Fast and Effective Wireless Handoff Scheme using Forwarding Pointers and Hierarchical Foreign Agents

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ABSTRACT

Mobile IP is used to keep track of location information and make data available to the Mobile Host (MH) anytime, anywhere. In order to maintain uniform connectivity during mobility of the MH from one cell to the next, handoff latency must be minimized. In Mobile IP, when the MH is in a foreign domain far away from its home domain and Home Agent (HA), latency for registrations is high. This latency implies that many data packets could be lost during handoff from one domain to another. Hierarchical mobility management and forwarding pointers are two methods of reducing handoff latency. We propose a mobility management scheme called Hierarchical mobility management with Forwarding Pointers (HFP), that combines the two methods. In HFP, when the MH moves within a foreign domain, registration requests are handled locally. When the MH moves from one foreign domain to another, forwarding pointers between the two domains are used to track the location of the MH and perform smooth handoff. We show that HFP performs better than hierarchical mobility management during inter-domain mobility and better than forwarding pointers during intra-domain mobility. Simulation results that validate the performance improvement are presented and discussed.

Keywords: Mobile IP, Forwarding pointers, Hierarchical Mobility Management, Wireless handoff scheme.

1. INTRODUCTION

Mobile IP, an extension to the Internet Protocol (IP), is used to connect mobile devices to the wired network. Emergence of short-range low bandwidth, new generation radio devices like Bluetooth[1] enabled devices, which operate in picocells and nanocells will revolutionize wireless communication, increasing the number of people using wireless devices exponentially. As the ratio of mobile devices per cell increases, the effective bandwidth per cell decreases. Hence, to ensure sufficient bandwidth for each mobile device, the cell size has to be reduced. Small network cells would not only allow high bandwidth, but also accurate location information. It is envisaged that mobile devices would be frequently crossing cell boundaries while accessing data. Whenever a mobile device crosses a cell boundary, a handoff has to be invoked. The handoff mechanism informs the HA (responsible for the MH) of current cell location of the MH. The HA, in co-operation with Foreign Agents (FAs), is then able to ensure that data destined for the MH is actually delivered.

Some of the goals of performing a fast handoff are to reduce data loss and make data available continuously to the MH. The handoff mechanism should also be scalable. The Mobile IP standard defines a straightforward method to implement such handoffs. Every time the MH changes cells, the new location is propagated to its HA in the home network. The HA is responsible for keeping track of the location of the MH. All packets destined for the MH first arrive at the HA. The HA then tunnels the packet to the FA of the corresponding cell. This scheme, though elegant, is based on a few assumptions. It assumes that the cell sizes for the mobile devices will be sufficiently large, so as not to overload the HA with frequent handoffs. It also assumes that the MHs will not change cells very frequently. We foresee that in the near future the number of cells would increase drastically, leading to very frequent handoffs. This would overload the HA when the number of MHs attached to a HA is quite significant. Moreover, if the MH is very far from the HA, then the handoff latency between cells might become comparable to the time the host spends in that cell. This might lead to intermittent disconnections and subsequent packet losses.

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Many schools of thought exist for solving such a problem. One is the hierarchical scheme for mobility management,[2] which introduces the concept of Domain Foreign Agents (DFA) and Subnet Foreign Agents (SFA). This scheme, however, assumes the locality of the MH to be within one administrative domain most of the time. Another scheme deals with maintaining a list of forwarding pointers[3] in each cell traversed by the MH. Thus, if an MH were not present in the current cell, the FA of the cell would forward the packet to the next corresponding cell in the path. A third scheme forms part of the extensions to Mobile IP[4] which describe the method of avoiding triangle routing involving the HA, a Correspondent Host and the FA. The hierarchical scheme and forwarding pointer scheme achieve reduced handoff latency and location management cost. We claim that a scheme combining both schemes will perform better in these two aspects than either scheme alone.

In Mobile IP, the HA is the central player. At any given time, the HA is aware of the current location of every MH it supports. It achieves this, of course, by maintaining bindings for each MH whenever it receives a registration request from it. This most important step must be performed, every time an MH changes location. We immediately notice that if an MH changes locations frequently, the number of registration requests and replies at the home agent could very quickly make it a bottleneck. Thus, the question is: Is it possible to reduce the number of registration requests at the home agent even further (as compared to hierarchical mobility management and forwarding pointers)? Another problem related to registration management is distance of the MH from the HA. Registration requests and replies take longer to reach their destinations as the MH moves farther away from home. In this case, the question is: How can it be ensured that the MH registers with the "HA" as quickly as possible? We attempt to answer these two specific questions in this paper.

The rest of this paper is organized as follows. In section 2, we describe some of the relevant work in this area. In section 3, we propose and discuss HFP. In section 4, we discuss the implementation of HFP. Section 5 presents the experimental results and discussion. Section 6 explains our views about security considerations related to this work. We present conclusions and future work in section 7.

