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Abstract

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Comparative Analysis of Resource Reservation Cost for Different RSVP Extension Schemes in Mobile Environments

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Abstract—In wireless networks, advanced resource reservation becomes a necessary requirement for fast handover with QoS guarantee because of the mobility of nodes. However, advanced resource reservation would unavoidably lead to system resource wasting. In this paper, taking the representative RSVP extension schemes with mobility support, MRSVP, Multicast RSVP and Fast RSVP as examples, we analyze factors affecting resource reservation costs and present formalized expressions of reservation costs for these different resource reservation schemes. On this basis, we quantify and compare the reservation costs for different resource reservation schemes, and then give recommendations on resource reservation schemes design for mobile environments.

I. INTRODUCTION

In recent years, accompanied by the development of mobile communication technologies and the increase of available wireless transmission bandwidth, deploying multimedia services in next generation mobile IPv6 [1] networks has become an inevitable trend. However, multimedia sessions containing real-time voice and video are very sensitive to delay and delay jitter, and hence have strict QoS requirements. To fulfill the QoS needs of such multimedia sessions, adequate network resources must be reserved for their transmissions. This can be done using the signaling protocol in IntServ [2], Resource Reservation Protocol (RSVP), that IETF proposed [3] in 1997. It makes every intermediate node on the transmission path reserve proper resources for a session, thus providing an end-to-end QoS guarantee for multimedia communication.

However, RSVP is designed for hardwired and fixed networks, and it can not be used directly due to the host mobility in mobile environments. Since the RSVP protocol does not include an advanced resource reservation scheme, a mobile node has to wait to initiate the reservation process in a new cell until it indeed hands over to the new cell. As a result, the QoS of the session can be badly affected during the reservation setup time after handover. To overcome the impact of mobility on RSVP, a series of extension protocols

with advanced resource reservation scheme have been proposed, of which MRSVP, Multicast RSVP and Fast RSVP are the most representative ones.

Since resources reserved in the handover target cell can not be used until the mobile node indeed hands over to the target cell, an advanced reservation scheme would unavoidably incur system resource wasting to some extent. Although most schemes with advanced reservation introduce the “Passive Reservation” which allows resources reserved in target cells to be temporarily lent to best effort flows with low priorities, however, only flows with low priorities can benefit from this scheme and it is unhelpful for flows with high priorities. In this paper, we quantify and compare the reservation costs for different resources reservation schemes, and then we give recommendations on resource reservation schemes design for mobile environments.

The organization of the paper is as follows: We provide a brief overview of the representative resources reservation schemes in mobile environments in Section 2. Section 3 presents formalized expressions of reservation costs for MRSVP, Multicast RSVP and Fast RSVP. In Section 4 we calculate and compare the reservation costs for MRSVP, Multicast RSVP and Fast RSVP. Section 5 summarizes the paper and presents our conclusions.

II. RELATED WORK

Experts and scholars all over the world have already carried out a lot of research work on resource reservation schemes in mobile environments and a series of proposals [7]-[11] with mobility support have been made. In this section, three representative proposals will be briefly introduced.

The MRSVP scheme [7] defines a new entity-proxy agent in each cell to deal with the resource reservation related messages in mobile environments. And two new notions, Mobility Specification-MSPEC and Active/Passive Reservation, are introduced. MSPEC is used to record all the corresponding proxy agents of the possible cells (all the neighbor cells of the current one) the mobile node may visit in

the near future. When a recipient mobile node hands over to a new cell, it needs to update its MSPEC first. The updated MSPEC is sent as a Receiver_MSPEC message to the session sender to inform it all the possible cells the recipient mobile node may visit. In addition, the recipient mobile node sends each proxy agent recorded in MSPEC a Receiver_SPEC message from which the QoS guaranteed parameters can be retrieved. And then through the exchange of Active Path/Active Resv messages between the sender and the receiver, the active reservation path is set up. At the same time, the passive reservation paths are established through the exchange of Passive Path/Passive Resv messages between the sender and the proxy agents recorded in MSPEC. The passive reservation paths are only reserved in advance without any actual packet flows transmitted over, and the resources reserved can be borrowed by flows with low priorities temporally. When the mobile node moves to a new cell, MRSVP changes the passive reservations along the sender to the corresponding proxy agent of the new visited cell into the active status, and the active reservations along the original active reservation path are altered to the passive status at the same time. To sum up, the MRSVP scheme supports advanced resource reservations in all the neighbor cells, thus realizing mobile node handover with QoS guarantees.

