FAST HANDOFF WITH POSITION INFORMATION FOR MOBILE IP

by

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Abstract

Mobile IP is designed to support uninterrupted connectivity of mobile computers as they roam from place to place. We propose a fast intra-domain and inter-domain handoff scheme using the location of routers to meet the delay and packet loss requirements of real-time services. The scheme achieves an intelligent and dynamic neighborhood discovery and avoids the use of multicast addresses in intra-domain handoff. In addition, it decreases the registration time and distributes home agent data base dynamically in inter-domain handoff depending on how far from the home agent mobile host is. Simulation and implementation results for an interactive voice communication are presented.

1 Introduction

The Internet has attachment points at the edges that connect wireless mobile users to the Internet. The primary aim of Mobile IP is to adapt IP to achieve a robust communication between users who change their attachment points [1].

A major problem in Mobile IP arises in providing real-time services while achieving certain QoS requirements. The high bandwidth required for real-time services is only be solved through smaller cells. However, small wireless cells cause frequent handoffs.

Frequent handoffs in non-overlapping cells increase latency and loss in the rerouting of packets in handoffs. While a mobile moves from one cell to another, he will not be able to get any message until he makes connection to the new access point and gets confirmed by his home network. Since the packets are forwarded to the old access point during this time period, packet loss will occur in addition to the latency.

Frequent handoffs in overlapping cells causes ping-pong effect. When the mobile is moving inside the coverage of more than one access point, he is changing his access point back and forth among these points since the signal strength favors different access points at different times.

Our system achieves fast handoffs by using both hierarchical structure of the network [2] and GPS (Global Positioning System) devices in the routers. The network is thought to be composed of administrative or geographical domains. Each domain has a hierarchical tree of foreign agents with a domain foreign agent at the top. Using a GPS device, each router knows its own position. A special advertisement-messaging scheme informs other routers in the domain of its position. Routers use this position information to send the packets directed to one foreign agent to adjacent foreign agents as well. In addition, we use the position information of domain foreign agents to decide whether to send a registration request to home agent or to the previous domain foreign agent of the mobile host. This brings local home agent functionality to domain foreign agents if a mobile host does not go geographically away from this domain compared to its distance from the home agent.

Our objectives are to achieve performance equivalent to that obtained by non-mobile protocols, scalability and security. The first goal, achieving the performance as non-mobile protocols, requires efficient fast handoffs when the user moving from one cell to another since the user should not understand that he is roaming from cell to cell. The second goal, scalability, is necessary in order to avoid the bottleneck of the MH location database as the number of MHs increases. The third goal, security, is necessary in order to prevent the redirection of packets to malicious eavesdroppers.

Organization of our paper is as follows. Section 2 introduces the previous works on achieving fast handoff. Section 3 describes the basic architecture of our system with the possible improvements that it brings to the current structure. Section 4 presents the performance results of our simulations in

Network Simulator (ns2) and our implementation environment. Section 5 concludes the paper and highlights the areas for future work.

2 Previous Works on Fast Handoffs

The problem of excessive mobility management traffic and handoff time has been addressed in various works during the past years.

One proposal is the hierarchical mobility scheme of Caceres and Padmanabhan [2]. The key idea is to decrease packet loss in hand-off by localizing the registration to the domain foreign agent and buffering the packets in the old FA before redirecting them to the new FA. This scheme handles packet loss but suffers from the delay between packets when the mobile moves from one FA to another since it takes time to learn the new care-of-address of MH. It also suffers from additional handoff overhead since after a certain latency, packets may be of no use.

Perkins [3] proposes a different kind of handoff with the hierarchy of foreign agents. The registrations due to the handoff from one FA to another will only be up to the lowest common ancestor in the tree. This prevents the trip of the registration messages to the domain foreign agent. However, all

FAs in the route from the domain foreign agent to the MH's FA have to keep the MH location information, which may cause a bottleneck as the number of MHs increases. Also, the handoff can again be slow when the lowest common ancestor is very high up the tree.

The scheme of Seshan et al. [4] is to assign each MH a multi-cast address. When an MH registers an FA, this FA identifies the handoff targets and makes them join the multicast group of MH. These handoff targets buffer the last packets to transmit in case of a hand-off. This scheme avoids the wasteful trip to HA to make it aware of the new position by using multi-cast addresses. However, multicast address conflicts may occur if one packet passes through another network where the same multi-cast address is used. The solution brought to the multicast conflict problem by C. L. Tan et al [5] is to assign a multicast address to each MH by domain foreign agent inside the domain. However, since they assign multicast address to handoff targets in addition to MHs, they require a continuous messaging between all routers to learn about new multicast address allocations. The multicast strategy is also introduced to achieve fast inter-sub domain handoffs [6]. The proposal is to determine the edge base stations for each sub-domain and to send packets to other sub-domain edge routers, which are handoff targets, using multicast address.

The last three cited papers all require messaging between adjacent FAs to form multicast groups and an intelligent neighborhood discovery mechanism to eliminate the manual configuration of handoff targets.

3 Motivation

The novelty of our handoff scheme is to provide an adaptive algorithm in the determination of handoff targets, to eliminate the messaging overhead related to forming multicast groups, to prevent potential conflicts related to the usage of multicast addresses and to perform fast handoff among the domains.

