Handoffs for Real-Time Traffic in Mobile IP Version 6 Networks

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Abstract—**Current commercial growth in wireless and mobile communications is being fueled by wireless Internet access and the promise of mobile multimedia applications. However, the delivery of such services depends on the ability of the mobile Internet to support real-time traffic flows with guaranteed quality of service (QoS). The current mobility protocol for the Internet, Mobile IP, was designed for best effort packet delivery, and, as a result of being based on IP version 4, has inefficient handoff routing procedures that limit its performance for real-time traffic. In this paper, a new *two-path handoff* is proposed for Mobile IP networks that enables the Internet to support large-scale mobility while maintaining QoS guarantees for multimedia traffic. First, we discuss related work on Internet mobility. Then, we introduce the new two-path handoff technique, which incorporates IP version 6 and the Integrated Services (IntServ) QoS architecture. Finally, we compare the performance of our new technique with other proposed protocols for Mobile IP in terms of bandwidth use efficiency and handoff disruption times.**

I. INTRODUCTION

THE last two decades of the twentieth century marked an explosion in the growth of wireless and mobile communications, fueled by the demand for cellular telephones, pagers and messaging devices. The next rise in market growth is being fueled by the promise of Internet access for wireless laptops, cellular telephones, and palm pilots, including access to wireless multimedia services. The delivery of such services depends on the ability of the mobile Internet to support real-time traffic flows with guaranteed quality of service (QoS). The current mobility protocol for the Internet, Mobile IP, was designed for best effort packet delivery, and, as a result of being based on IP version 4 (IPv4), has inefficient handoff routing procedures that limit its performance for multimedia traffic. IPv6 has new features, such as security support and increased address space, that can be used to achieve more efficient handoff routing techniques [1].

Research on handoffs in Mobile IP networks has mainly focused on achieving fast intra-domain handoffs [2], [3], [4], or has focused on QoS for Mobile IP based on an ATM backbone network [5], [6]. However, the intra-domain techniques are not efficient for large scale mobility, and the ATM based techniques do not apply to Internet backbone networks. Recently, researchers have begun to address QoS guarantees for large scale mobility, based on the Internet Integrated Services (IntServ) QoS architecture and the the Resource Reservation Protocol (RSVP) [7], [8], [9]. RSVP enables a destination node to reserve resources along a fixed path to a source node, according to specified QoS guarantees. In [7], a protocol was presented that attempted to minimize disruption of the handoff data path by using RSVP tunnels from the mobile node's (MN) home agent (HA) to the MN's current location. Due to the technique's use of the Mobile IP version 4 procedure, the approach achieves a triangular handoff path which consumes excess bandwidth. In [8], advanced resource allocations are used to cache packets for the MN simultaneously at multiple locations according to a pre-selected movement pattern. This scheme expends additional bandwidth by caching packets, and also depends on the predictability of the movement of the MN. In [9], multiple advanced resource reservations are also maintained for each MN at several neighboring cells, called a multicast group. Again, this scheme results in excess bandwidth consumption for the multicast paths, and also increases background processing to calculate a new multicast group after each MN movement.

In this paper, a new *two-path handoff* technique is introduced for Mobile IP version 6 networks that enables the Internet to support large-scale mobility while maintaining QoS guarantees for multimedia traffic. In Section II, we discuss the impact of IP version 6 on Internet mobility. Then, in Section III, we describe the new technique. In Section IV, we present a framework to compare the performance of the new technique with related work. Section V presents numerical results, followed by the conclusion in Section VI.

II. ADVANCES IN INTERNET MOBILITY

Consider the Mobile IPv4 triangular handoff routing procedure shown in Figure 1. When the MN is located at home, it is co-located with its *home agent* (HA). Incoming packets from a *correspondent node* (CN) are received by the MN through the HA (route 1). When the MN moves away from its HA, the incoming packets are encapsulated by the HA and forwarded to the MN at its new address at a *foreign agent* (FA) (route 2). The new address is referred to as a *care-of-address* (CoA). If the CN remains stationary, the MN is able to send packets directly to the CN (route 3), forming a triangular path. Route optimization is required to enable the CN to reroute packets on a direct path to the MN, but route optimization is not always available in IPv4, which suffers from a lack of security. In IPv6, route optimization is always available, as well as an increased address space and additional security features that can

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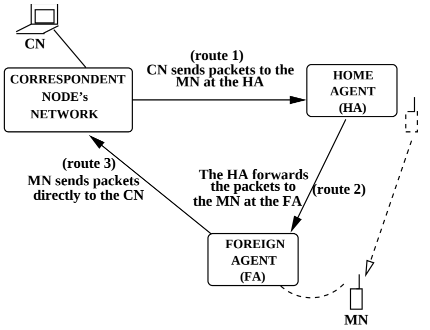


Fig. 1. Mobile IP Version 4 Triangular Routing

be used for managing and updating the path [1]. In the next section, we use these new features to create a new two-path handoff technique that preserve QoS for the MN while limiting the additional bandwidth expense.