Authors in [8] proposed utilizing multicast technology to realize resource reservation in mobile environments (Multicast RSVP). A mobile proxy in a cell is similar to the proxy agent defined in MRSVP, it is an entity that acts as an agent for a mobile node to make various reservations along the path from the current cell and the neighbor cells toward sender. And Conventional Reservation and Predictive Reservation are introduced. Conventional Reservation reserves resources along the path from the sender to the current cell of the recipient mobile node just as Active Reservation in MRSVP. Predictive Reservation reserves resources along the multicast tree from the sender to the neighbor cells surrounding the current cell of mobile node just like Passive Reservation in MRSVP. Every session is assigned a multicast address. When a mobile node enters a new cell, the Mobility Proxy at the current cell would notice the corresponding Mobility Proxies of all the neighbor cells joining the multicast group. After neighbor cells join the multicast group, their Mobility Proxies would receive Path messages from the session sender, thereby the neighbor cells could reserve resources for the mobile node in advance. Therefore, a handover with QoS guarantees can be realized. Meanwhile, to eliminate duplicate reservations on the internal routers shared by different reservation paths (the conventional reservation path and the predictive reservation paths), Conventional and Predictive Reservations for the same session are merged by utilizing the mechanism in Integrated Service specification [12].

Fast RSVP proposed in reference [9] utilizes a handover prediction mechanism to determine the handover target cell before a mobile node hands over to a new cell, and then a

resource reservation neighbor tunnel, along which passive reservations are made, between the corresponding routers of the mobile node's current cell and target cell is setup in advance. Therefore, in Fast RSVP, resource wasting due to over-reservation in all neighbor cells can be avoided. When a mobile node indeed hands over to the new cell, passive reservations made along the path from sender to the current cell before are changed into the active status immediately. Even if the handover prediction fails, the extra reservation cost is low, because resource reservations are only needed on routers along the neighbor tunnel which is usually very short in length. Moreover, Fast RSVP introduces a new mechanism "path merge" (by importing a new object-MSESSION) to avoid duplicate reservations on the internal routers shared by the active reservation path and the passive reservation path, thus further decreasing the reservation cost.

III. RESERVATION COST ANALYSIS

In order to quantitatively evaluate reservation costs of the three different proposals introduced above, we set up a model based on the same assumption in [13]: the paths from the corresponding node CN to the mobile node MN's current cell as well as all its neighbor cells form a tree structure. To simplify, we consider it a binary tree. As is shown in Fig. 1, the corresponding node, CN, is considered to be the sender while the mobile node, MN, is considered to be the receiver. The elliptical leaf nodes denote wireless access routers through which mobile nodes get access to the network, and the square internal nodes denote routers along the path from MN's access router to the Internet. Define the corresponding cell of wireless access router i to be cell i . Note that, the corresponding routers of two neighbor cells may not be adjacent in the binary tree topology. For example, in Fig. 1, cell 2, cell 3 and cell 4 can be all geographically adjacent to cell 1, that is, they are neighbors.

Fig. 1. Reservation Cost Analysis Model. Cell 1, 2, 3, 4 are neighbors. The solid line depicts the current transmission path from CN to MN, the hatched cells denote the routers needed to reserve resources by MRSVP and Multicast RSVP, and the dashed line represents the neighbor tunnel set up by Fast RSVP when MN is now in cell 1 and cell 4 is predicted to be the target cell.

In the network topology described above, suppose that the neighbor cells of cell 1 include cell 2, 3 and 4. MN first gets access into the network through router 1, and then it moves towards cell 4. In this scenario, the three resource reservation schemes, MRSVP, Multicast RSVP and Fast RSVP can be described as follows (Considering reservation paths inside Internet to be the same in different schemes, we neglect to point this part out in the following analysis.).