2. RELATED WORK

The idea of hierarchical registration and fast handoffs originated from RFC 2002.[4] Perkins and Johnson proposed the idea of a hierarchy of FAs with each level of the hierarchy embedded in network regions having a different granularity, with the hierarchy being either static or dynamic.

Padmanabhan[2] *et al* propose a hierarchical mobility management scheme for networks that include a large number of portable devices moving among small wireless networks. They exploit the aspect of locality in user mobility to restrict handoff processing to the vicinity of a mobile node. They organize the wireless network such that the edge router (DFA) is at the top of the hierarchy. The SFAs in each domain form the next level and the FAs connecting the MHs to the network form the lowest level of the hierarchy. The SFAs handle movements of the MH within a subnet and the DFA handles the movement between the subnets. The network hierarchy in HFP has been adopted from the hierarchical mobility management scheme. The hierarchy helps in reducing the handoff latency due to mobility within a domain.

Vaidya[3] *et al* have suggested the use of forwarding pointers in addition to home location servers to help in providing efficient location management. The paper shows that the use of forwarding pointers reduces the network load during updates, but at the same time may increase the search cost due to increased chain lengths. Two different heuristics - movement-based and call-based - are proposed to limit the length of the forwarding pointer chain. HFP maintains forwarding pointers between DFAs, which are essentially edge routers. This helps in providing efficient location management without involving the HA.

Gustafsson[5] *et al* are working on an Internet draft that formalizes the minutes of the Mobile IP Working Group Meeting[6] and introduces the term "Regional Registration". A regional registration is local to the visited domain (foreign network). The introduction of regional registrations would reduce the number of signaling messages to the home network and reduce the signaling delay when a mobile node moves from one foreign network to another, within the same administrative domain. This work is very closely related to the hierarchical mobility management scheme. Marki[7] *et al* have proposed extensions to Mobile IP Regional Registration in terms of fast handoffs and avoidance of triangle routing within the hierarchical domains. Extensions are also proposed for Mobile IPv6[8] and neighbor discovery[9] to allow for the introduction of a hierarchical MIPv6 mobility management model.

Perkins[10] proposed strategies compatible with route optimization and its security model. Foreign agents buffer packets for an MH and send them to its new location when it leaves. In addition, hierarchical foreign agent management reduces the administrative overhead of frequent local handoffs, using an extension of the Mobile IP registration requests. Performance improvements in terms of throughput, registration overhead, lost and duplicate packets during a handoff are obtained.

Cellular IP[11] is a lightweight and robust protocol that is optimized to support local mobility. It also efficiently inter-operates with Mobile IP to provide wide area mobility support. Cellular IP proposes great benefit in comparison to existing host mobility proposals for environments where MHs migrate frequently. Cellular IP maintains distributed cache for location management and routing purposes. The paper states that the distributed location management and routing algorithms make the implementation of Internet host mobility to be simple and low cost, which requires no new packet formats, encapsulations or address spaces beyond present IP, because it is built over existing IP.

Acampora[12] *et al* describe an approach for handling a high rate of handoffs in cellular ATM networks. In an ATM network, at connection setup time, a call processor establishes a call or a network route. A mobile user's call must be re-routed each time the connection is handed over to a new base station. Hence, the network call processor could become a bottleneck when the frequency of handoffs is high. This paper describes a virtual connection tree that avoids the need to involve the network call processor for every cell handoff attempt. Connection of mobile users who remain within a geographical area may be handed over to any base station in a distributed manner without involving the network call processor. This methodology enables the use of physically small radio cells to provide very high system capacity. However, this may occasionally cause the volume of traffic to be handed by one cell site to exceed that cell site's capacity.

Awerbuch and Peleg[13] have described a mechanism for tracking mobile users in a distributed network. The mechanism uses a distributed directory server and describes issues in maintaining one. The concept of regional matching is introduced and used to demonstrate how regional matching enables efficient tracking of mobile users. A distributed directory server contains location information of the mobile user. The network is divided into regions and a regional directory is associated with each region. The regional directories are arranged in a hierarchy. The intuition is that the i^{th} level regional directories would be used to *find* a mobile user within a distance of 2^i, and forwarding pointers between regional directories would be able to track the user on a *move*. The regional directories at a level *l* are all updated whenever the user moves a distance greater than 2^l since the last update at each directory. Regional directories at levels *l+1* and greater are not updated. To be able to use these directories in locating the user's current position, a forwarding pointer is left at the host corresponding to level *l*.

Wang[14] proposed a system called Universal Personal Communication System (UPCS) that enables anyone to communicate with any portable device anywhere in the world. A crucial problem of such a system would be in locating hundreds of millions of moving portables in an efficient manner. Other possible drawbacks could involve maintenance of a central database and overhead in updating the database. The architecture of the UPCS includes three different layers - the access network consisting of the portable device, the fixed layer that consists of the PSTN network and the intelligent network which is itself an hierarchical organization. The intelligent network is organized on basis of geographical locations while our approach organizes the foreign agents on basis of their network organization. Our approach hence reduces the handoff latency since the adjoining foreign network would be at most one or two hops away from the current foreign agent.