All of the previous handoff schemes rely on manual configuration of handoff targets since it is impossible to say anything about the location of access points from their IP address. Our scheme does not assume anything about the network configuration. We only require GPS devices in each access point and implement a simple messaging to propagate this information to the other access points. This messaging overhead can be ignored since it runs only if there is a change in the network configuration or in the times of the day when there is least amount of traffic in the network. Since access points are wired instead of wireless, we do not need to send location information periodically.

Most of the previous handoff schemes use multicast addresses to send more than one router in intra-domain handoff. This addressing scheme requires a continuous messaging between all routers to learn about new multicast address allocations. Our scheme completely eliminates this messaging overhead. We do not use any multicast address instead we use the hierarchical structure of the access points in the network. Forming this hierarchical structure, as location advertisement messages, does not produce any overhead since it can be updated only if there is a change in the network configuration or in the times of the day when there is least amount of traffic in the network.

Previous handoff schemes did not provide much support for inter-domain handoff based on the assumption that this kind of handoff is very rare. Our assumption is that the development of power-efficient processors and the increase in the battery lifetime of laptop computers will lead to an increase in the inter-domain usage. Using GPS devices in this respect decreases the latency considerably.

4 Proposed System

This section describes the intra-domain and inter-domain mechanisms and the extra messaging that our system requires following the overall structure of the network with its elements.

4.1 Structure of the Network

The network (See Figure 1) is composed of administrative or geographical domains. The structure of each domain is assumed to contain a hierarchy of foreign agents that includes a domain foreign agent at the top. Every FA knows its ancestors and its children in the tree.

Our system is designed according to IPv4 specifications with the following entities:

- `Mobile Host (MH):` A host or router that is portable with wireless network hardware with a constant IP address.

- `Home Agent (HA):` A stationary router on a mobile host home network that keeps the host's current care-of-address and forwards the packets accordingly.

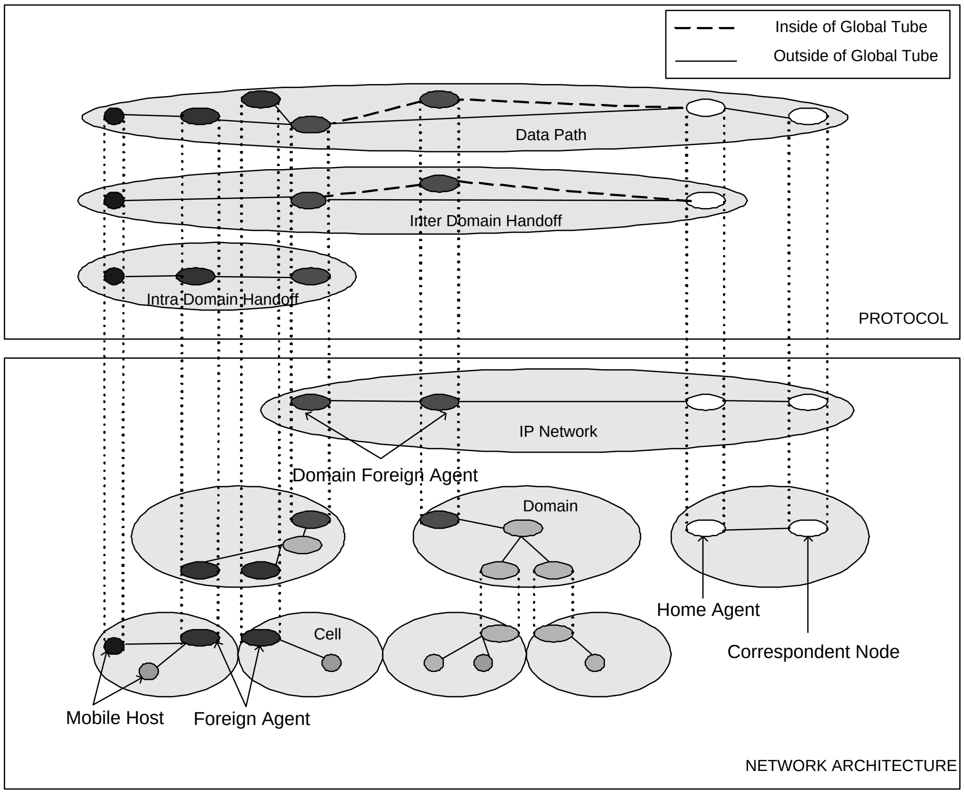

Figure 1: Network Architecture

- `Corresponding Host (CH):` Any host on the Internet that sends packets to a mobile host.

- `Domain foreign agent(DFA):` A DFA keeps the care-of-address of each MH visiting its domain and forwards the packets to MH. It updates the MH care-of-address in intra-domain handoff and informs either the previous DFA or HA in inter-domain handoff.

  DFA has a *Visitor list* of all the MHs visiting the domain at that time.

This list includes the constant IP address of each of these MHs and their current care-of-address. This current care-of-address can either be the care-of-address of a FA inside the domain that MH is connected to at that time or the address of the DFA of another domain if MH has moved to another domain while giving to this DFA a local home agent functionality.

DFA also has a *Location-FA Table* keeping the location information of each FA inside the domain together with its care-of-address. This will be used in the forwarding of MH packets to multiple FAs to provide fast handoffs.

- `(Normal) Foreign agent(FA)`: A FA keeps the MHs currently connected to this FA and the MHs that recently visited this FA. It forwards the packets either to MH or to other FAs according to its tables.