- MRSVP makes active and passive resource reservations on all the branches of the tree topology from sender to the current cell and all the neighbor cells respectively, including router 1, 2, 3, 4, 9, 10, and 13. And duplicate reservations will be made on the internal routers shared by different paths, including router 9, 10, and 13.
- Similar to MRSVP, Multicast RSVP makes conventional and predictive resource reservations on all the branches of the tree topology from sender to the current cell and all the neighbor cells respectively, including router 1, 2, 3, 4, 9, 10, and 13. However duplicate reservations for the same session are merged by utilizing the mechanism in Integrated Service specification
- Fast RSVP utilizes a handover prediction mechanism to realize reservation on the neighbor tunnel and avoid redundant reservations on the branches of the tree topology from sender to other neighbor cells except the predicted one. Besides, the path merge mechanism is introduced to eliminate duplicate reservations on the internal routers along the path. Therefore, only active reservations on router 1, 9, 13 and passive reservations on 4, 10 are needed here.

Assume that each cell has k neighbor cells. In addition, we define the following parameters to calculate the reservation costs of MRSVP, Multicast RSVP and Fast RSVP. α represents the active resource reservation cost on each node along the transmission path and θ is the ratio of the passive resource reservation cost to the active resource reservation cost on a single node. Since passive reservation allows resources reserved in target cells to be temporarily lent to best effort sessions with low priorities, the cost of passive reservation is always lower than that of active reservation, thereby, θ is always less than 1. d represents the depth of the transmission tree and p is the probability of wrong handover predictions in Fast RSVP.

A. Reservation Cost for MRSVP

As described above, MRSVP make active and passive resource reservations on all the branches of the tree topology from CN to MN's current cell and all the neighbor cells respectively. And since no merging mechanism included in MRSVP, duplicate reservations are made on the internal routers shared by different reservation paths. So the reservation cost can be calculated using (1) below.

$$\begin{aligned} Cost_{MRSVP} &= Cost_{Active} + Cost_{Passive} \\ &= (d-1)\alpha + k(d-1)\theta\alpha \end{aligned} \quad (1)$$

As is shown in (1) above, $(d-1)\alpha$ represents the active reservation cost on the routers along the transmission path from CN (the sender) to the current cell for MN (the receiver). $(d-1)\theta\alpha$ denotes the passive reservation cost on the routers along the transmission path from CN to one of the neighbor cells, and $k(d-1)\theta\alpha$ denotes the overall passive reservation cost since the current cell for MN has k neighbor cells.

B. Reservation Cost for Multicast RSVP

Similar to MRSVP, Multicast RSVP needs to make conventional and predictive reservations on all the branches of the tree topology from CN to MN's current cell and all the neighbor cells respectively. However, in this scheme duplicate reservations are eliminated by merging the conventional and predictive reservations for the same session. Thereby, the reservation cost can be expressed by (2) below.

$$\begin{aligned} Cost_{Multicast\ RSVP} &= Cost_{Active} + Cost_{Passive} \\ &= (d-1)\alpha + [k + (\left\lceil \frac{k+1}{2} \right\rceil - 1) + (\left\lceil \frac{k+1}{2^2} \right\rceil - 1) \\ &\quad + \dots + (\left\lceil \frac{k+1}{2^{i-1}} \right\rceil - 1)]\theta\alpha \quad (2) \\ &= (d-1)\alpha + k + \sum_{j=1}^{i-1} (\left\lceil \frac{k+1}{2^j} \right\rceil - 1) \\ i &= \min\{\lfloor \log_2 K \rfloor + 1, d\} \end{aligned}$$

Where $\lceil \cdot \rceil$ represents the Ceiling Function while $\lfloor \cdot \rfloor$ represents the Floor Function. As is shown in (2) above, $(d-1)\alpha$ represents the active reservation cost on the routers along the transmission path from CN to the current cell of MN. Since duplicate reservations are eliminated, when calculating the passive reservation cost, we should exclude the routers along the current transmission path first, and then we only count the number of the remaining routers in each level of the neighbor cells related subtree ($\lfloor \log_2 K \rfloor + 1$ represents the depth of this subtree); the sum of them represents the total number of the routers on which passive reservations are needed. Then we multiply this total number by $\theta\alpha$ to get the passive reservation cost for Multicast RSVP.