III. TWO-PATH HANDOFF TECHNIQUE

In the new two-path hop handoff technique, the CN has the option of using two different RSVP paths to reach the MN. The first path is called the *mobile path*, which is a direct RSVP path to any new location of the MN. Since the mobile path does not depend on forwarded packets from the HA, it is the more efficient and preferred path to use. However, while the MN is moving to a new location, incoming packets may be lost or may arrive out of order. Therefore, we periodically use the *home path*, i.e., from the CN to the HA to the MN, to ensure uniform and ordered forwarding of incoming packets, and to reduce packet loss.

The new technique requires new procedures and signaling messages to coordinate the use of the mobile path and home path. These are illustrated in Figure 2 and described below:

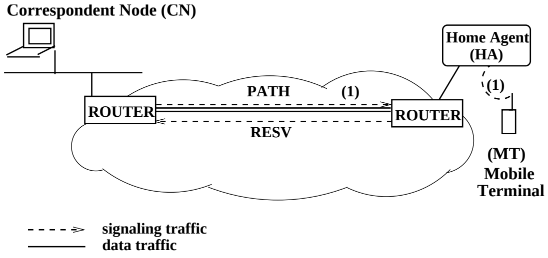
1. Figure 2(a). The MN, located at home, is communicating through an RSVP session with the CN, which is maintained by the exchange of PATH and RESV messages between the CN and the MN.

2. Figure 2(b). When the MN moves into a new subnetwork, the MN's new CoA is sent to both the HA and to the CN.

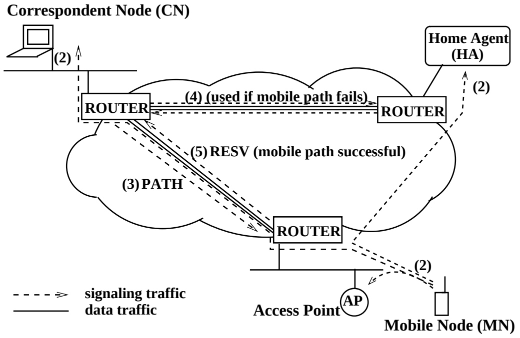
3. When the CN receives the MN's new CoA, the CN sends a PATH message to the MN to establish a new mobile path.

4. If the direct mobile path attempt from the CN to the MN is not successful, the CN continues to use the home path.

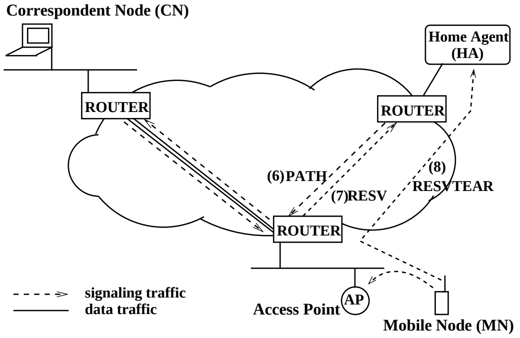
5. If the mobile path attempt is successful, the MN returns RESV messages to the CN and the new RSVP session can begin. When this happens, the CN stops sending data packets on the home path, and the home path resources are temporarily re-assigned to non-real-time or controlled load traffic until the home path is once again needed by the MN.



(a) "Home Path" (MN located at home)



(b) "Mobile Path Attempt" (MN moving to a new location)



(c) "Mobile Path Success" (HA forwards remaining packets)

Fig. 2. Two-Path Handoff Procedure

6. Figure 2(c). When the HA receives a new CoA for the MN, the HA automatically attempts an extended RSVP path to the MN. Incoming packets for the MN are buffered until the new path can be established.

7. When the MN receives the PATH message from the HA, it sends a RESV message to the HA to initiate the RSVP session. The HA forwards the remaining packets.