  A FA has a *Visitor list* containing the MHs currently connected to this FA. It includes the constant IP address of all these MHs. It updates this table according to the responses coming from MHs to each beacon packet that it sends.

  A FA has a *Cache list* keeping all the MHs recently visited this FA.

When FA does not receive a response from a MH in visitor list, it puts this entry to the cache list with a specified lifetime. If it does not know the new care-of-address of this MH, it puts an "all ones" entry as the new location of the MH. If it learns the new place of the MH, it puts the new care-of-address of the MH to the table. This list is used for the bandwidth efficient intra-domain handoff.

It also has a *Location-FA table* just as the DFA.

4.2 Intra-Domain Handoff

Our system uses the hierarchical structure in order to eliminate the wasteful trip to HA for each movement of the MH inside the domain. Each domain has one domain foreign agent (DFA), which is the ancestor of all other routers inside this domain.

The communication between the MH and FA is achieved through the wireless network hardware of the MH and one of the radio interfaces of the FA. Each FA broadcasts a beacon packet with a beacon period. When an MH wants to register with an FA, it registers with the DFA and sends the address of the DFA to its HA. Therefore, when an MH moves inside this domain, it does not need to inform HA of its current FA.

Switching from one FA to another can still be a problem inside the domain for real-time services since this kind of services cannot tolerate delay. To solve this problem, we have two modules: delay sensitive fast intra-domain module and bandwidth efficient fast intra-domain module. They can be used alternatively depending on the available bandwidth in the network and on the delay characteristic of the flow coming to this MH.

4.2.1 Delay Sensitive Fast Intra-Domain Module

The implementation of this module requires the following exchange of messages:

- DFA takes the encapsulated packet coming from HA or CH and decapsulates it.

- DFA examines the destination address and finds from its visitor list the care-of-address of MH.

- DFA finds the adjacent FAs of the MH's FA from the location-IP address table. Then from its routing table, it decides to which of its branches it should send these packets in order to cover all of the adjacent FAs, and sends these packets to these branches by encapsulating with the CoA of MH.

- When the routers at the end of these branches take the packets, they check the location-IP address table to find the adjacent FAs of the MH's current FA according to CoA and decide to which of their branches they should send these packets.

- Adjacent FAs buffer the packets with a specific buffer size in case of a registration.

- Adjacent FAs periodically empty their buffers.

By applying this method at each of the FAs, we achieve the multi-cast forwarding of datagrams without allocating any multi-cast address. By applying this scheme we avoid the extra burden of signaling and push the complexity of signaling to the FAs. This handoff provides minimum delay for the reception of the next packet from the new FA while it may introduce extra traffic in the domain if the MH does not move frequently.

4.2.2 Bandwidth Efficient Fast Intra-Domain Module

The following exchange of messages occurs in the implementation of this module:

- DFA takes the encapsulated packet coming from HA or CH and decapsulates it.
- DFA looks at the destination address and finds from its visitor list the care-of-address of the MH and sends the packet to this address.
- The FA taking the encapsulated packet decapsulates the packet and checks whether the destination address, the constant IP address of the MH, is inside its visitor list.
- FA decides whether to send the packet over the radio link, send the packets to adjacent FAs or buffer them.
- If MH is inside its visitor list, it sends the packet via radio link.
- If MH is not inside its visitor list but inside its cache list, this means that MH has just left this FA. If the destination address of this cache list entry is "all ones", this means that FA does not know the new care-of-address of the MH. Since MH has moved to one of its adjacent routers, it finds its adjacent routers from the location-IP address table and sends the coming packets to its adjacent FAs. If the destination address is not "all ones", this means that FA knows the new care-of-address of the MH and send the incoming packet only to this address.

- If MH is neither inside its visitor list nor inside its cache list, it buffers the packet, which indicates that it is an adjacent FA of some FA.
- Adjacent FA periodically empty their buffers.

This handoff gives a better performance compared to the existing handoff mechanisms with a good movement detection algorithm [16] since it is able to send the packets to the new FA even if it is unaware of the new CoA of MH. Compared to the delay-sensitive fast handoff, it saves the bandwidth if the MH does not move while introducing more delay and jitter.

4.3 Inter-Domain Module

The inter-domain handoffs will be needed more and more as the battery-power of laptop computers increases and the world becomes tiled into small wireless cells. Therefore, our system tries to achieve fast handoffs between the domains and gives local home agent functionality to DFA by using geographical information.

As the world is tiled into small cells, macro mobility of a user will be frequent and an intelligent fast inter domain handover scheme will be needed. For instance, suppose a user starts an Internet telephony or real video session with its hand-held computer and connects to an FA in Berkeley campus domain. Then he decides to go to San Francisco. On his way he comes across several domain changes. User will expect an uninterrupted service for these real-time services. Our system tries to make all handoffs transparent to the user during his journey.

The procedure of changing domains without inter-domain fast handoffs upon reception of the registration request from an MH is as follows:

- The MH sending the registration request is not inside the visitor list of the DFA receiving its packet.
- DFA sends registration request to the HA of the MH, takes registration reply from HA, updates its visitor list with the MH entry and sends the registration reply to MH.

The procedure of changing domains with inter-domain fast handoffs upon reception of the registration request from an MH is described as follows (This is the procedure of our system and we assume that the registration request coming from the MH includes the location and IP address of its old local home agent and the IP address and location of its HA):

- The old local home agent DFA entry in the registration request is not the same as the address of the DFA receiving the packet.