3. REGISTRATION MANAGEMENT SCHEME

This paper introduces a specific change to the scheme of forwarding pointers incorporating the idea of a hierarchical mobility management when the MH is in a foreign network. We argue that a scheme blending the two ideas of hierarchical mobility management and forwarding pointers would perform better than implementing any one of them in a network. The hierarchical mobility management scheme will be highly advantageous when the mobility is concentrated inside the domain. Forwarding pointers maintained between edge routers ensure fast handoff when the MH travels outside the domain. Thus, a combination of the two location management schemes achieves faster and smoother handoffs. The main overhead due to the incorporation of both the ideas is borne by the edge routers and the hierarchy. However, the additional overhead involved in message delay is very small as compared to the handoff latency involved in standard Mobile IP.

3.1. Network Architecture

The network consists of numerous foreign agents that support the mobile host. The area covered by an FA is called a cell. The FAs are in a subnet that is managed by an SFA. A DFA exists for each domain in the network. It maintains a binding of the MHs with the corresponding SFAs. The SFAs in turn maintain a binding of the MHs with the corresponding FAs. SFAs in the HFP map to Home Location Servers (HLS) in the forwarding pointer scheme. FAs in the proposed scheme map to Mobile Support Stations (MSS) in the forwarding pointer scheme. Forwarding pointers are maintained between DFAs, unlike Vaidya's approach, where the pointers are between HLSs (SFAs).

3.2. Registration and Handoff Scheme

When an MH first enters a foreign domain, it first registers with the HA by sending a registration request to its current FA (1, 2, 3, 4: Figure 1). The request travels hop-by-hop up the hierarchy (FA to SFA to DFA), before being received by the HA. The registration reply from the HA traverses the same path in reverse and reaches the MH (5, 6, 7, 8: Figure 2). On receipt of the reply, the DFA creates a binding of the MH with the corresponding SFA. The SFA creates a similar binding of the MH with the corresponding FA. When an MH changes FAs in the same subnet, the SFA traps the registration request meant for the HA. The SFA changes it's binding for the mobile node and does not forward the registration request any further (10, 11, 12, 13: Figure 1). When the node changes subnets, the DFA traps the registration request. Again, the registration request is not forwarded to the HA and it changes the binding entry for the mobile host to the new SFA (15, 16, 17, 18, 19, 20: Figure 1). This mechanism is called local handoff or intra-domain handoff. This is shown in figure 1.

The HA maintains a binding between an MH and a DFA. When the host moves across foreign networks and into the domain of another DFA, a forwarding pointer is maintained from the previous DFA to the new DFA. This is done by the MH, which sends a registration request to the previous DFA, on determining that it has entered a new domain. This scheme is called inter-domain handoff.