8. Then the MN sends a RESVTEAR message to the HA to explicitly tear down the RSVP session with the HA.

The new technique introduces path disruptions while the CN switches between the home path and the mobile path. However, the disruptions are short in duration. In addition, the new technique preserves bandwidth in comparison to related schemes. In the next section, we describe a framework to measure the disruption time and bandwidth use for the new technique.

IV. SIMULATION

The performance of the new *two-path handoff* technique was evaluated by simulating the necessary exchange of signaling messages between the MN, HA and CN, for a MN traversing the hierarchical router configuration shown in Figure 3. The MN begins at the HA and continues to move away from the HA along the lowest level of routers for the duration of the simulation. Meanwhile, the MN continuously communicates with its CN, which is located several hops away from the HA, and remains stationary.

A. Residency Time and Node Distance

The movement of the MN is modeled as an exponentially distributed random variable:

$$r(t) = \lambda exp(-\lambda * t), \tag{1}$$

where $r(t)$ is the probability distribution function of the residency time of the MN, and λ is the mean residency time.

The node distance, $D_{i,j,c}$, between node-pair (i,j) at router location c, is determined by the number of hops between the nodes in the hierarchy:

$$\begin{aligned} D_{i,j,c} &= N_{Ri,Rj} \\ &= N_{Ri,Rjoin} + N_{Rjoin,Rj} \end{aligned} \tag{2}$$

where (i,j) are the node pairs (CN,MN), (CN,HA), and (HA,MN), $N_{Ri,Rj}$ is the number of hops from router R_i to router R_j, and R_{join} is the joining point in the router hierarchy, i.e., the lowest hierarchy router that has direct egress routes to both of the endpoints in the path.

B. Path Activation Time

The path activation time, $\{T_p\}_{i,j,c}$, for node-pair (i,j) at router location c, is calculated:

$$\{T_p\}_{i,j,c} = (\{T_{coa}\}_{i,j,c} + \{T_{RSVP}\}_{i,j,c}) * D_{i,j,c} \tag{3}$$

where $(i,j)\ \epsilon$ {(CN,MN), (CN,HA), (HA,MN)}, $\{T_{coa}\}_{i,j,c}$ is the time for the MN to advertise the new CoA, $\{T_{RSVP}\}_{i,j,c}$ is the time to perform RSVP signaling, and $D_{i,j,c}$ is the node distance from node i to node j, as calculated in (2). The signaling time derivation in [10] is used to determine $\{T_{coa}\}_{i,j,c}$ and $\{T_{RSVP}\}_{i,j,c}$ based on the message signaling time, $M_{i,j,c}$, the transmission time, $\alpha_{i,j,c}$, the the propagation time, $\beta_{i,j,c}$, and the processing time for control messages, $\gamma_{i,j,c}$:

$$\{T_{coa}\}_{i,j,c} = \begin{cases} M_{i,j,c}, & \text{wireline links} \\ M_{i,j,c} * \frac{1+q}{1-q}, & \text{wireless links,} \end{cases} \tag{4}$$

and

$$\{T_{RSVP}\}_{i,j,c} = \begin{cases} M_{i,j,c} * \frac{1+p}{1-p}, & \text{wireline links} \\ M_{i,j,c} * \frac{1+q}{1-q}, & \text{wireless links,} \end{cases} \tag{5}$$

where is the q probability of wireless link failure, and p is the probability of resource assignment failure during RSVP. When resource failure occurs, the RSVP signaling is assumed to be repeated until either a session is successfully established, or until the MN moves to a new router location.

C. Bandwidth Use

The total bandwidth use per CoA, U_c, is defined as the total amount of resources that are expended at each router location. It is calculated:

$$U_c = \sum_{(i,j)} U_{i,j,c}, \quad (i,j)\epsilon\{\text{(CN,MN), (CN,HA), (HA,MN)}\} \tag{6}$$

where $U_{i,j,c}$ is the bandwidth used to establish node-pair (i,j) for the given CoA. $U_{i,j,c}$ is calculated:

$$U_{i,j,c} = BW * D_{i,j,c} * (r(t_c) + \{T_d\}_{i,j,c}) \tag{7}$$

where BW is the bandwidth allocation for the link, $D_{i,j,c}$ is the node distance calculated in (2), $r(t_c)$ is the residency time at the current CoA calculated in (1), and $\{T_d\}_{i,j,c}$ is the time to deactivate the link at the current CoA.

The deactivation time occurs anytime that communications must be transferred from one path to another, and some time is expended in deactivating the path and purging it of packets. As discussed in Section III, when a particular path is deactivated, some cost is incurred in terms of the disruption time of the communication path. Next, calculations are made to determine the disruptions caused by the MN's movements.

