Route Optimizations In Mobile IP

Amit Mahajan, Ben Wild (amahajan,benwild)@eecs.berkeley.edu

Abstract

The Mobile IP protocol(MIP) was proposed in response to the fact that mobility is not supported in current version of IP, IP version 4. MIP introduces the concept of mobility agents (home agents and foreign agents) t provide continuous network connectivity to the mobile hosts. As per the original design of MIP, it's also compatible with IPv4. The main disadvantage of Mobile IP is the triangle routing problem which makes routing very inefficient. Also, MIP requires that all the traffic to the mobile node go through the home agent(HA), and thus a failure of the HA would disallow any further communication between the sender and mobile. In this paper, we propose a new routing scheme that reduce both these problems to a great extent without requring the present day IPv4 nodes to bring about changes in their protocols.

Keywords

MN - Mobile Node or mobile host, FA - Foreign Agent, HA - Home Agent, CH - Corresponding host, ROMIP - Route Optimization in Mobile IP, MIP - Mobile IP, Mobile router, COA- Care of address

I. **Introduction**

With the ever increasing use of mobile computing devices such as laptop computers, there has been a growing demand for host mobility. Host mobility can be thought of as the movement of the local interface of the host over different internet subnets. The mobile host(or mobile node) gets connected to these subnets using the data link layer protocol that the visited subnets use e.g. Ethernet, Wavelan etc. Since the IP layer is common to all the networks, supporting mobility at the IP level is most logical. But the fact that the internet has been organized in subnets, which help in making the internet routing protocols easy and keeping the routing tables small, has created difficulties in allowing a mobile node to move to a different geographic location and maintain their connectivity. Actually, the first field of an IP Address of a host is common to all the hosts connected to the same subnet. This scheme helps in heirarchical routing but prevents a host from maintaining an address while it moves away from the subnet. Also changing the address of the host when it moves means terminating an already existing connection and making a new one (since the transport protocols identify a connection using the source and destination addresses).

The Mobile IP protocol[1] was proposed to support host mobility while allowing any host to communicate with the mobile hosts using the already existing protocols if they(CH) don't desire to change their existing protocols. So, MIP doesn't require any changes to be made to existing hosts though it requires new infrastructure to be put to support location detection and handoffs. However MIP is inefficient in terms of the route length that typical packets will traverse from the source to destination. This gives rise to a typical problem known as triangle routing (explained briefly later) which is very inefficient for routing. Optimizations have been proposed for this, which include Route Opimized Mobile IP (ROMIP) as well as Reverse Routing. These schemes, though good,have severe limitations, as will be shown in the next section. The remainder of this paper is organized as follows. In section 2 we review the basic operation of Mobile IP, we then discuss the optimizations that have been proposed over the past few years for Mobile IP and the disadvantages associated with these. In section 3 we introduce our scheme for dealing with these limitations. In section 4, we present a simulation tool we developed to study the performance of our scheme. In section 5 we present the results of our simulation. Finally, in section 6 we discuss future develpments that can further increase the efficiency for mobility support in internet.

II. Mobile IP overview and existing proposals

The Internet was not designed with mobility in mind. This is evident in the mechanism that IP addresses contain the subnet addresses, which directly correspond to the physical location of the network. This has helped the present day internet protocols to be relatively easy by providing heirarchical routing. But this heirarchical routing prevents the hosts from being mobile if they want to use the same IP address everywhere. So, the hosts need to change their address as and when they move. But this means that the transport layer connection (transport layer connection depends on source and destination addresses) need to be terminated and reestablished as the mobile changes locations.This is really irritable for most applications.