C. Reservation Cost for Fast RSVP

As described above, Fast RSVP adopts handover prediction based resource reservation on the neighbor tunnel to avoid redundant reservations on the branches of the tree topology from sender to other neighbor cells except the predicted one, and introduces path merge to eliminate duplicate reservations on internal nodes. So the maximum and minimum reservation costs for Fast RSVP can be respectively calculated using (3) and (4) below.

$$\begin{aligned}
Cost_{Fast\ RSVP}^{\max} &= Cost_{Active} + Cost_{Passive} \\
&= (d-1)\alpha + (1+p)i\theta\alpha \\
i &= \min\{\lfloor \log_2 K \rfloor + 1, d\}
\end{aligned} \quad (3)$$

$$\begin{aligned}
Cost_{Fast\ RSVP}^{\min} &= Cost_{Active} + Cost_{Passive} \\
&= (d-1)\alpha + (1+p)\theta\alpha
\end{aligned} \quad (4)$$

Note that p is the probability of wrong handover predictions. As we can see from (3) and (4) above, the passive resource reservation cost of Fast RSVP is decided by the relative positions of the current cell and the handover target cell. When the corresponding routers of the target cell and the current cell share a parent router in the tree topology, the cost is the lowest. For example, in Fig. 1, when cell 1 is the current cell and cell 2 is the target cell, passive reservation is only needed on router 2. In this situation, we can obtain the reservation cost by (4). With the distance between the corresponding routers of the target cell and the current cell in the tree topology getting longer, passive reservations are needed on more routers along the neighbor tunnel. For example, in Fig. 1, when cell 1 is the current cell and cell 4 is the target cell, passive reservations are needed on router 4 and router 10. The remaining scenarios can be deduced by analogy and the maximum reservation cost is calculated using (3) where $\lfloor \log_2 K \rfloor + 1$ represents the depth of the neighbor cells related subtree.

Therefore, the reservation cost for Fast RSVP can be expressed by (5).

$$\begin{aligned}
(d-1)\alpha + (1+p)\theta\alpha &\leq Cost_{Fast\ RSVP} \leq (d-1)\alpha + (1+p)i\theta\alpha \\
i &= \min\{\lfloor \log_2 K \rfloor + 1, d\}
\end{aligned} \quad (5)$$

IV. NUMERICAL RESULTS

In this section, we quantify and compare the reservation costs in different resource reservation schemes.

To simplify the quantitative estimation of the reservation costs, we use the average of $Cost_{Fast\ RSVP}^{\max}$ and $Cost_{Fast\ RSVP}^{\min}$ to represent $Cost_{Fast\ RSVP}$.

$$Cost_{Fast\ RSVP} = (Cost_{Fast\ RSVP}^{\max} + Cost_{Fast\ RSVP}^{\min})/2 \quad (6)$$

First, we quantitatively analyze the variations of the reservation costs for different schemes as the passive/active reservation cost ratio θ increases. With the parameters configured as ($\alpha=1$, $k=6$, $d=5$, $p=0.1$), we obtain Fig. 2 using (1), (2) and (6).

The curve on the top of Fig. 2 represents the reservation

Fig. 2. Resource reservation costs with different values of θ ($\alpha=1$, $k=6$, $d=5$, $p=0.1$).

cost for MRSVP, the curve in the middle depicts the reservation cost for Multicast RSVP and the curve near the base of Fig. 2 depicts the reservation cost for Fast RSVP. With the increase of θ , the reservation cost for MRSVP goes up significantly. Multicast RSVP alleviates this reservation cost increase by introducing a merging mechanism. And since Fast RSVP only needs to reserve passive reservations along the neighbor tunnel, its reservation cost can still remain at a very low level even when θ reaches 0.9.

Next, the variations of the reservation costs for different schemes as the neighbor cell number k increases are depicted in Fig. 3 ($\alpha=1$, $\theta=0.6$, $d=5$, $p=0.1$) by (1), (2) and (6).