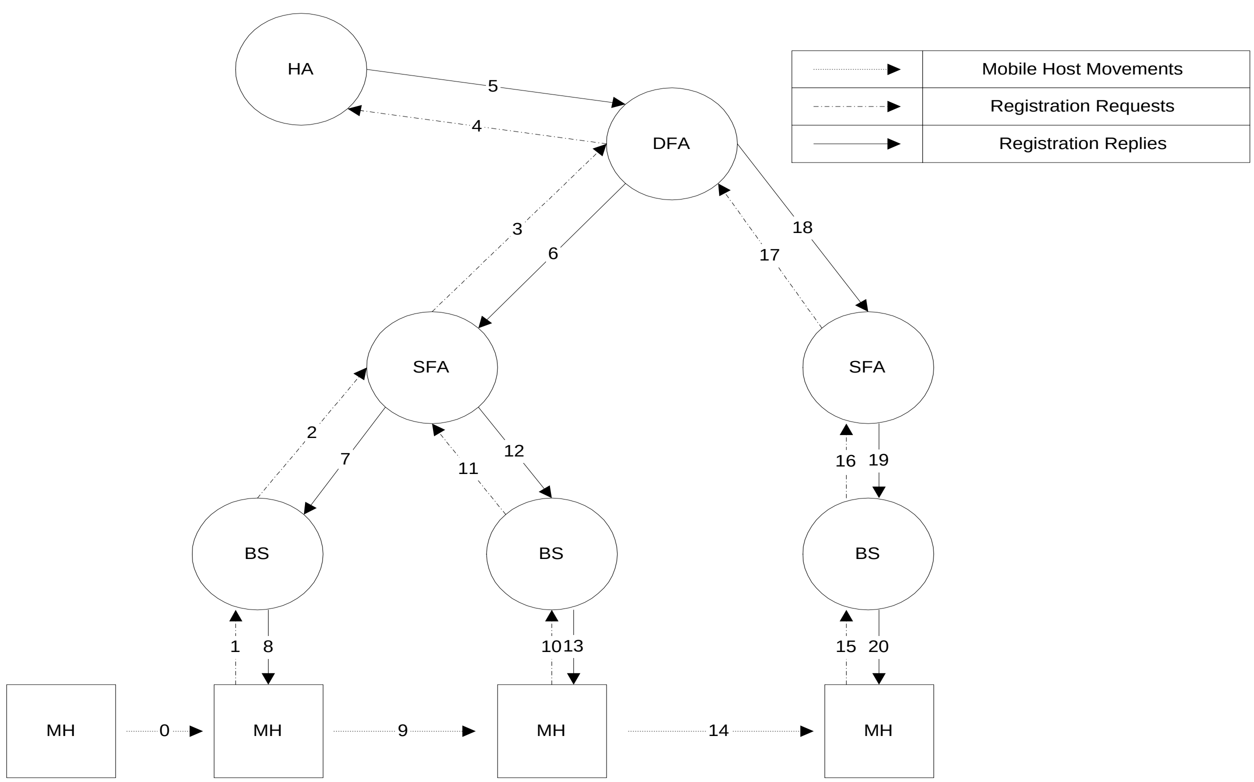


Figure 1. Registration in a foreign domain

3.3. Communication Scheme

A correspondent host (CH) transmits a packet destined to an MH (1: Figure 2). As per Mobile IP specifications, the HA intercepts the packet and tunnels it to the DFA (2: Figure 2). The DFA, on receiving a packet from the HA forwards the packet to the corresponding SFA. The SFA transmits each packet received to the corresponding FA, which in turn transmits the packet to the MH on its air interface (3a, 3b: Figure 2).

In case of inter-domain movement, the previous DFA, on receiving packets for the node forwards them to the current DFA (6: Figure 2). As the MH traverses different domains, a chain of forwarding pointers is formed and maintained between DFAs. When this chain of forwarding pointers reaches a particular limit, the current DFA transmits the registration request directly to the HA and collapses the chain. Upon receiving a reply from the HA, the current DFA now effectively becomes the head of a possible new chain. The appropriate length of the chain that should be allowed to grow before the chain is collapsed is a subject of experimental measurements. Figure 2 thus summarizes the intra-domain and inter-domain handoff handling capabilities of HFP.

