Performance of the Double Tunneling with Handoff Prediction in Mobile IP Network

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Abstract: Mobile IP protocols allow a mobile host to send and receive packets addressed with its home IP address, regardless of the IP address of its current point of attachment in the Internet. Four routing schemes, home, optimal, hierarchical and pointer forwarding approaches are discussed with regard to the handoffs. In the existing methods packets are delayed and lost during the change of the care-of-address from an old foreign agent to a new agent.

To handle the packet loss and delay problem we propose a double tunneling method in which received packets at an agent are copied and sent to both the old and new foreign agents. The method is backed up by the predicted handoffs. Computational results show that the double tunneling method outperforms existing handoff procedure in view of lost and delayed packets.

1. Introduction

Mobile networking technology supports the requirements of today’s new class of Internet users as they roam about with sophisticated mobile computers and digital wireless data communication devices. Integrating wireless networks into the global Internet poses a new challenge. The main reason is that the TCP/IP based Internet technologies were designed for wired networks with mostly fixed hosts. Host mobility requires changes in the routing protocol so that packets for a moving host can be delivered to their correct destination. Mobile IP (*home approach*) provides a basic framework to solve this operability problem [1], [2]. A mobile host can communicate with a base station, which is statically connected to the Internet. However, several performance problems in Mobile IP need to be addressed. First, Mobile IP’s tunneling scheme creates a triangle routing problem, causing packets to travel through sub-optimal routes. Second, packets in flight during a handoff are often lost because they are tunneled based on out-of-date location information. Third, base stations with small cells result in frequent handoffs, and requiring a registration with a distant home agent for each such local handoff causes higher overhead and further aggravates packet loss.

Mobile IP route optimization (*optimal approach*) alleviates triangle routing problem [3]. This approach provides a means for correspondent hosts to cache the binding of a mobile host and then to tunnel their own packets for the mobile host directly to that location, bypassing the route for each packet through the mobile host’s home agent. This alleviates data loss during a handoff by informing the correspondent host and the previous foreign agent of the mobile host’s care of address. However, frequent handoffs in small cells cause higher overhead to the home agent.

Several mobility management schemes that are based on the cellular communication technique have been proposed to solve the frequent handoffs problem [4] ~ [8]. Perkins and Wang [4] proposed a smooth handoff scheme (*hierarchical approach*) with a hierarchical foreign agent structure. With a hierarchy of foreign agents, the packet from the correspondent host is delivered to the highest layer foreign agent and forwarded through the hierarchy to the mobile host. Small changes of location are handled by one of the foreign agents in the hierarchy within whose covering range the mobile host remains. Bejerano and Cidon [6] proposed an anchor chain scheme (*pointer forwarding approach*) which combines pointer forwarding and caching methods. Each anchor defines the location of the mobile host at a certain degree of accuracy. The packet from the correspondent host is forwarded along the chain until it reaches the mobile host. When the handoff occurs, the anchor is modified to specify the new location of the mobile host. Although these schemes alleviate the offered loads to the home agent, the packet delay during handoff still remains to be done.

In this study we examine an improved handoff procedure which reduces or excludes the retransmission of lost packets and reduces the packet delay. The handoff prediction mechanism and double tunneling procedure is proposed. Proposed method is applied to the four routing schemes. The performance of the proposed method is compared to the existing methods.

The remainder of this paper is organized as follows. In Section 2, we discuss the packet delivery process in Mobile IP. Section 3 presents a handoff prediction mechanism and a double tunneling procedure during the handoff. Computational results are presented in Section 4. Finally, we conclude the paper in Section 5.

2. Packet Delivery by Four Approaches

The goal of Mobile IP is to provide mobility support for hosts connected to the Internet without changing their IP addresses. When a mobile host (MH) moves to a new location, it registers its current IP address of a foreign agent (FA) with its home agent (HA). When the correspondent host (CH) wishes to send packets, CH connects to the HA of the MH and gets the location information of MH.