D. Disruption Time

The disruption time, $\{T_{dis}\}_{i,j,c}$, is a measure of the time that a node is not able to send packets, i.e., the time between the deactivation of the old path at the old CoA, $c-1$, and the path activation of the new path at the new CoA, c. It is calculated:

$$\{T_{dis}\}_{i,j,c} = \{T_d\}_{i,j,(c-1)} + \{T_p\}_{i,j,c}, \tag{8}$$

where $\{T_d\}_{i,j,(c-1)}$ is the deactivation time for node pair (i,j) at the old CoA, and $\{T_p\}_{i,j,c}$ is the path activation time for node pair (i,j) at the new CoA, as calculated in (3).

The goal of the new procedure is to reduce the inefficiency in bandwidth use for Mobile IP handoffs and to minimize the disruption time introduced by the new technique. Next, we compare the numerical results of the performance of the new two-path handoff technique with the performance of the related work.

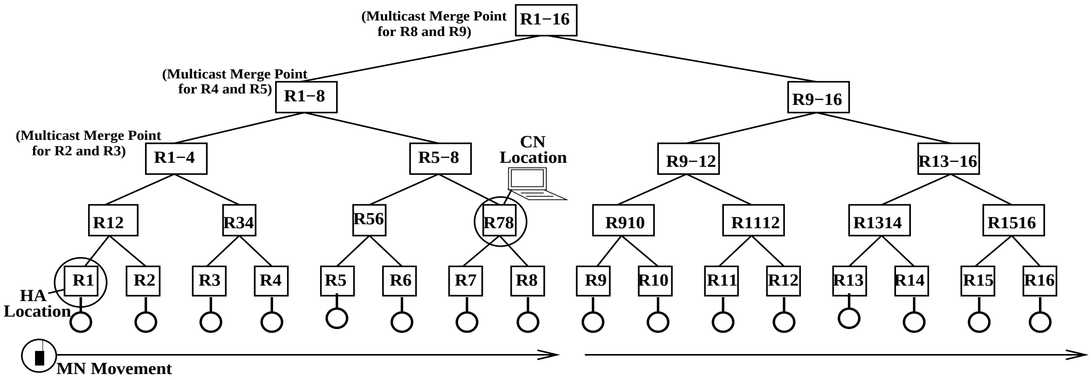


Fig. 3. Hierarchical Router Configuration

System Parameter	**V**alue
Mean MN Residency Time, λ, (1)	15 minutes
Wireless Propagation Time, $\beta_{i,\,j,c}$ (4), (5) [10]	2 mseconds
Wireline Propagation Time, $\beta_{i,\,j,c}$ (4), (5) [10]	0.5 mseconds
Signaling Processing Time, $\gamma_{i,\,j,c}$ (4), (5) [10]	50 μseconds
RSVP Processing Time, γ_{RSVP}, (4), (5) [10]	0.5 mseconds
RSVP Time Out Threshold, $\{T_{TO}\}_{MT,CN,c}$, (7)	30 seconds
Packet Size, S, (4), (5) [10]	50 Bytes
Probability of Link Failure, q, (4), (5)	0.5
Probability of Resource Denial, p, (5)	0.5
Wireless Bit Rate, B, (4), (5) [10]	144 Kbps
Wireline Bit Rate, B, (4), (5) [10]	155 Mbps