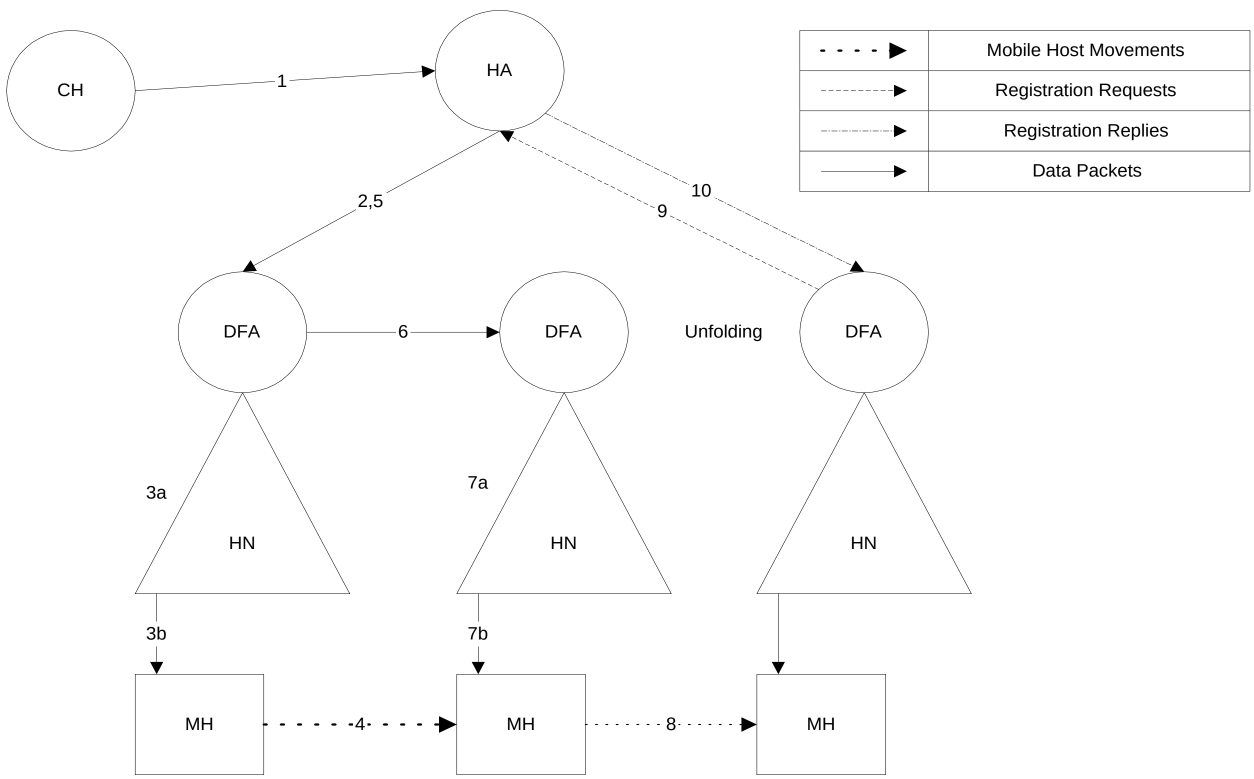


Figure 2. Local and Global Handoff in HFP

4. IMPLEMENTATION

The ns simulator[15] (developed at the University of California, Berkeley with Mobile IP extensions provided by Carnegie Mellon University) was used to simulate and evaluate HFP. As specified in the extensions, an MH belongs to the Mobile Node class. Each mobile node has the functionality of moving within a mobile network topology, transmitting and receiving data from a wireless channel. For each node created, a stack consisting of the link layer, interface queue, MAC layer and the network interface layer is constructed and connected to the channel. Specifying the coordinates of the node's destination with the required speed of motion generates its movements. The functions performed by an MH - receiving advertisements, sending registration requests and receiving the corresponding replies - are all implemented in the Mobile Host Agent class.

The HA and the various FAs belong to the Base Station class. They have the capability of wired and wireless routing. They can be enabled to perform the encapsulation and decapsulation for receiving and sending data packets. The Base Station Agent class performs the various functions of the HA and FAs. Functions, such as setting up the decapsulator and encapsulator are implemented in Tcl.

The simulator provides the option of creating either a flat network or a hierarchical network. We have created foreign networks as hierarchies, in order to implement HFP. Each node in the foreign network is part of a domain and a specific cluster within that domain. We chose a hierarchy consisting of three levels. The number of DFAs determines the number of domains. Within each domain, there are multiple clusters - each consisting of a single SFA. Finally, each SFA is responsible for multiple FAs.

4.1. Local Handoff Implementation

We have made changes to the Base Station Agent that handles registration requests and replies. Every FA determines its SFA's address using its own hierarchical address. Similarly, every SFA determines its corresponding DFA's address. This enables the nodes in each hierarchy to unicast requests and replies to each other. The local handoff scheme works as follows. The FA, upon receiving a registration request from an MH, unicasts it to its corresponding SFA. The SFA checks to see if the same MH had transmitted a registration request earlier. We assume that the MH's binding with the HA has not expired when the SFA performs this check. If the check fails, then it sends the registration request to its DFA. If, on the other hand, the SFA determines that a registration request from the same MH was sent to the DFA and a valid reply was received, then it infers that the MH must have changed positions within its subnet (i.e., changed FAs). It then replies to the request without allowing it to travel any further up the hierarchy. The DFA also behaves similarly with respect to a SFA. The registration request goes to the DFA only when an MH registers with a different SFA in the same domain or if the current SFA never handled a registration request from this MH earlier. Similarly, if the DFA is handling the request from this MH for the first time, it allows the request to travel to the HA. One important aspect that has to be addressed (due to the behavior of a hierarchy) is the lifetime of the MH's registration with the HA. In standard Mobile IP, the registration is valid at the HA only for the duration of the lifetime parameter. However, introduction of a hierarchy between the HA and MH implies that this parameter must be distributed to all nodes in the hierarchy for appropriate handling of registration requests. We have ensured that the registration of the MH remains valid at the HA until the end of the simulation.

4.2. Global Handoff Implementation

To simulate global handoff, we have made changes to the MH Agent code that handles reception of advertisements and transmission of registration requests. The MH first determines whether it is at home or in a foreign domain. It accomplishes this by comparing its "home subnet" with the foreign subnet (using the FA address from the advertisement). In addition, the MH also determines the address of the DFA corresponding to this FA. The functionality of location tracking across domains is also implemented in the MH. The MH keeps track of the previous domain to which it belonged (using the DFA's address). When it enters a new domain, it first checks to see if the new domain is its home network in which case it would register with the HA. If it determines that it has entered another foreign domain, it sends a registration request to its previous DFA, using the hierarchy of the current foreign domain. Thus, the previous DFA is now effectively the new HA of the MH. Thus, at any given time during its journey through foreign domains, the MH always knows the addresses of its current and previous DFA's. The MH accomplishes this by keeping an array of addresses of its previous DFA's. The current DFA is responsible for deciding whether or not to collapse the forwarding pointer chain. It does this by transmitting the registration request directly to the HA instead of the previous DFA.

5. EXPERIMENTS

The main aim of the work is to reduce the burden on the HA due to increased handoffs and reduce handoff latency. The inherent characteristics of the registration mechanism implemented reduce the overhead of handling every registration request by the HA. The DFAs and the SFAs handle the requests when the MH is in a foreign domain. The length of the forwarding pointers maintained determines the effective number of registration requests sent to the HA when the MH crosses domains.

On an average, the number of registration requests being handled by the home agent has been observed to be four times lesser than that in the regular Mobile IP implementation with a forwarding pointer length of one. Thus, the overhead in the home agent is drastically reduced indicating the scalability of the above mechanism.