2.1. Home Approach

In home approach CH transmits the packet to the HA of an MH. When a packet for the MH arrives at its home network, the HA intercepts and forwards it to the care-of-address by encapsulation. Then the FA decapsulates the packet and delivers it to the MH. While the MH can send out packets through the FA and along an optimal path, incoming packets have to travel through the HA (*triangle routing problem*). If the current location of the MH is close to the sender's but the HA is far away, packets have to take a long detour [1] [2].

Figure 1 shows the packet delivery in home approach. CH sends packets through 1-2-3 paths and MH sends packets through 4-5 paths. There is a 1-2-5-triangle route in this approach. When a handoff occurs, MH moves from FA_1 to FA_2 (6 in the figure). Although the MH cannot communicate with FA_1, HA sends packets with the wrong care-of-address. When the MH finds out the break from the old FA, it searches a new FA in Agent Solicitation and Agent Advertisement processes (7 in the figure). The new FA gets the information of MH and connects to the HA in Registration and Authentication processes (8 in the figure). If the HA certifies that the MH is valid customer, the FA assists in communication between the CH and the MH. Then the MH can receive the not-delivered packets caused by the handoff.

2.2. Optimal Approach

In optimal approach the triangle routing problem is solved. Any host maintains a binding cache. When the HA intercepts a packet for an MH that is away, it may send a binding update message to the CH, informs the MH's current care-of-address. The CH then updates its binding cache, and tunnels any ensuing packets for the MH directly to its care-of-address [3].

The packet delivery in optimal approach is presented in Figure 2. Since CH sends packet through a direct 2-3 path as in the figure, triangle route does not occur. When the MH moves from FA_1 to FA_2, Agent Solicitation, Agent Advertisement, Registration and Authentication processes are completed. When the HA receives a valid *Registration Request* message from the new FA, it may transmit new *Binding Updates* message to each CH that is on its list for the particular MH (9 in the figure). Because the HA sends the message to every CH for the information accuracy, the offered load of the HA and the packet delay are significant in frequent local handoffs.