- DFA decides whether to become the new local home agent with the global tube algorithm.

- If it decides to become the new local home agent, it sends the registration request to HA and takes the registration reply from HA.

- If it does not decide to become the new local home agent, it sends the registration request to the old local home agent and receives the registration reply from it.

- Then it sends the registration reply to MH by encapsulating it with the care-of-address of the MH, which includes the new local home agent information.

4.3.1 Global Tube Algorithm

The main objective of the global tube algorithm is to eliminate the unnecessarily long handoff times and the traffic created to inform HA when MH changes domains.

Our system aims to use the DFA of one of the previously connected domains as the local home agent and send registration requests to the DFA of this domain as long as the DFAs of the following domains lie inside an R radius. This R radius is determined by the global tube with the help of the Θ constant in Figure 2.

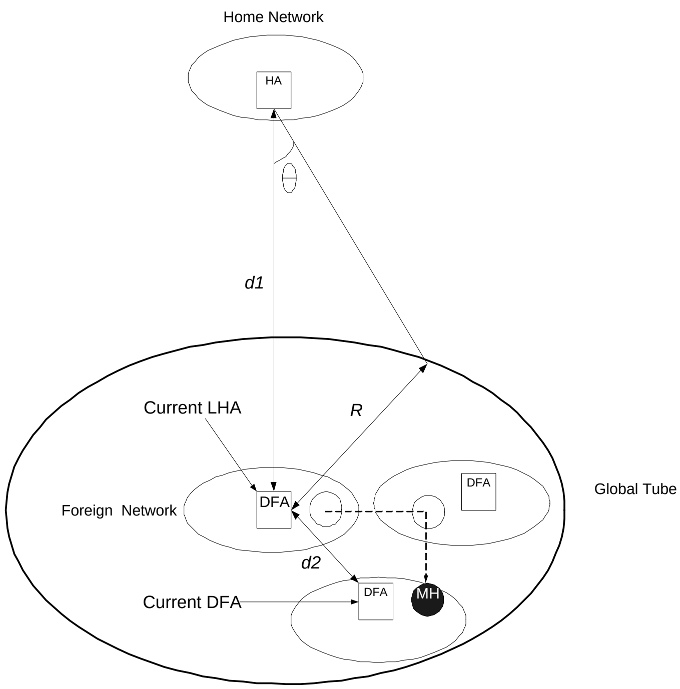

Figure 2: Global Tube

The need for the global tube arises from the necessity of an R radius depending on the location of the DFA treated as a local home agent. If the local home agent (DFA) is near the HA, it is better to send the registration request to HA instead of this DFA even if the difference between the two DFAs is small. On the other hand, if the previous DFA is far from the HA, it is better to send the registration request to DFA instead of HA for the same distance between the two DFAs. Therefore, the R radius must be adaptive.

The global tube algorithm is as follows:

$d1 = |(X, Y, Z)_{CurrentLHA}$-$(X, Y, Z)_{HA}|$;

$R = d1 * sin(\theta)$;

$d2 = |(X, Y, Z)_{CurrentDFA} - (X, Y, Z)_{CurrentLHA}|$;

If $(d2 > R)$

$NewLHA = CurrentDFA$;

else

$NewLHA = CurrentLHA$;

4.4 Control Messages

4.4.1 Registration Messages

Our system uses the same Mobile Agent discovery mechanism as Mobile IP. On the other hand, it requires using the extension parts of the registration request and reply messages of IETF Mobile IP standard.

Local home agent address, local home agent geographical location and HA location is included in the extension part of registration request format while local home agent address and geographical location is added to the registration reply format.

4.4.2 Location Advertisement Messages

Our system assumes that each FA contains a GPS device so knows its location. Location Advertisement Messages are used in order to send this location information to all routers inside the same domain.

Each router is expected to have a location-FA table, the entries of which include the IP address and the location of each foreign agent care-of-address inside its domain. This avoids the manual configuration of handoff targets of each FA.

4.5 Security

Mobile computing environment is very different from the ordinary computing environment in terms of the security. Since the links are wireless and IP addresses change frequently, the traffic can easily be disrupted by malicious users. Our system uses the security features of current Mobile IP structure [7],[10],[11].

IPSec [10]is one solution to security problems in Mobile IP. IPSec includes the IP Authentication Header and the IP Encapsulating Security Payload. The former can provide authentication, integrity checking, and possibly non-repudiation of IP Header and payload. The latter can provide confidentiality and possibly authentication and integrity checking of IP payload.

Our system sometimes requires sending a registration request from one DFA to another DFA. We assume that these DFAs share a security association in each other.

The procedure of sending packets to the adjacent FAs is also secure in our system. From DFA to FAs, bogus Denial of Service Attack can be eliminated by ingress filtering since its DFA who forwards the packets. When an adjacent FA receives packets, it decapsulates and checks its visitor list to find appropriate MH whose home address is the same as the original source address of the decapsulated packet. If it finds, this means that secure registration is achieved so it sends the packets. If it does not, it buffers them and does not relay the packets unless the MH finishes its registration procedure with the appropriate DFA. After a certain time FAs clean their buffers.