We performed experiments with two different topologies. In the first set of experiments, we considered 2 DFAs, each of which controlled 2 SFAs. Each SFA controlled two FAs. The MH traveled from the first FA in the topology to the last FA. This would require 8 registration request reply pairs to be sent and received by the MH, as shown in figure 3.

We observed that the average handoff latency in HFP is reduced, as compared to that in base Mobile IP. Intra-domain handoff latency is the latency for the registration reply to reach the MH when the reply is coming from the foreign domain. Inter-domain handoff latency is the time required for the corresponding reply to come from the previous DFA. The average intra-domain and inter-domain handoff latencies (in ms) are calculated for the base Mobile IP implementation and HFP. Table 1 shows the average results for five runs of the simulation.

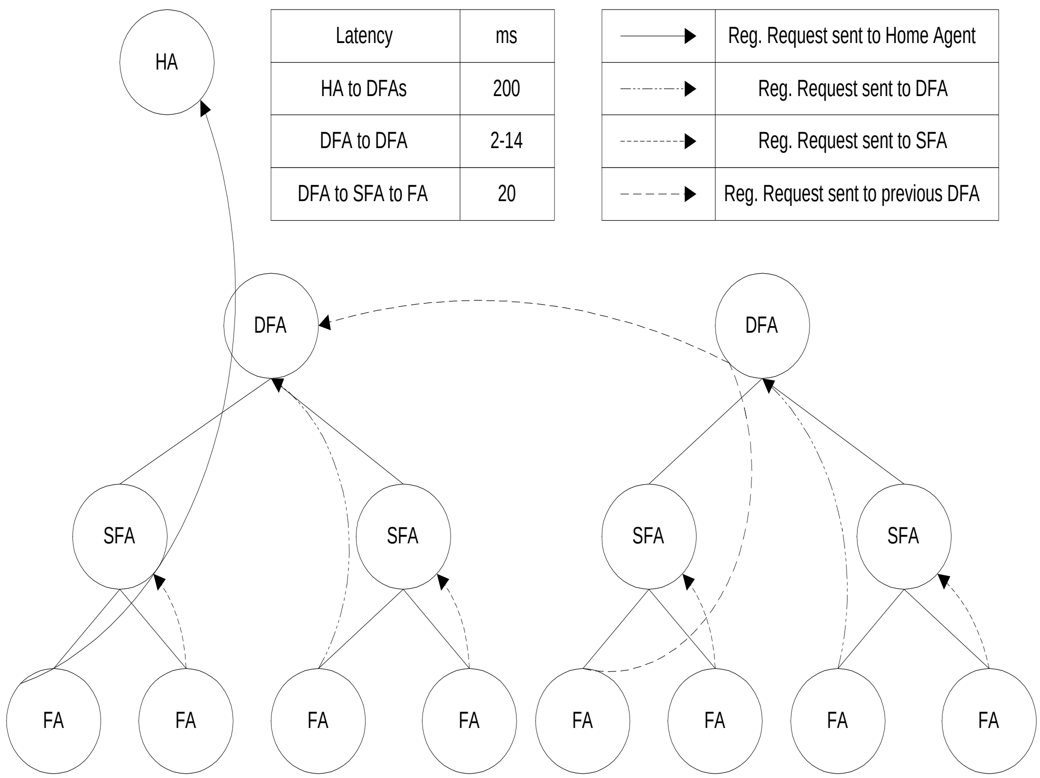


Figure 3. Registration frequencies in HFP

Handoff Latency type	Base Mobile IP (ms)	HFP (ms)
Intra-domain	41.0	8.133
Inter-domain	41.0	16.44

Table 1. Handoff latencies for the two schemes

The distribution of registration requests for HFP is as shown in Table 2. The table shows the *total* number of registration requests the MH needs to send as it traverses the entire topology described above. The measured average handoff latency for each type of registration request is shown the third column.

The above calculations were made by setting the link delay between the HA and each DFA to 200ms (equivalent to placing the HA "far" away from the from the foreign domain(s). We observe a performance improvement by an order of magnitude from base Mobile IP to HFP. We assume that the two domains being traversed by the MH are in close proximity to each other and set the link delay between DFAs to 2ms. The reason for this assumption is that close proximity of domains is the common case as far as short-term mobility of MHs is concerned (as opposed to domains thousands of miles apart). The average handoff latency was calculated by combining both intra-domain and inter-domain latencies. **Average handoff latency in HFP is calculated to be approximately 3 times lesser than that in base Mobile IP.**

Message Type	No of msgs	Average handoff latency (ms)
Registration request to HA	1	41.0
Registration request causing update to current DFA (Intra-domain)	2	12.0
Registration request causing update to previous DFA (Inter-domain)	1	16.44
Registration requests to current SFA	4	6.2
Overall Average handoff latency = 13.46		

Table 2. HFP (Chain Length=1)

One drawback of our implementation could be the packet delays caused by the additional processing in the DFAs and the SFAs, along with pairwise link delays (set to 2ms) each between all nodes (DFA, SFAs and FA) in the hierarchy. This overhead might increase the handoff latency whenever the request goes to the HA. However, we determined that the overhead, including link delays, is approximately 4 ms (4.6 % of the original registration time). Considering the frequency with which registration requests go to the HA (very low), we believe that this is not a significant overhead.