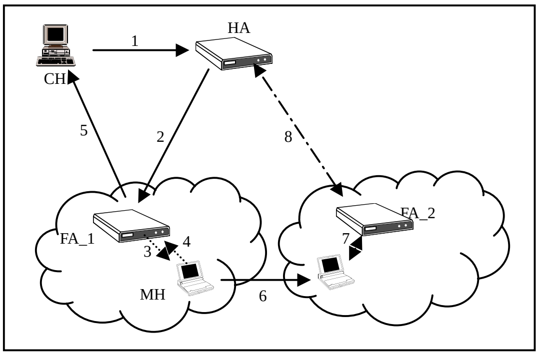


Figure 1. Home Approach

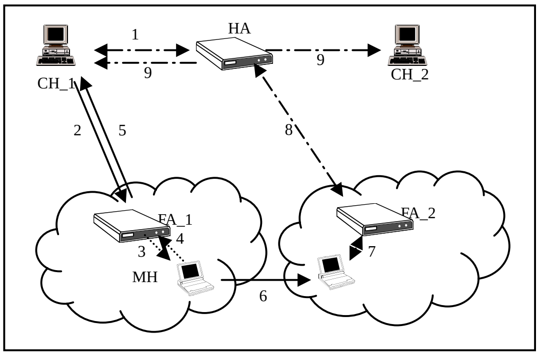


Figure 2. Optimal Approach

2.3. Hierarchical Approach

In hierarchical approach the FAs are logically organized into a hierarchy to handle local movements of MHs within the domain (see Figure 3). An FA includes in its *Agent Advertisement* a vector of care-of-address, which are the IP addresses of all its ancestors as well as its own. When an MH arrives at an FA, it registers with its HA not only that FA as the care-of-address, but all its ancestors. A registration goes through and is processed by the FA, all its ancestors and the HA. When a packet for the MH arrives at its home network, the HA tunnels it to the root of the FA hierarchy. When an FA receives such a tunneled packet, it tunnels it to its next lower-level FA. Finally the lowest-level FA delivers it directly to the MH (*multi-tunneling*) [4]. In Figure 3 when MH first arrives at FA_7, it registers FA_7, FA_3, and FA_1 as its care-of-addresses. A registration request goes through this path to HA and a registration reply the same path in the opposite direction. A packet for MH is intercepted by HA and tunneled to FA_1, which tunnels it to FA_3, which again tunnels it to FA_7, which delivers it directly to MH.

When a handoff occurs, MH compares the new vector of care-of-addresses with the old one. It chooses the lowest-level FA that appears in both vectors, and sends a *Regional Registration Request* message to that FA (8 in the figure). Any higher-level agent need not be informed of this movement since the other end of its forwarding tunnel still points to the current location of the MH. In the meantime, HA has no knowledge of local movements and hence registration overhead is reduced. For smooth handoff a foreign agent buffering mechanism is included in this scheme. Besides decapsulating tunneled packets and delivering them directly to an MH, the FA also buffers these packets. When the FA receives a *Previous Foreign Agent Notification* message (9 in the figure), it re-tunnels the buffered packets to the MH's new FA (10 in the figure). Packet loss during a handoff can be completely eliminated, unless the MH takes too long to find a new FA after it loses contact with its previous FA. In this approach the offered load of HA is reduced significantly but the packet delay problem still remains.

2.4. Pointer Forwarding Approach

In the pointer forwarding approach the location of each MH is defined by a chain of anchors. Each anchor is a host that has been visited by the MH and the first anchor is the HA. Every anchor records the location of the MH to a certain degree of accuracy and points to its successive host in the chain. These anchors are also used for efficient delivery of packets to the MH. Upon initializing a communication with a CH, the MH provides it with a record of its anchor chain. When the CH wishes to send a packet to the MH, it selects an anchor from this record, termed an *access point*, and sends the packet to it. From that point the packet is forwarded along the chain until it reaches the MH. To bounds the packet delivery delay the length of chain is constrained in this approach. A valid anchor must be in the pointer domain of the upper anchor of the chain.

In Figure 4 the anchor chain {HA, FA_1, FA_2, FA_3} is valid and the CH selects FA_1 for the access point. When the MH moves from FA_3 to FA_4, the MH finds that FA_4 is not in the pointer domain of FA_3, that is, the chain {HA, FA_1, FA_2, FA_3, FA_4} is not valid. Then the MH requests the chain update and FA_4 searches a valid chain through the reverse direction of the old chain (8 and 9 in the figure). Finally FA_4 finds that it is in the pointer domain of FA_2 (10 in the figure) and {HA, FA_1, FA_2, FA_4} performs the new anchor chain of the MH. However, HA and FA_1 are not informed for this change. The handoff process is completed without loads of HA.