TABLE I

SYSTEM PARAMETERS

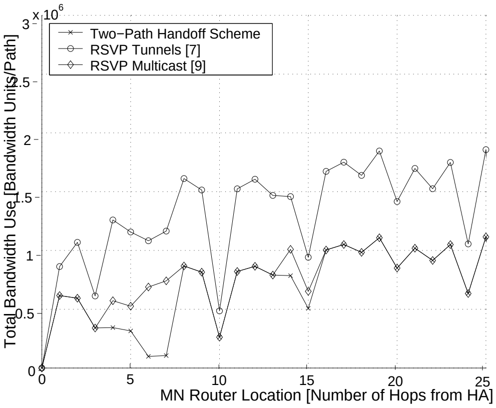


Fig. 4. Comparison of Bandwidth Use for Each MN Location

V. NUMERICAL RESULTS

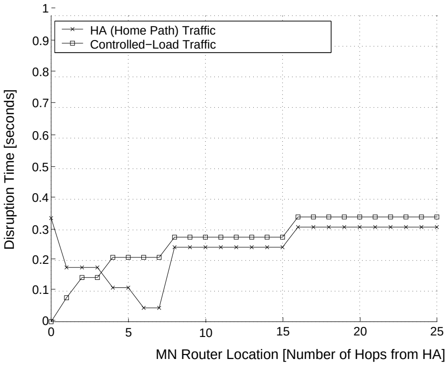
Table I shows the system parameters that were used to compare the new two-path handoff technique and the related work [7], [8], [9]. The scheme in [7] is referred to as the *RSVP tunnels* technique, while the scheme in [9] is referred to as the *RSVP multicast* technique. The schemes in [8] and [9] are based on the same advanced reservation process. Since the scheme in [9] had the advantage of the faster multicast technique to form new routes to the MN, [9] was chosen to represent the advanced reservation approach.

A. Bandwidth Use

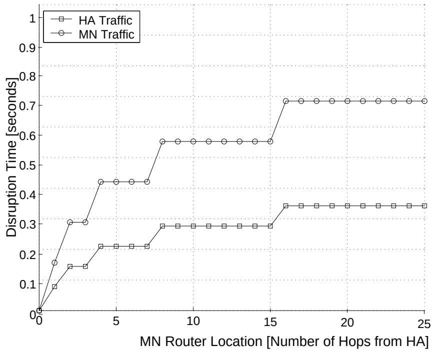
Figure 4 shows the comparison of the new two-path handoff technique with the related work with respect to the bandwidth use at each router location c, U_c, (6). Since the total bandwidth consumed at each location depends on the residency time of the MN as in (7), Figure 4 shows sharp changes, or dips, caused by the random nature of the residency time of the MN defined in (1). For each MN location, the new two-path handoff technique used far less bandwidth than the RSVP tunnels [7] scheme, from a 30% to 90% reduction. In addition, the new technique used equivalent or less bandwidth than the RSVP multicast [9] technique, with an improvement of up to 85%.

B. Disruption Time

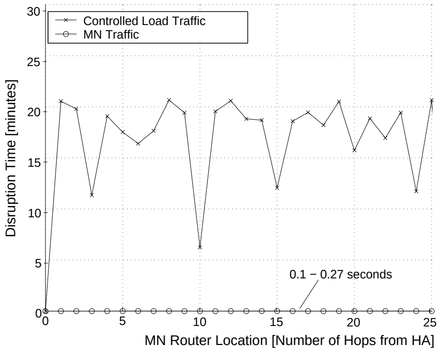
Figure 5 shows the simulation results for the disruption time, $\{T_{dis}\}_{i,j,c}$, (8), for node-pair (i, j) at router location c for the new two-path handoff technique and the related work. Figure 5(a) shows the disruption times for the new technique. For both the home path and for the controlled-load traffic, the disruption time was limited to a value below 0.4 seconds, or 40% of the nominal handoff times for GSM [10]. In Figure 5(b), the disruption time is shown for the RSVP tunnels scheme [7]. For the HA traffic, the disruption is the same as for the new two-path handoff technique. However, the disruption time for the MN to send packets to the HA is greater, reaching 0.7 seconds, or 70% of the nominal GSM handoff time. Figure 5(c), shows the results for the RSVP multicast scheme [9]. Because



(a) Two-Path Handoff Technique



(b) RSVP Tunnels Technique



(c) RSVP Multicast Technique

Fig. 5. Comparison of Disruption Times

of the pre-allocated multicast groups used in this scheme, the disruption of the MN traffic is smaller than the new technique, from 0.1 to 0.27 seconds, or 10-27% of the GSM handoff time. However, the disruption time for the controlled-load traffic is from 6 to 20 minutes, which is most likely too disruptive even for non-real-time traffic, and results in a higher incidence of dropped calls. (Note once again that the sharp changes in disruption time in Figure 5(c) are a reflection of the random nature of the MN residency time at each location within the multicast group.)

VI. CONCLUSION

In this paper, a new two-path handoff technique was introduced for real-time traffic in Mobile IP version 6 networks. Mobile IP procedures were adapted to the new IntServ QoS mechanism and the RSVP protocol, by transferring the CN communications from a home path through the MN's HA to a direct mobile path to the MN's new location. The new technique greatly reduced bandwidth consumption compared to related techniques, and improved bandwidth efficiency by reassigning controlled-load traffic to the unused resources on the home path. Comparatively little disruption was caused for the MN when communications were transferred between the home path and the mobile path.

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