We performed experiments to separately compare HFP with the forwarding pointer scheme and the hierarchical mobility management scheme. In the forwarding pointer scheme, each SFA transmits a location update to the previous SFA with which the MH was registered. The previous SFA behaves like a HA and replies to the MH. We have compared HFP with the forwarding pointer scheme with chain lengths of 1 and 2. With forwarding pointer scheme (chain length = 1), the distribution of registration requests is as shown in Table 3.

Message Type	No of msgs	Average handoff latency (ms)
Registration requests to HA	2	41.0
Registration requests causing update to the previous SFA	2	11.83
Registration requests to current SFA	4	6.2
Overall Average handoff latency = 16.30		

Table 3. Forwarding Pointer Scheme (Chain Length=1)

Increasing the forwarding pointer chain length to 2 does not change the latency values provided by the forwarding pointer scheme for the topology under discussion (two domains with four SFAs). This is because the chain collapses as soon as the MH reaches the third SFA, forcing another registration request to the HA. Thus, we obtain the same results as shown in Table 3.

The distribution of registration requests in the hierarchical mobility management scheme is shown in Table 4. As expected, when the MH changes domains, a registration request must be sent to the HA. Therefore, a total of two requests go to the HA.

Message Type	No of msgs	Average handoff latency (ms)
Registration requests to HA	2	41.0
Registration requests causing update to current DFA	2	11.83
Registration requests to current SFA	4	6.2
Overall Average handoff latency = 16.30		

Table 4. Hierarchical Mobility Management Scheme

Table 5 summarizes the performance of HFP versus the forwarding pointer scheme and the hierarchical management scheme for the topology under consideration (2 DFAs, 4 SFAs and 8 FAs).

We performed a second set of experiments by expanding the topology to 4 DFAs with 2 SFAs under each DFA and 2 FAs under each SFA. Thus, the topology contained a total of 8 SFAs and 16 FAs We have compared HFP with the forwarding pointer scheme with chain lengths of 1 and 2, and the hierarchical mobility management scheme.

Scheme	Total average handoff latency (ms)	% Increase in time (compared to HFP)
HFP	11.75	0
FP (chain length = 1)	16.30	18.5
Pure hierarchical scheme	16.30	18.5

Table 5. Performance of the various handoff schemes

In the new topology, the distribution of registration requests for the forwarding pointer scheme (chain length = 1 and 2) is shown in Tables 6 and 7. We see in Table 7, the gain achieved by the forwarding pointer scheme when the chain length is increased to 2 and one less registration request needs to go the HA. The distribution of registration requests for the hierarchical mobility management scheme, as expected, is the same as that of forwarding pointer scheme with chain length equal to 1. Table 8 shows how results in Table 7 can be further improved by sending only 2 registration requests to the HA, although the MH traverses all four domains. Table 9 summarizes the performance of the various handoff schemes for the new topology.

Message Type	No of msgs	Average handoff latency (ms)
Registration request to HA	4	41.0
Registration request causing update to previous SFA	4	12.0
Registration requests to current SFA	4	6.2
Overall Average handoff latency = 16.35		

Table 6. Forwarding Pointer Scheme (Chain Length=1)

Message Type	No of msgs	Average handoff latency (ms)
Registration request to HA	3	41.0
Registration request causing update to previous SFA	5	12.0
Registration requests to current SFA	8	6.2
Overall Average handoff latency = 14.53		

Table 7. Forwarding Pointer Scheme (Chain Length=2)

A fast handoff scheme might have an indirect effect on the number of registration reply packets dropped as the speed of the MH increases. As the speed of the MH increases, the time it remains in the radio range of a particular FA decreases. If we consider a constant time interval for re-registration requests, then the number of such requests would decrease. We performed experiments by increasing the speed of the MH. We observed that as the speed of the MH increases the average number of requests lost by HFP is lower than that in base Mobile IP. One anomaly observed is that the number of requests lost decreases as the speed of the MH increases. We have not been able to determine the reason(s) for this behavior. This open question might form part of our future work.

The gain obtained by using forwarding pointers between DFAs would reduce if the network links between the DFAs had high delays. We performed experiments to determine the link delay at which the inter-domain handoff latency in HFP becomes equal to that in base Mobile IP. Table 10 shows these results. Thus, when the delay in the inter-domain link increases to 14ms, the inter-domain handoff latency in HFP becomes equal to that in the base Mobile IP. This simulates the scenario where all domains traversed by the MH are very far from each other. It would appear that base Mobile IP is a good solution for such scenarios.