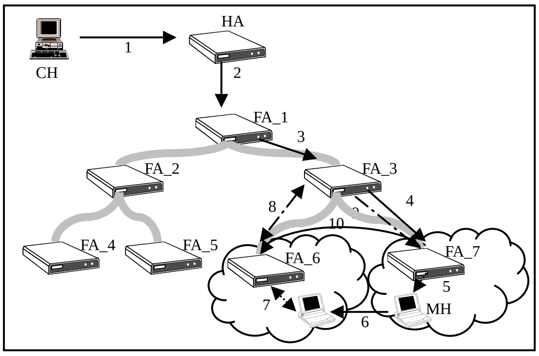


Figure 3. Hierarchical Approach

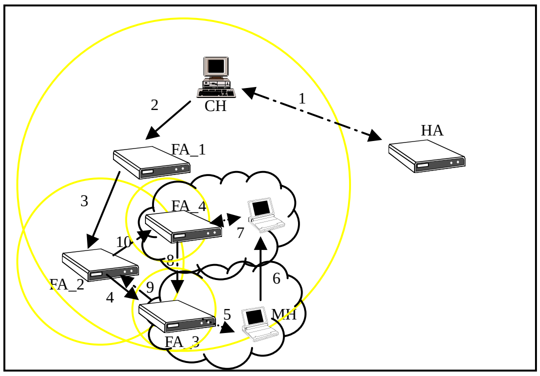


Figure 4. Pointer Forwarding Approach

	Home Approach	Optimal Approach	Hierarchical Approach	Pointer Forwarding Approach
Triangle Route	Yes	No	No	No
Routing Overhead	Medium	Large	Small	Small
Binding Cache	No	Yes	Yes	Yes
Binding Update	Frequent	Frequent	Occasional	Occasional
# of Intermediate	Single (HA)	No	Multi	Multi
Delivery Delay	Medium	Small	Medium	Medium
Buffering	***Possible***	***Possible***	***Yes***	***Possible***
Info. Accuracy	Yes	Yes	Yes	Yes
Mobile Security	Registration Key	Registration Key	Registration Key	Anchor Key

Table 1. Characteristics of Four Routing Approaches in Mobile IP

3. Double Tunneling with Handoff Prediction

We propose a procedure that alleviates the packet delay and loss problem during the handoff. The scheme can be easily implemented to general routing schemes with several assumptions.

3.1. Prediction of Handoff

We assume that MH can predict the change of FA ahead of time, that is, MH in motion is able to predict future disconnection time. Such a prediction can be accomplished in two methods.

In the first method, we assume a free-space where the received signal strength of a MH solely depends on its distance to the FA tranceiver (transmitter + receiver). Therefore if the MH knows its mobility parameters (e.g. speed, direction, and transmission range), it will be able to determine the duration of time that the MH and the FA will remain connected [9].

Assume that FA tranceiver is located at (0,0) in two-dimensional space. Let the position and the speed of MH be (x, y) and (v_x, v_y) respectively. Let R_{TX} be the transmission range of MH. Then D_T, the amount of time that the MH and the FA will remain connected satisfies the following equation.

$$(x + D_T v_x)^2 + (y + D_T v_y)^2 = R_{TX}^2$$

$$D_T = \frac{-(xv_x + yv_y) + \sqrt{(x^2 + y^2)R_{TX}^2 - (xv_y - yv_x)^2}}{(x^2 + y^2)}$$

This method will require each MH to know its own position and speed. This is not critical problem because the MH is able to use sources such as Global Position System or own instruments and sensors (e.g. compass, odometer, speed sensors, etc.). The MH can inform the FA of the obtained results through the packet header.

The second method to predict time until connection exploits received power measurements. Basically, received power samples are measured periodically from packets received for a MH. From this information it is possible to compute the rate of change for a particular MH's power level. Therefore, the time that the power level drops below the acceptable value can also be computed. The weakness of this method is that the system cannot identify the expected route of the MH.

3.2. Double Tunneling

In this section, we propose the handoff procedure based on double tunneling to exclude retransmission due to packet loss. Let T_E be the expected handoff time when the connection with the old FA is physically closed. Also, let TP_D be the dwell time during which a handoff ready process is completed for the connection with new FA. Then the "critical time", T_C to start the handoff request is computed as

$$T_C = T_E - TP_D.$$

The critical time is that the system starts the process of smooth handoff. The procedure of the predictive handoff is as follows:

When the MH determines the critical time, the current FA generates *Handoff Request* message and sends it to the agent that is able to handle the handoff of the MH (The agent is different in each routing approach). The current FA informs the agent of the new FA through the *Handoff Request* message. Then the handoff processing agent sends *Handoff Setup* message to the new FA. The new FA prepares the radio resource for the communication with the MH and the buffer to store packets for the MH. When this reservation is completed, the new FA sends a *Handoff Ready* message to the agent.