5 System Extensions

5.1 Determining the location of indoor access points

GPS is a wide-area technology that supports location information in outdoor settings. However, the mobility of mobile users inside office buildings and homes requires location support also for indoor environments. The location of access points in indoor environments can be obtained via infrared signals[13] or the use of concurrent radio and ultrasonic signals[14][15].

5.2 Roaming at the boundary of the domain

When the mobile roams at the boundary of the domain, a copy of the packet can also be forwarded to the adjacent DFA, with an introductory message indicating the CoA and location. Then adjacent DFA forwards the packet to the FAs which reside near the mobiles location. As a result of this dynamic learning mechanism, DFA learns the FA which belongs to other domains but reside near their boundary.

5.3 Avoiding Ping-pong effect

As mentioned in the introduction, ping-pong effect occurs when the mobile is moving inside the coverage of more than one access point and changing the access point frequently due to the change in the signal strength coming from these points. In the current Mobile IP, this increases loss and latency that is caused by the registration to a different access point and the rerouting of packets. On the other hand, in our scheme, the registration to the new access point will be just like a registration update to the current access point. As soon as the mobile is connected, the access point will start forwarding the packets eliminating the loss and delay caused by the rerouting of packets and registration.

6 Performance Evaluation

The performance of our algorithm is examined by simulation and implementation. We performed simulation for intra-domain and inter-domain handoff in Network Simulator (ns2) and implementation for intra-domain handoff in LINUX operating system.

6.1 Simulation Results

Our simulation scenario is shown in Figure 3. In the simulation of intra domain handoff, MN performs handoffs, the main concern is to observe the registration time and in the inter domain handoff scenario, registration time depending on the HA geographical distance is compared. Packets are sent to MH from an audio source with 20ms inter-arrival time and average packet size of 200 bytes.

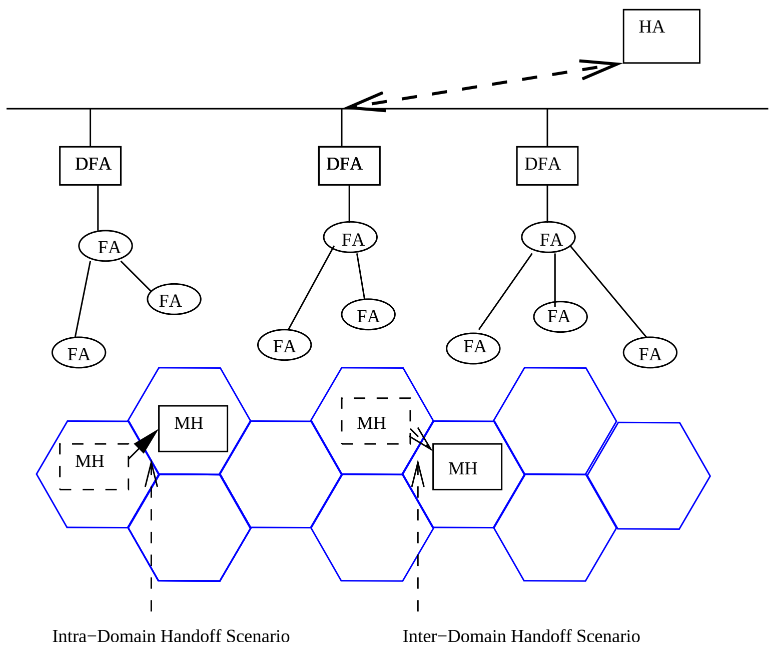

Figure 3: Intra and Inter Domain Simulation Scenario

6.1.1 Simulation of Intra-Domain Handoff

The aim of the Intra-Domain Handoff simulation is to measure how much time is required for an MH to complete handoff for different wired delays and for different number of mobile hosts.

6.1.2 Handoff Delay Performance

The aim of this simulation is to measure the registration time of the MH roaming inside a domain. The handoff delay can be divided into two: FA detection time and registration time.

The FA detection time depends on beacon period and agent solicitation (i.e. Mobile send agent solicitation before waiting for a beacon). Maximum possible detection time is one beacon period unless MH sends agent solicitation [5], and occurs when a MH moves just after hearing the beacon message of the cell that it has left and just before the beacon of the cell that it has entered.

The registration time includes sending time of a registration request message to DFA and waiting time for the registration reply message after MH detects FA. The registration times for a 1MB wireless link and different delays and bandwidths of the wired links are given in Figure 5.

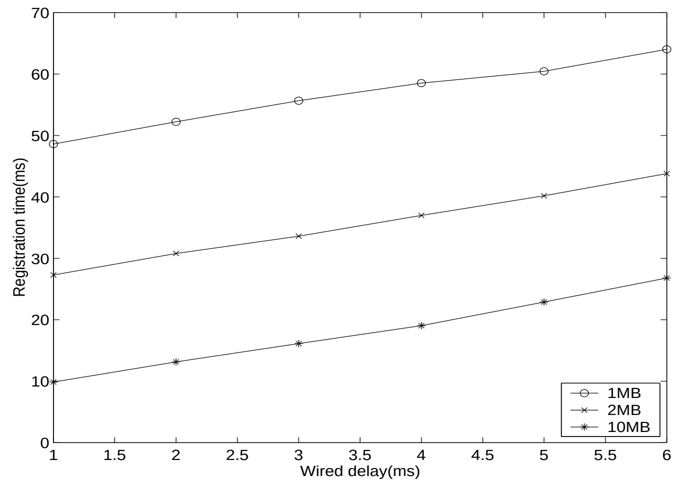

Figure 4: Registration Time for Different Wired Delays

The simulation results for different number of hosts connected to the base station that MH has just moved after handoff are plotted in Figure 6 for a 2Mbps bandwidth and 4ms delay wired links, and 1MB bandwidth wireless link. As can be seen from the graph, as the number of mobile hosts increases, the registration time increases since MH also waits for the communication of other MHs.