Mobile IP , proposed to the IETF in the 1990s, addressed this problem. The problem here is that we need a new address to refer to the new location of the mobile but we also need to maintain a constant address for the mobile node so that other nodes which want to contact it don't have to bother about its mobility. This is also needed to maintain the already existing connections(without termination) when the mobile moves. Hence we have a problem with contradicting issues. Mobile IP solves this problem by converting this problem into a routing problem. This is done by associating the mobile with two addresses - a fixed IP address(home address) and a Care of address(COA). This scheme works as follows. A mobile node has an assigned home network and a router on the home network called the home agent(HA) which it is registered with. When the mobile node is in the home network, regular internet routing is used to send a packet to its destination. In one version of Mobile IP Any foreign network that a mobile wishes to travel to must contain a router called a "Foreign Agent (FA)".The mobile node which is in the foreign network requests a care of address from the foreign agent. Once this address is granted from a foreign agent, the MN contacts its HA through the FA, notifying it of its new location i.e its COA. This care of address is the IP address of the foreign agent. When packets are sent to the mobile node, they will thus be intercepted by the Home Agent and tunneled to the foreign agent. The foreign agent will then decapsulate the packet and deliver it to the mobile node which should be 1 hop away from the foreign agent. To send a packet to the correspondent host (CH), the MN does not need to go through the HA but can directly send the packets to the CH using normal IP routing(A special case when the packets to the CH from the MN need to go through the HA is when the foreign network the MN is visiting, uses ingress filtering).

The second version of Mobile IP is when the mobile directly requests an IP address from the foreign network using some mechanism such as DHCP[20]. In this way, it bypasses the need for a foreign agent. The disadvantage of both these schemes is that the routing is not optimal as seen by the long path that a packet will traverse going from sender to mobile node instead of the direct path while from the MN to the CH, the direct path is used. This creates a problem known as the triangular routing problem[2]. This is shown in figure 1.

Several schemes have been proposed to minimize this inefficiency in route length, some of

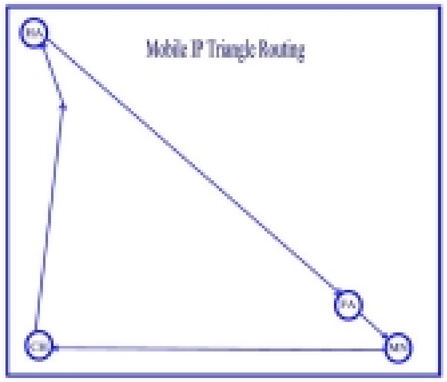

Fig. 1. Mobile IP Routing

which are described ahead.

A. ROMIP

One of the schemes is called Route Optimized Mobile IP (ROMIP)[19]. In this protocol, the sender must have a "cache binding", which allows it to route packets directly to the care of address of the mobile node. Initially, when the CH doesn't have a binding for the MN, it sends the packets destined for the mobile to its home network. These packets are received by the HA, which then sends the MN's COA to the CH. The CH stores this information in a binding for the MN in its binding cache. The problem with this scheme is that this would imply that every sender on the internet wishing to communicate with a mobile node would have to have software and hardware that is capable of caching these mobililty bindings. Today, IPV4 is not capable of supporting cache bindings, and to implement this would thus require major software changes to the sending nodes. So the scaleability of this approach is questionable.

B. Reverse Routing

A second method to improve the route efficiency is called Reverse Routing [19]. In this sheme, the MN directly sends its COA to the CH it is in contact with. When this message reaches the CH's network, it is intercepted by a mobile router(MA agents that can support cache bindings) there, which updates its routing tables and then discards this message(Here we assume that the CH is fixed). When the packets are sent to the MH after this routing table update, the packets are sent to the MN by tunnelling them directly to its COA. But the problem we envision with this approach is that for this to work, the mobility router needs to be the default router. If not, then the normal routers need to understand the packet format to be able to forward it to the mobility router. Hence, we need to bring a change in all the routers in the CH's network. So, the scaleability can pose a problem here also.