The three curves in Fig. 3 represent reservation costs for the same schemes respectively as in Fig. 2. As can be seen

Fig. 3. Resource reservation costs with different values of k ($\alpha=1$, $\theta=0.6$, $d=5$, $p=0.1$).

from Fig. 3, because the MRSVP scheme and Multicast RSVP scheme make reservations in all the neighbor cells, the reservation costs of them go up significantly as the increasing of k . Moreover, due to the lack of reservation merging mechanism, the cost of MRSVP is higher than that of Multicast RSVP. Fast RSVP only reserves passive resources along the neighbor tunnel between routers of the mobile node's current cell and target cell, and therefore the cost of it is insensitive to the number of the neighbor cells. Seen from Fig. 3, reservation cost of Fast RSVP remains almost unchanged even when k reaches 10.

Finally, we analyze the change of reservation costs for different schemes as the depth of the transmission tree d increases. With the parameters configured as ($\alpha=1$, $\theta=0.6$, $k=6$, $p=0.1$), we can get Fig. 4 using (1), (2) and (6)

As is shown in Fig. 4, the three curves denote the reservation costs for the same schemes respectively as in Fig. 2. The reservation cost for MRSVP grows drastically with the increase of d . This situation gets much better for Multicast RSVP and Fast RSVP since merging mechanisms are utilized. Again, Fast RSVP has the lowest cost of the three schemes because of its avoidance to reservation in all the neighbor cells.

Note that it is reasonable for us to set p , the probability of wrong handover predictions, to be 0.1 since some existing handover prediction schemes [4], [5], [6] can achieve quite high probabilities of successful handover predictions already. Besides, since p only affects passive resource reservation on the small number of routers along the neighbor tunnel excluding the ones along current transmission path, the reservation cost for Fast RSVP will not be affected too much by the increase of p .

In summary, we can draw the following conclusions from the Fig. 2-4.

Fig. 4. Resource reservation costs with different values of d ($\alpha=1$, $\theta=0.6$, $k=6$, $p=0.1$).

- Among the three schemes, the cost of MRSVP is highest and the cost of Fast RSVP is the lowest.
- Introducing reservation merging on the internal routers shared by different paths can remarkably reduce the reservation costs.
- With the increase of θ , k or d , the resource reservation costs for all the schemes will increase more or less. However, compared with the other schemes, reservation cost for Fast RSVP increases much slowly. This means that Fast RSVP is insensitive to the parameter variations mentioned above.

V. CONCLUSIONS

In mobile environments, advanced resource reservation becomes a necessary requirement for handover with QoS guarantee. However, advanced resource reservation would unavoidably incur system resource wasting.

From the qualitative and quantitative analysis above, we can conclude the factors affecting the resource reservation costs as follows.

- The number of cells predicted to be the handover target

Both the MRSVP and Multicast RSVP schemes require passive resource reservations in all neighbor cells for a mobile node to ensure the seamless handover with QoS guarantee. However, this over-reservation lead to significant resource wasting which seriously affects network performance. In order to avoid this over-reservation, Fast RSVP adopts a handover prediction mechanism to determine the precise handover target cell.

- The extra cost for recovering from failed prediction

A correct handover prediction can avoid over-reservation, but an incorrect handover prediction will incur reservation re-setup after handover and lead to extra cost. And the extra cost for recovering from failed prediction should be reduced. Fast RSVP utilizes resource reservation on the neighbor tunnel to reduce this extra cost.

- Duplicate resource reservation on the same router

Different reservation paths may share some internal routers, and hence during the process of resource reservation, lots of duplicate reservations are made on these internal routers along the transmission path. This problem can be resolved by merging the reservations for different paths in Fast RSVP and Multicast RSVP schemes.

As we can see from Fig. 2-4, Fast RSVP has the lowest resource reservation cost under different conditions, and it is insensitive to the parameter variations including the ratio of passive/active reservation cost θ , the number of neighbor cells k and the depth of the transmission tree d .

Therefore, handover prediction based reservation, resource reservation on neighbor tunnel and reservation merge mechanisms are worthy of considering when designing a resource reservation scheme in order to save the relatively scarce resources for mobile environments.

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