6.2 Simulation of Inter-Domain Handoff

In this part of the simulation, we compared the inter-domain handoff registration time of the current Mobile IP structure with the maximum and minimum possible registration time in our system by using different HA dis-

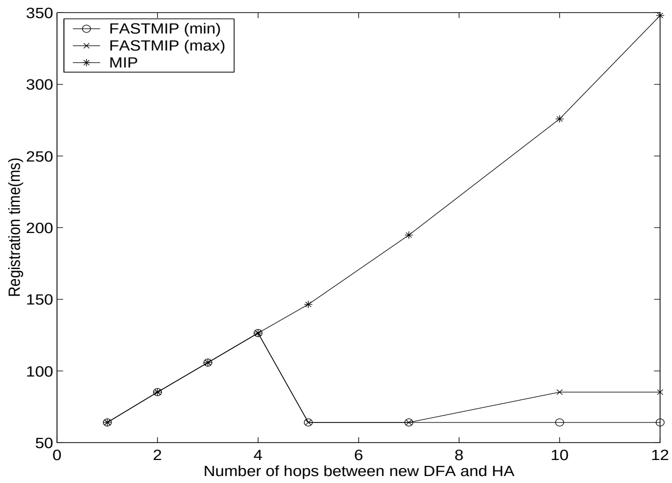

Figure 5: Registration Time for Different Wired Delays

tances. Here the minimum and maximum registration times are taken to be the registration times for nodes one hop away from the local home agent and for nodes at the boundary of the global tube respectively.

We assume that the distance between DFAs can be used to judge their physical layer distance. The reason for this is that there is a strong relation between the geographical distance and delay for macro movements although we cannot say that IP addresses are distributed geographically in micro movements. We have also assumed that the distance is proportional to the number of hops between two nodes to find approximate number of hops for the node at the boundary of the global tube.

As it can be seen from Figure 7, up to a specific distance, both the

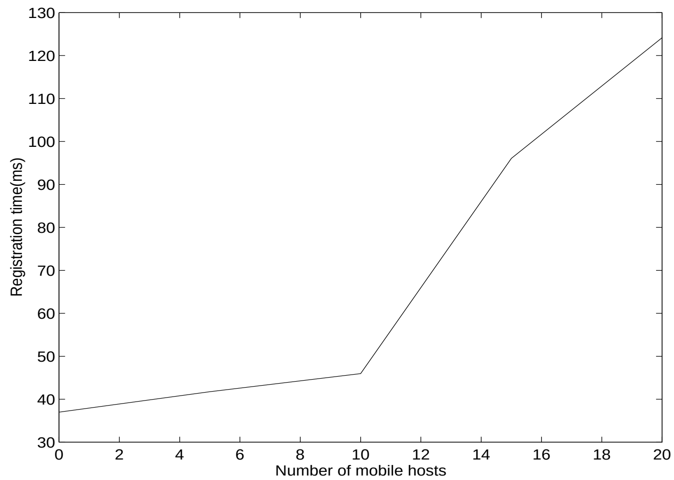

Figure 6: Registration Times for Different Number of Mobile Hosts

basic Mobile IP and our scheme have the same registration time since our scheme chooses HA to make the registration when the distance between HA and MH is very small. As the distance between HA and MH increases, the basic Mobile IP handoff time continues to increase up to 350 ms. whereas the maximum possible registration time of our scheme increases only up to 85ms. This proves for the audio receiver that it is impossible to achieve handoff transparent to user with basic Mobile IP but transparent handoff can be acquired by adjusting beacon period such that the sum of beacon period and registration time is guaranteed to be below 200ms in our scheme.

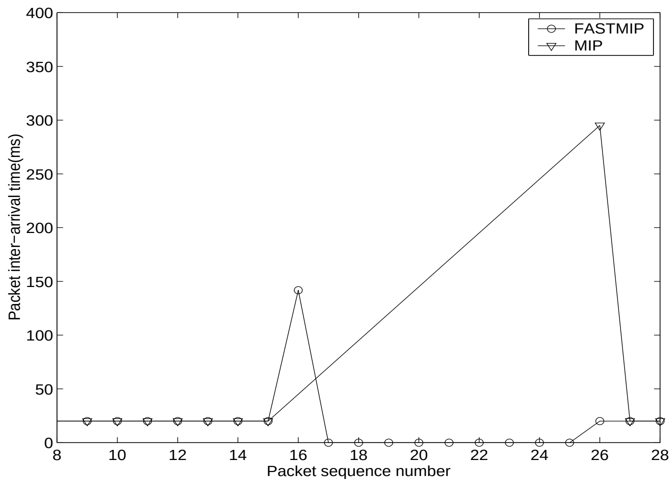

Figure 7: Comparison of Registration Time HA/DFA

6.3 Implementation Notes

In this section, we introduce FASTMIP implementation. The implementation is compliant with Mobile IP RFC 2002 [12]. In this implementation, agents and mobile run the Linux operating system.