C. Location Registers

Another approach, which proposes to reduce the problem of triangle routing, deals with use of location registers(LR) along with Mobile IP [5]. This scheme doesn't use HA's or FA's. In this scheme, the information about the MN's location is kept at HLR's (home location registers). In order to obtain a new address in a foreign network, the MN uses some technique like DHCP (dynamic host configuration protocol) and informs it's HLR's about this new COA by registering with them. In order to send traffic to any MN, the CH queries the HLR's of the MN about its present location. After getting the COA for the MN, the CH sends the traffic directly to the MN's present location. The problem here is that this approach is designed for small enteprise environments. This is because the CH's have to be mobile aware i.e they should have the capability to query the HLR. Secondly, this scheme proposes that the HLR's need not be present in the home network of the MN. So, this means that the CH should know the addresses of the HLR's of the MN to query them. So again, this approach has to come to grips with the scaleability problem.

III. **Proposed Protocol**

In our scheme, we propose to modify the mobility agents of Mobile IP, i.e foreign agents and Home agents. Functionally these routers will operate in the same manner as normal routers, i.e have the capability of forwarding normal packets. In addition, these routers will have a wireless link in order to be able to communicate with mobile hosts. The routers can also function as foreign agents to mobiles if the mobile happens to be in the mobile router's cell. When the corresponding host wishes to send a packet to a mobile node, it sends it to the home network. The home agent intercepts this packet and tunnels it to the mobile node as with normal Mobile IP. *Our scheme requires the mobility agents to have the functionality of caching agents as well, i.e they should be able to cache the bindings of a mobile host. When this new functionality is added to the mobility agents, we call the new entities as mobile routers.* The proposed scheme works as follows - Once the Home Agent receives the packet, it will also send back a message to the CH notifiying it of the mobile nodes position. This message will be in the form of an ICMP packet, which is meant for nodes(routers or hosts) which support Mobile IP. This will be determined by the type of the packet. The CH will ignore these ICMP pakcets since its protocol does not support binding caches.There is a probability however, that one or more of the mobile routers will be on the route from the HA to the CH and also on the route from CH to HA . There is also a strong probability that some of the mobile routers on both the routes will be the same. In this case the mobile routers on the path from HA to CH will put a binding into its cache whose entry is the home address of the mobile node and its corresponding care of address. The next time that the CH sends a packet destined to the home network, if a mobile router that has a binding is on the packets path, it will intercept the packet and forward it directly to the mobile node. In this scheme even if there are multiple mobile routers that happen to have a binding entry for the mobile node, it will be the first mobile router that intercepts the packet that will forward it. The binding entries on these mobile routers will be valid for a binding lifetime period at which point it expires in order to decrease the probability of forwarding packets to a foreign network that the mobile has already left. This routing scheme is shown in figure 2. In the rare case that this does occur, we propose a smooth handoff sheme. In this scheme, once the mobile node moves from one foreign agent to the next, it sends a message to its previous foreign agent notifying it of the new FA's address. The old FA will keep this binding for a binding lifetime as well before expiring. By doing this, any packet sent to the old FA will be forwarded to the new FA. Figure 3 illustrates this handoff scheme. In this handoff scheme the probability of losing packets due to routing from an old binding is decreased significantly.

Also, when the HA receives a binding update from the mobile node notifying it that it has moved to a different FA, the HA will send a message back to the CH to notify mobile routers on the downstream path about this change . In the event that the packet destined for the home network did not pass through any mobile routers, the HA will just forward the packet to the foreign agent as in Mobile IP. Also, just before the binding for the MN in the mobile router is going to expire, the HA sends another binding update towards the CH. If the same mobile router receives this binding and is also still receiving packets from the CH destined for the MN, it proceeds as before. If it doesn't receive th packets for some time(to be decided based on delays etc), it sends a warning to the HA telling that there's no connection between the MN and the CH may have been terminated. The HA stops sending binding updates to this CH unless it receives indication that all the connections between the CH and the MN have not been terminated. One of these indications can be - the HA receiving packets for the MN from the same CH.