At this moment, the agent starts to copy the packets and send them to both of current and new FAs (double tunneling). Thus the double tunneling effectively excludes the retransmission of lost packets during the handoff. When the MH detects the disconnection with the old FA, it propagates *Agent Solicitation* message. The message includes the sequence number of the last packet that arrived at the MH and the authentication information of the MH. When the connection between the new FA and the MH is open, then the double tunneling is terminated. The new FA immediately sends packets in buffer to the MH. Thus the packet delay during the handoff is negligible compared to the existing routing methods.

4. Computational Results

In this section, we test the efficiency of the proposed algorithm for the smooth handoff in

Mobile IP. The handoff procedure described in the previous section was implemented in Visual C++ (Version 6.0), and run on a 500 MHz Intel Pentium III based personal computer with 128 Mbytes of memory under Windows 98.

We assume that the simulation area consists of 16 local networks as in Figure 5. Each square represents a 100m × 100m local network A local network has an agent which serves MHs in the area. Each MH moves according to the transition probabilities as in the figure. The radio transmission range is 120 meters and the data rate of the wireless link in 2 Mbps. The frame error rate in wireless environment is set to 0.2 %. The packet length for data packets is 10 Kbits and 500 bits for overhead routing messages used in each approach.

4.1. Four Basic Scenarios

To compare the performance of the four routing approaches with the proposed algorithm we design the four basic scenarios as in Figure 6. The clouds in the figure present the simulation area of 16 local networks. In the first case MH, FA, CH, and HA are located in the same simulation area. In the second case MH and HA are in the same area but CH is not. In general, a MH stays around its home network. In the third case a MH travels far away from its home network. The fourth case is a special of the third case.

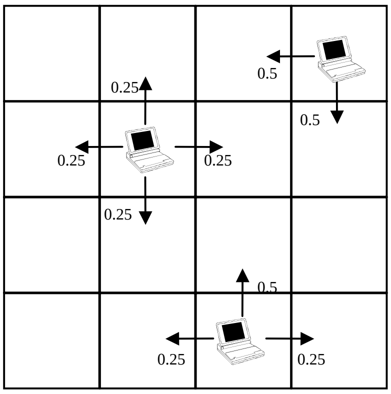
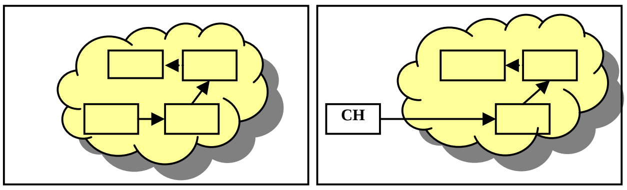
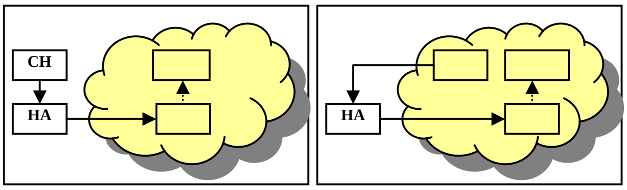


Figure 5. The simulation area of 16 local networks



(a) MH, CH, and HA are in the same area

(b) CH is far away from the home



(c) MH is far away from home

(d) MH and CH are in the same area

Figure 6. Four Basic Scenarios

4.2. Packet Interarrival Times

Figure 7 shows the packet interarrival times of home approach in the first scenario. Because packets travel through the wired network in the simulation area, the packet interarrival times are almost uniformly distributed. High peaks in the figure represent packet retransmission due to frame errors in wireless environment.

In Figure 8 we see that the home approach is not reliable in Scenario_3 and 4 even without the handoffs. Figure 9 shows packet interarrival times during handoff by the four methods. We see that the packet delay during the handoff in the optimal approach is serious in most cases except

Scenario_1. This shows the maintenance of the binding cache of the optimal approach is inefficient. If the case of inefficiency is removed, the optimal approach will become a very powerful routing scheme.