HA software consists of two threads, implemented by pthread library, running in parallel (Tunneling Protocol and Registration Protocol). Registration protocol listens for UDP registration requests and updates the Binding Table when it gets a request. Tunneling Protocol listens to the traffic in the home network and captures the packets sent to mobiles registered with itself. When the HA receives a packet it checks its binding table and decides whether this packet is for one of its mobiles or not. If the packet is for one of the mobiles then the HA tunnels the packet to the care-of-address of the mobile. The Tunneling Protocol and the Registration Protocol are implemented using the pthread library which comes with Linux.

DFA and FA software consists of two processes running in parallel. Agent Advertisement Protocol, which runs as a separate process, periodically sends out agent advertisements (UDP broadcasts) to advertise the presence of the FA in the wireless environment. The other process includes two threads for Registration Protocol and Tunneling Protocol. Tunneling Protocol sends packets according to the Location-FA table by comparing the position of target CoA with that of other FAs. FAs check their visitor list when they receive a packet. If the packet is not in the visitor list then this mobile is not currently connected to FA but this FA is a potential handoff agent. Adjacent FAs buffer a certain number of packets for a specific expiration time. The Binding Table data structure is shared between the two threads. Registration Protocol listens for registration requests from the mobiles. After receiving a request, it updates the Binding Table, forwards this request to HA and then sends all the buffered packets that MH has not received yet to MH.

The MH runs an FA detection software derived from the wireless Linux extensions [17]. Mobile Agent continuously listens for agent advertisement messages from the Foreign Agents and stores signal qualities for all links in a data structure. If the mobile loses its connectivity to the network while it is roaming, it scans the three disjoint frequency bands that the Wavelan cards can operate, until it finds a new Foreign Agent. In order to prevent the Mobile from losing packets, HA capturing function is also inserted to the DFAs and FAs in our implementation in order to get the packets which are directed to adjacent FAs. MH keeps the source address and the sequence number of the last packet received, and sends this information to the new FA during registration. This eliminates the FA from sending the packets in his buffer that MH has already received.

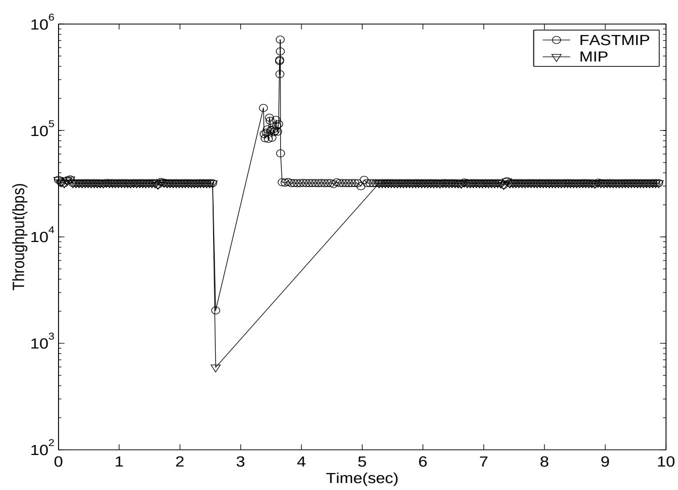

Figure 8: Instantaneous Throughput vs Time packet rate=50ms

Figure 8 shows the instantaneous throughput during a handoff when the packet size is 200byte, which is an average real-time audio packet size, and inter-sending time is 50ms. This figure shows that basic Mobile IP (MIP) loses all the packets during handoff, which causes an unrecoverable throughput decrease for 3 seconds. These 3 seconds include the time necessary for the detection of the new access point, which is equal to beacon period of access points at maximum, the time necessary for the registration request to reach home agent and for the registration request to reach the access point back. On the other hand, our scheme (FASTMIP) buffers the packets at the prospective access points and send the packets that the mobile missed during the handoff when mobile is connected. The period during which the throughput decreases is around 300ms, which is less than 3 sec in MIP since FASTMIP registration is done only to a specific foreign agent in the local region instead of the home agent in a far away network. In FASTMIP, although the instantaneous throughput decreases during handoff, it is compensated after the handoff by sending back the packets that mobile host has missed. Since this forwarding operation inter-sending time is less than 50ms(they are already in the buffer) the throughput is above the average throughput for about 500ms.

Figure 9 shows the instantaneous throughput during a handoff when the packet size is 200byte and inter-sending time is 20ms. The throughput graph behaviour for Mobile IP is the same as that with 50ms inter-sending time. The reason is that the handoff time 3 sec does not depend on sending rate and the inter-arrival of packets reaches the average value since there is no compensation for packets lost.

The overall throughput graph for different rates, as given in Figure 10, shows that the throughput increases as the sending rate increases and fast MIP performs better than MIP. The reason for the throughput increase is that more packets are sent overall although the number of packets lost increases as the sending rate increases. Fast MIP performs better than MIP since the number of packets lost is smaller in Fast MIP as we have seen in instantaneous throughput graph.

The number of packets lost depends both on the size of buffer used to store packets for potential handoffs and the sending rate as seen in Fig. 11. The number of packets lost is constant for MIP since no buffer is used and increases as the sending rate increases since more packets are sent while mobile is unable to receive during handoff. On the other hand, the number of packets sent decreases as buffer size increases for fast MIP. This means that the packet loss can be totally eliminated if the buffer size is chosen large enough. Furthermore, this buffer size can be adjustable to the sending rate since the number of packets lost increases as sending rate increases for constant buffer size.