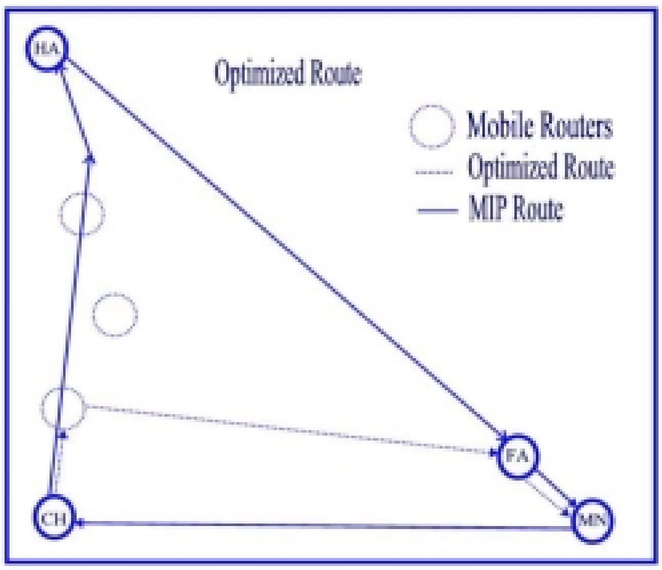

Fig. 2. Optimized Routing Example

We believe that our scheme will greatly decrease the average route length of a packet destined for a mobile router therefore decreasing the average packet delay. Furthermore, the density of mobile routers to normal routers in the internet does not need to be large for significant improvements.

Our scheme requires slight changes to be made to the structure of mobility agents(as specified in MIP). Since the mobility agents have not yet been deployed, this change can easily be made. Compared to other proposed schemes, our scheme scales well. It's better than ROMIP because it doesn't require any changes to be made to the existing nodes(present day hosts). It scales well as compared to reverse routing because the router(mobile router) which stores the cache binding for the MN doesn't need to be in the CH's subnet. We saw that the Location Register scheme requires changes to be made to the CH. This is because the CH needs to query the Location Registers and hence needs to know their IP addresses. Again, our scheme scales well since it does not require any changes to be made to the existing nodes.

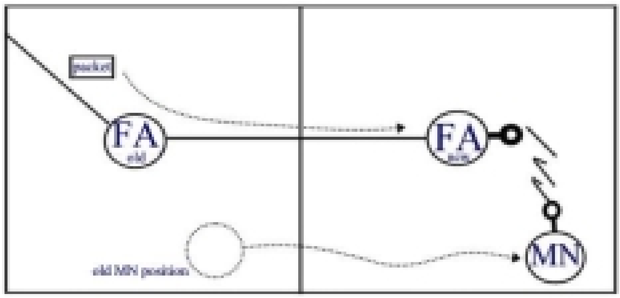

Fig. 3. Smooth Handoff Scheme

IV. **Simulation Setup**

In order to verify our results we designed a simulator to test the route optimization benefit of our scheme. The software was written in C. The setup of our simulation is as follows.

- Generate a random topology which is broken down into a cell based network consisting of 100 cells. Each cell contains one mobile router. The mobile router can serve as a foreign agent to any MN within the cell. In the first case we start with 100 routers in the topology, all of which are mobile routers.
- Routers are then connected to a random number of neighbors. All links are two way and have the same bandwidth. We placed the MN and HA in several different starting positions.
- Simulator then runs dijkstras algorithm to find the distance and route from the CH to the nearest router in the Home network. Dijkstras is then run again in the reverse direction from the HA to the CH. The first mobile router closest to the CH that was on both the forward and reverse paths is used as the mobile router that will tunnel packets directly to the FA of the MN.
- Dijkstras algorithm is then run again from this mobile router to the Foreign Agent and the route and distance are saved.
- We have a single fixed CH. This generates data for the MN as per a Poisson Process of rate 25 packets/s.
- The movement of the mobile occurs at the arrivals of a poisson process of rate .1/s. We simulated the results for poisson processes of different rates for the movement of the mobile, however, these results were similar since we do not take handoff losses into account. Secondly, this is because we don't take into account the overhead due to mobile movement i.e registration requests, registration replies etc.
- After simulating for the above set up we add normal routers into the network and proceed as above.