A direct effect of decreasing the time required to register with the HA in Mobile IP is the corresponding increase in the quality of Service. Due to faster re-registrations, the number of data packets being dropped, due to intermittent disconnections of the MH with the HA, decreases. On the other hand, data packets follow a longer path to the MH leading to an increase in average packet delay and response time. Experiments were carried out to calculate the variations in average data packet losses and average transmission time. Figure 4(a) shows the effect on average packet losses due to increasing chain length in the HFP scheme. The effect on the average packet delay due to increasing chain length is shown in figure 4(b). We observe from the

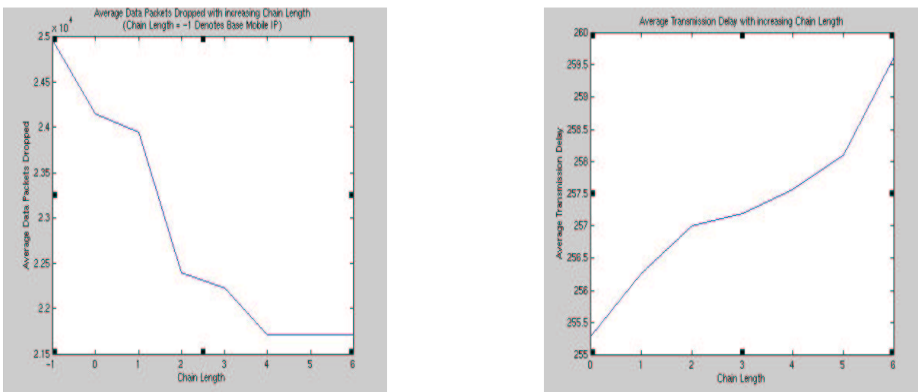
Message Type	No of msgs	Average handoff latency (ms)
Registration request to HA	2	41.0
Registration request causing update to current DFA (Intra-domain)	4	12.0
Registration request causing update to previous DFA (Inter-domain)	2	16.44
Registration requests to current SFA	8	6.2
Overall Average handoff latency = 13.28		

Table 8. HFP (Chain Length = 1 & 2)

Scheme	Total average handoff latency (ms)	% increase in time (compared to HFP)
HFP	13.28	0
FP (chain length = 1)	16.35	23.11
FP (chain length = 2)	14.53	9.41
Pure Hierarchical	16.35	23.11

Table 9. Performance of various handoff schemes for expanded topology

graphs that as packet losses decrease, reliability increases. However, overall transmission delay also increases leading to an increase in overall round-trip time. Based on the QoS requirements of the particular network, these two parameters could be tuned to ensure better performance.



(a) (b)

Figure 4. (a) Average Data Packets Dropped with Increasing Chain Length (b) Average Transmission Delay (ms) with Increasing Chain Length

6. SECURITY CONSIDERATIONS

In this paper, we have described a modification to the standard Mobile IP architecture in order to achieve reduced packet losses and decreased registration delay. Undoubtedly, security issues are a consideration when registration packets are being intercepted by intermediate nodes like SFAs or DFAs. This work does not focus on detailing the security solutions needed in successfully designing and using networks based on the HFP architecture. In addition, we emphasize that security issues are not specific to this architecture, but need to be addressed whenever a Mobile IP based network is being designed. The Mobile IP standard provides means of authenticating an MH with an FA by using the mobile-foreign authentication extension to a Mobile IP header. It also provides an extension to authenticate the FA with the HA and the MH with the HA. We can use these authentication extensions to authenticate an MH with a SFA or a DFA. We can also use the FA-HA authentication extension to authenticate an SFA or a DFA with the HA. In the paper, we have also described a situation where the MH sends a registration request to the DFA of the domain from where it has migrated after determining that it has entered a new domain. In this case, the new DFA only acts as a router sending the registration request to the previous DFA. Hence, authentication between the DFAs is not required. The DFA of the previous domain can use the MH-FA authentication extension to ensure that the registration request actually originated at the MH.

Inter-domain link delay (ms)	Inter-domain handoff latency (ms)
2	17.88
4	20
6	25.0
8	28.73
10	32.73
12	36.73
14	41.0

Table 10. Effect of increase in the inter-domain link delay on the inter-domain handoff latency

7. CONCLUSIONS AND FUTURE WORK

This paper presents the design and evaluation of a mobility management scheme in an IP type network for supporting mobile users. The paper shows how blending the hierarchical mobility management scheme with forwarding pointers can reduce handoff latency. Our implementation is scalable and achieves faster handoffs. Achieving faster handoffs would reduce packet losses and hence would take current Mobile IP a step ahead in maintaining uniform connectivity.

Future work in this area includes design improvements to avoid "triangle routing" between the Correspondent Host, MH and HA. That is, the current DFA could inform the CH about the current location of the MH. The DFA would perform this by sending a "binding update" to the CH. It would also be interesting to implement HFP in a real Mobile IP environment and perform more accurate experiments. This would help determine the actual gains provided by HFP over Mobile IP, Hierarchical Mobility Management and Forwarding Pointers.

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