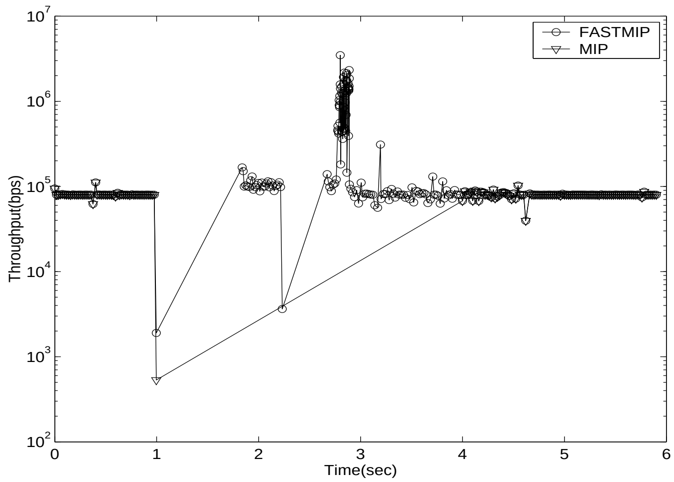

Figure 9: Instantaneous Throughput vs Time packet rate=20ms

7 Summary and Discussion

In this paper, we have presented an algorithm for doing faster handoffs with less control traffic than previous algorithms in wireless networks. Our scheme uses the hierarchical structure of the network,(i.e, the Internet is a network of domains) and location information of the foreign agents inside every domain of the network. We have shown the necessary changes in registration messages and the format of location advertisement messages. We have

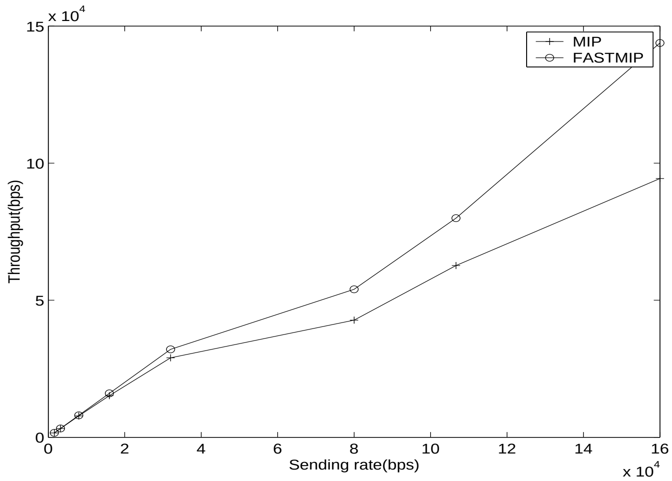

Figure 10: Throughput vs Rate

achieved an intelligent neighborhood discovery mechanism eliminating the manual configuration of adjacent FAs by these location advertisement messages. Moreover, we have obtained fast handoffs inside the domain by sending the packets to multiple foreign agents without needing any multi-cast address allocation. We have demonstrated that our scheme meets the delay requirement of a real-time audio applications. Furthermore, we have achieved faster handoffs between the domains in contrast to all other systems ignoring inter-domain handoffs. By using local home agent functionality inside the global tube, we avoided the need to register home agent for each domain change.

Our work can be investigated further in various ways. Neighborhood discovery mechanism can be made adaptive to different domain structures

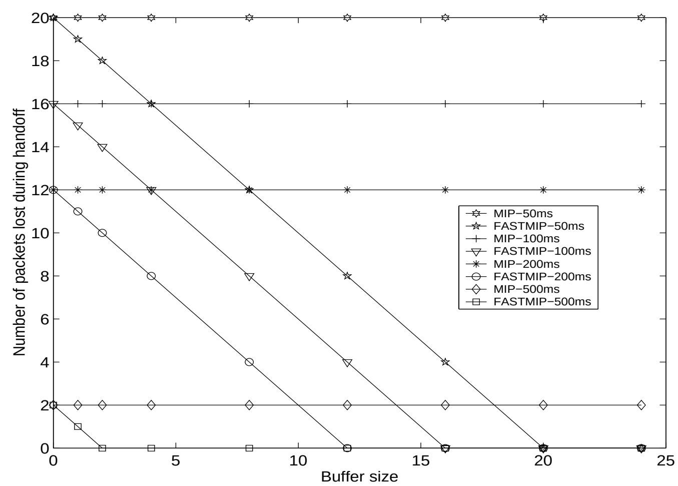

Figure 11: Packet Loss vs Buffer Size

and different cell size. Movement detection of the MH by the FA can be investigated in order to decrease bandwidth usage.The angle Θ can be made adaptive to the environment, i.e. country Θ, continental Θ, city Θ. 3-D volumes can be considered in global tube calculations and procedures can be adjusted accordingly. Furthermore, the choice between the delay sensitive and bandwidth efficient intra-domain handoff schemes can be investigated in more detail.

The popularity of real-time applications and wireless networks has demonstrated the need for the support of these applications over the wireless Mobile IP. The requirement of bandwidth by the real-time applications will be provided by tiling the world into smaller cells, which requires frequent hand-offs.

Since real-time applications are not delay tolerant, the fast handoff scheme described in this paper can be used to achieve good quality service in the future.

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