- We simulate up to a specified mobile router density (total mobile routers in topology/total routers in topology)

A sketch of the network topology is shown in figure 4.

The savings in route length is taken to be:

$$Route\,Savings = \frac{unopimized\,length - optimized\,length}{unoptimized\,length} \tag{1}$$

This process is continued until we reach a mobile router density of 10/cell. The expected percentage increase in route savings should decrease as we increase the routers since as the density of mobile routers in the network decreases, the probability that a path will intercept a mobile router also decreases.

A. Analysis of the Simulation Model

We have a network topology as in figure 4, which contains 100 cells, each cell contains one mobile router and several normal routers which are randomly distributed in the cell. A typical cell topology is shown in figure 5.

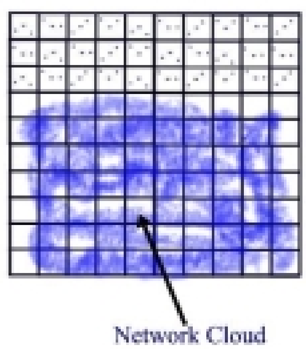

Fig. 4. Network Topology for Calculations, showing several routers in 100 cell topology

This network is broken up into 100 cells, in which each cell contains one mobile router which can function as a foreign agent to any mobile in the cell. The network grid is 100x100, so that there are 100 possible positions in each cell. The coordinate system is numbered from 1 to 100 in the x and y directions with the 1,1 point at the top left corner of the network. As shown in the figure, the HA is placed in the top left corner (x,y = 5,5) of the network, the sending node is placed in the bottom left corner (x,y = 1,100). The mobile node is at position (x,y). Actually, we assume the FA is at (x,y). Since the MN is just one hop away from the FA, we assume the distance between the present FA and the MN to be small as compared to the total route length. It is logical to assume that the best route optimizations will occur when the mobile

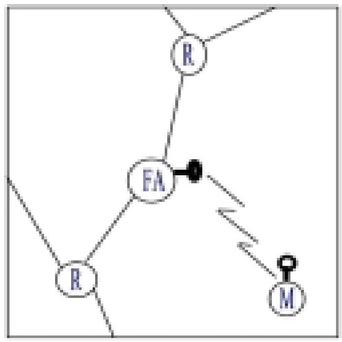

Fig. 5. Typical Cell Topology

node is closest to the CH. No optimization will occur when the MN is in the home network, in which case normal Mobile IP operates. We assume that the nodes in the network are randomly connected to a random number of neighbors. We also use Dijkstra's algorithm to find the shortest path between any two nodes. To simplify the calculations, assume that the routing algorithm randomly chooses 1 router in each cell as its optimal router. Given that there are n total routers and 100 mobile routers in the network, and that the normal routers are uniformly distributed, we have the following:

- Distance between CH and HA is approx 100
- Distance between HA and MN = $\sqrt{(5-x)^2 + (5-y)^2}$
- Unoptimized Distance = Distance between the CH and the HA + Distance between the HA and the MN
- Expected number of cells before a mobile router is intercepted=$n/100$ lets say that the coordinates of the intercepted mobile router are x1,y1
- Distance between the CH and the intercepted mobile router is approx. $\frac{n}{100} * 10$
- Distance between the intercepted mobile router and the MN = $\sqrt{(x1-x)^2 + (y1-y)^2}$
- Optimized Distance = Distance between the CH and the intercepted mobile router + Distance between the intercepted mobile router and the MN
- $Expected\, percent\; saving\; in\; route\; length\; = \frac{Unoptimized\, distance - Optimized\, distance}{Unoptimized\, distance}$
  Unoptimized distance refers to the route length from the CH to the MN in case of MIP without our scheme. Optimized distance refers to the route length from the CH to the MN in case of MIP with our scheme.
  From this position the mobile has 1/4 probability of moving into each of the neighboring locations. We find the savings in route length for each of these neighboring locations and

multiply each by 1/4. We continue the above procedure for each of the locations in a recursive manner. These calculations were conducted for various positions of the mobile node and the Home Agent.