The performance by proposed handoff prediction is shown in Figure 10. By applying the double tunneling during the handoff period a significant reduction in packet delay is obtained. Approximately 10 ~ 70 % reduction is shown in the figure. Especially, the delay of the optimal approach is significantly reduced in Scenario_3 and Scenario_4. Note that the control messages in the optimal approach for registration, authentication, and binding cache updating travel relatively long distance among the four approaches. However, these processes are completed during the handoff period in the proposed procedure. Thus the delay is effectively reduced.

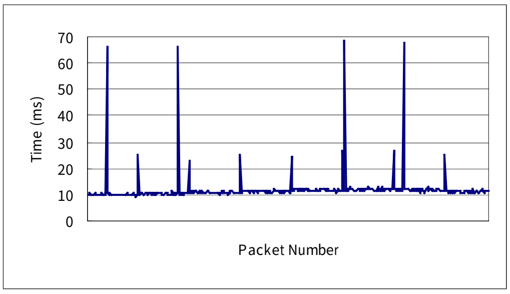


Figure 7. Packet Interarrival Times of Home Approach in the First Scenario

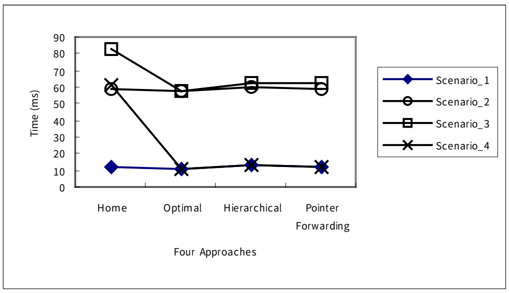


Figure 8. Packet Interarrival Times without Handoff

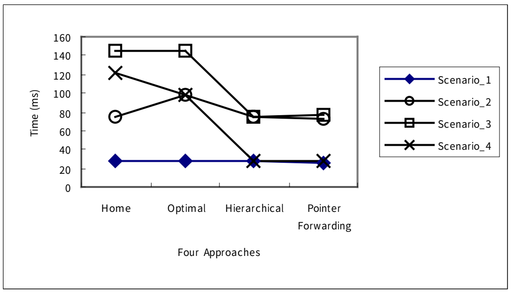


Figure 9. Packet Interarrival Times during Handoff

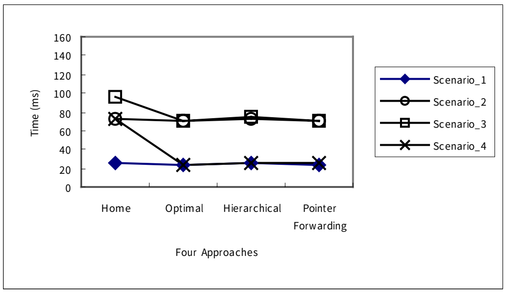


Figure 10. Packet Interarrival Times during Handoff with the Proposed Procedure

5. Conclusion

Mobile IP allows mobile hosts to send and receive packets addressed with their home IP address, regardless of the IP address of their current point of attachment in the Internet. The optimal approach complements Mobile IP to alleviate triangle routing by informing correspondent hosts of the mobile host's care-of-address. This extends the use of *Binding Cache* and *Binding Update* messages to provide smooth handoff. However, the packet delay during handoff is a serious problem in the approach. The hierarchical and pointer forwarding approaches reduce the administrative overhead of frequent local handoffs by using an extension of the Mobile IP registration process. The strategies can include a foreign agent buffering mechanism to eliminate packet loss during a handoff.

In this paper, we proposed a double tunneling scheme with handoff prediction in Mobile IP network. By assuming that a mobile host is able to predict the time of handoff and inform it to the current foreign agent periodically, better performance of packet delay is obtained in four different HA, FA, CH and MH locations. The proposed double tunneling procedure with handoff prediction reduced the packet delay to 10 ~ 70 % during the handoff.

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