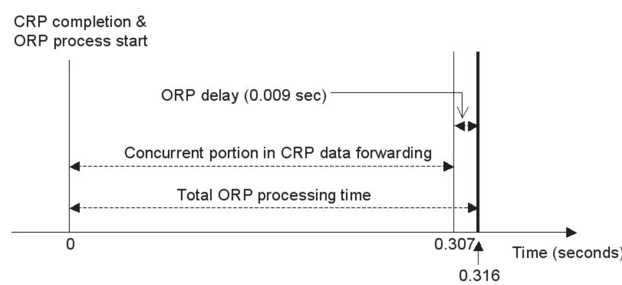


Fig. 10: ORP processing time

With the current CORP implementation, an ORP process begins just after a CRP process is completed. Figure 10 illustrates the elapsed times for performing an ORP process. The result is the mean value of 50 experiments on our testbed, where an MH is the receiver and the sender is 2 hops away. As shown in the figure, much of the ORP process is performed simultaneously with CRP data forwarding through an activated PRP and does not affect the data transfer rate, packet loss, and delay. The actual ORP delay time, during which an MH cannot receive data from a sender, is approximately 9 milliseconds. This delay is required for exchanging ORP messages and switching the sender's RSVP session into the optimized one. The results show that the ORP process causes only a short delay which can be ignored in transmission of multimedia data such as voice traffic.

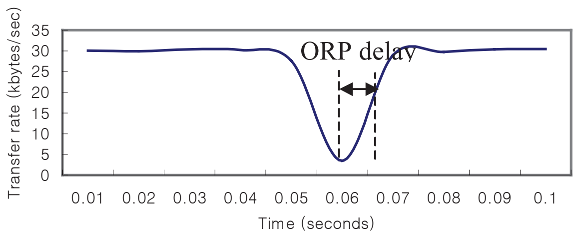


Fig. 11: Transfer rate variation during ORP delay

Figure 11 shows the transfer rate variations of traffic during ORP delay time. In this case, 30 kilobytes` of bandwidth have been reserved and a sender transmits 300 data packets per second with a fixed packet size of 100 bytes. Each value in the figure is the amount of data received by an MH in each 10-millisecond interval and the time referred to as *ORP delay* represents the period of time in which the MH cannot receive any traffic due to ORP processing.

The ORP delay time is also dependent on how far a CH is from the MH because an ORP message exchange time is proportional to the hop count between the CH and MH. However the rate of increase is not high. For example, the ORP delay is about 9 milliseconds when the sender is 2 hops away from the MH and the value increases to 13 ms when the sender is 7 hops away.

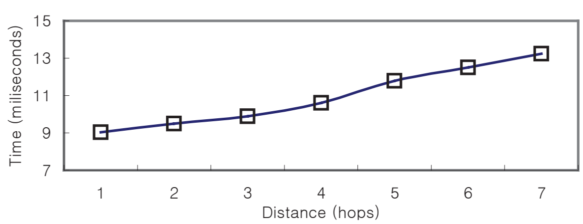


Fig. 12: ORP delays as a function of distance between MH and CH

Figure 12 shows the ORP delays with different values of hop count between the MH and CH. We observe that the values increase almost linearly. This backs up our claim that the ORP mechanism scales well. We can assume that most communication paths are 15 hops or less. The estimated ORP delay is approximately 18 ms when the distance between two communication end points is 15 hops. This confirms that our ORP mechanism can support QoS-guaranteed transmission of various multimedia traffic on the mobile Internet.

7. Conclusion

In this paper, we have proposed a new mechanism, called CORP, to minimize the delay and overhead when a mobile host (MH) participating in an RSVP session moves in the wireless network. The proposed mechanism overcomes the drawbacks of existing approaches. First, it supports inter-routing domain handoffs as well as handoffs within a routing domain. Second, our approach requires fewer functional and architectural changes to the existing network components. Third, the process and network architecture that support QoS-guaranteed handoff are simple. In the proposed architecture, only Base Stations (BSs) are required to have functions that support the proposed scheme because the BS takes care of every RSVP process and the additional functions to support mobility on behalf of an MH. Finally, the scheme scarcely increases the scalability problem inherent in RSVP because most of Pseudo Reservation Paths (PRPs) would be established between two BSs in the same routing domain.

An experimental testbed has been developed to demonstrate the feasibility of CORP. The experimental results show that the proposed mechanism can significantly reduce delay and overhead during QoS-guaranteed handoffs in the mobile Internet. The results also show that the performance advantage of CORP over establishment of a new RSVP session after handoff increases when an MH is farther away from the correspondent host (CH).

The current implementation of CORP performs an optimization process by using a newly established RSVP session between a CH and the current BS of the MH. An implementation of *Optimization for Reservation Path* (ORP) using multicast RSVP session is being worked on. Also, to demonstrate the generality of CORP, we are currently working on porting different multimedia applications on our testbed.

Acknowledgments

This work is supported by KOSEF (Korea Science and Engineering Foundation).

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