Figure 6 shows the plot of percent savings in route length (theoretical) versus mobile router density for this particular analysis.

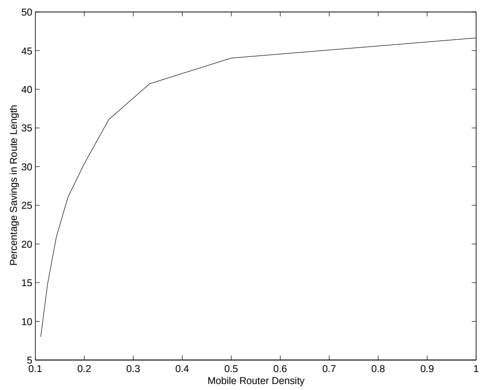

Fig. 6. Percent Savings in Route Length(theoretical)

From the figure we see that in this situation, we see that the maximum savings in route length is approximately 45%. Also, figure 7 shows a plot of economic benefit versus router density, where economic benefit is defined as:

$$Economic\,benefit = \frac{Route\,optimization}{Mobile\,router\;Density * \frac{cost}{density}} \tag{2}$$

where we take unit cost per router.We define this parameter because we need to know what value of mobile router density would give us the maximum benefit vis-vis the cost of putting mobile routers. figure 7 shows that we only need 18 percent router density to maximize our economic benefit as defined above.

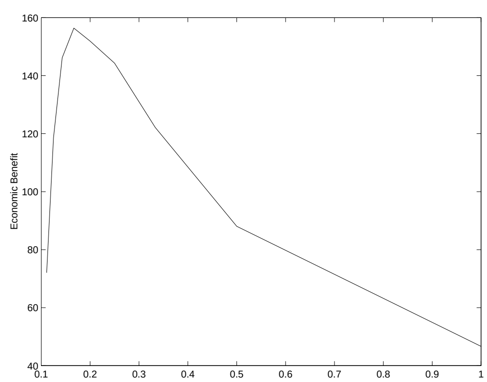

Fig. 7. Economic Benefit versus Mobile Router Density(theoretical)

To make the analysis more accurate, we need to consider packet loss due to handoffs and the additional overhead encountered for our scheme like that for binding updates etc.

B. Packet Delay

In order to measure average packet delay we do the following. For each position of the mobile node, measure how many packets have arrived. Assuming that packet delay is directly proportional to route length and all links have the same bandwidth, we define the relative packet delay (RPD),i.e the average delay per packet for our scheme divided by the average packet delay of the MIP scheme.

$$RPD = \frac{1}{Total\,Packets} * \sum_{n=1}^{M} packets\,arrived\,in\,interval\,n * \frac{Optimized\,Distance}{Unoptimized\,Distance} \tag{3}$$

V. Results

We run the whole simulation for 4 different initial starting postions of the mobile node. This is then again run for the Home agent in different positions. Lastly we vary the average staying time of the mobile in a particular cell. Table 1 and 2 summarize our set up for the simulations.

TABLE I

Mobile Node Start Position(x,y) for Different Trials

	Trial x1	Trial x2	Trial x3	Trial x4
MH	100,100	10,100	10,50	50,10

TABLE II

Home Agent Position(x,y) for Different Trials

	Trial 1x	Trial 2x	Trial 3x	Trial 4
HA	5,5	5,55	55,55	95,95

A. Route Length

Figure 8 shows a plot of percent savings in route length versus mobile router density. This is averaged for 4 different HA positions as shown in table II, as well as different random paths taken by the mobile router as discussed in the section IV.

As can be seen, the curve increases approximately linearly to a saturation value at a mobile router density of approximately 30%. In the theoretical results we found that the route efficiency kept increasing until a mobile router density of 1. We did not however take into account the fact that as the mobile router density decreases(i.e the number of mobile routers is fixed while the number of normal router is increased), the probability of a shorter path found by Dijkstra's algorithm will increase due to the increase in possible routes. This is observed in figure 8. We see a trade off between route improvement due to an increase in mobile router density (which increases the probability of intercepting a mobile router) but lowers the number of possible paths i.e a larger number of paths could have potentially caused a shorter path length. From the figure 8 we see that the peak route efficiency occurs for a mobile router density of 30%.

In figure 9 we plot the economic benefit versus mobile router density where economic benefit was defined earlier.

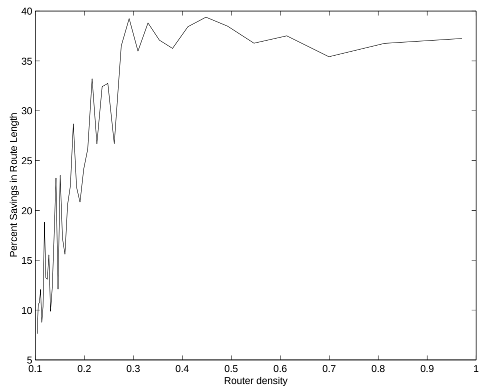

Fig. 8. Simulation Results showing pecent savings vs Mobile Router Density

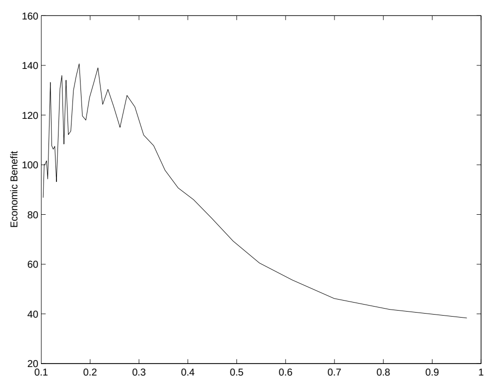

Fig. 9. Simulation Results showing Economic Benefit vs Mobile Router Density

B. Packet Delay

In figure 10 we find relative packet delay(RPD) from CH to MN by averaging 4 trials taken with the HA in different positions. The positions taken for the HA is tabulated in table 2. We see from this plot that at a router density of 30% or greater, we get almost half as much delay as you would without our scheme.

VI. **Further Work**

We also propose a protocol for authentication between the Home Agent and the mobile router. A scenario in which a lack of authentication may cause problems is as follows. Assume that an imposter node desires to intercept packets destined to the correct mobile node. So in the packet it places the address of the correct HA as the HA and its IP address as the binding. When the

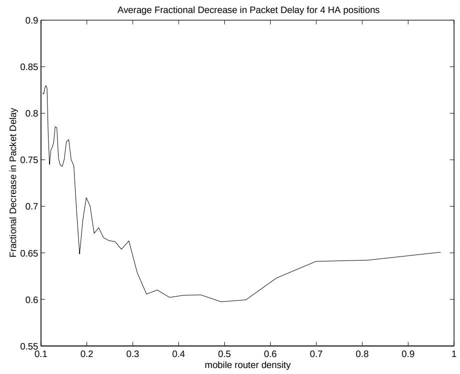

Fig. 10. Relative Packet delay vs mobile router density

mobile router intercepts this, thinking that it is a HA, it updates its binding cache. The next time a sender sends a packet destined for the HA and happens to intercept the mobile router with the binding update. This mobile router will then tunnel the packet to the imposter node thinking that it is the correct MN. To solve this problem, we propose to have a security binding between the HA and the mobile node. That is, when a mobile router receives a binding update from some node,it waits until the sending node sends a packet destined to the mobile node in its binding. At that moment, the mobile tunnels the packet to the home network with a security code. A bit in the option field is also set to notify other mobile routers that the packet is a security association packet and they should not take any action even if they have a binding for this particular MN. If the HA was actually responsible for the message it will reply with the security code. The mobile router at that point knows that the binding is authenticated and continues with normal operation. In order to decrease overhead, the home agent updates the mobile router directly whenever the MN attains a new COA or just before the binding with the mobile router expires. If the network topology changes however and a new mobile router becomes the one that is closest to the CH, this will require the authentication process to be started again since that binding will not have been authenticated yet.

The handoff schemes in various networks also need to be analyzed. Along with this, the overhead due to the mobile's movement vis-vis the binding updates etc needs to be taken into account to take its effect on the performance.

VII. **Conclusion**

In this paper we have proposed a scheme to improve route efficiency in Mobile IP. We first analyzed the existing schemes like ROMIP, Reverse Routing and Location registers and showed that these schemes do not scale well. In our proposal, we modify the mobility agents slightly by making them capable of caching the bindings for mobile nodes (we call these new entities - mobile routers) and saw that this yields considerable benefits in terms of routing efficiency. Above all, our scheme scales well because it works by making changes to the mobility agents which are yet to be deployed and this is really feasible. So, we don't need to make any changes to the existing hosts which is basically our strongest point against the already existing schemes for route optimization in MIP. Our Simulation results proved that we were able to optimize the typical packet route length and packet delay without going for very high mobile router densities.

Also, the HA's use is reduced because the packets are now routed through an intermediate mobile router. This implies that the probability of failure of the HA is reduced as it handles lesser load now.

Acknowledgments

The authors would like to thanks Dr.Jean Walrand for his excellent suggestions and support for the project.

References

[1] Perkins, C. *IP Mobility support for IPv4, revised draft-ietf-mobileip-rfc20020bis-03* , Sept 20,2000
[2] Perkins, C. *Mobile networking through Mobile IP*, Sun Microsystems, 1998
[3] Perkins, C. and Johnson,David *Mobility support in IPv6*, IEEE 1996
[4] Garg, K. and Joshi S., *Making Mobile IP More Efficient*, IEEE 9/98.
[5] Chang et. al., *Enhancing Survivability of Mobile Internet Access Using Mobile IP with Location Registers*, IEEE 6/99.
[6] Cvetkovic, M. et. al. *Performance Analysis of Mobile IP Handoffs*, IEEE 2/99.
[7] Mahadevan,Indu and Sivalingam, Krishna. *Quality of Service Architecture for Wireless Networks: Intserv and Diffserv Models*, IEEE 8/99.
[8] Campbell, Andrew and Gomez, Javier. *An Overview of Cellular IP*, IEEE 3/99.
[9] Pink, Stephen and Lin Tan,Cheng.. *A Fast Handoff Scheme for Wireless Netorks*, IEEE 8/99.
[10] Fukushima, Hideaki and Wada Hiromi. *Mobile Computing on Wireless Telecommunication Networks*, IEEE 4/96.
[11] Guo, Lei and Hac, Anna. *Mobile Host Protocols for the Internet*, IEEE 4/99.
[12] De Marco et. al. *Performance Evaluation of Mobile IP Protocols in a Wireless Environment*, IEEE 9/98.
[13] Perkins, Charles. *Mobile IP, Ad-Hoc Networking, and Nomadicity*, IEEE 7/96.
[14] Pei, Guangyu et. al. *A Wireless Hierarchial Routing Protocol with Group Mobility*, IEEE 3/99.
[15] Corson, Scott et. al. *Internet-Based Mobile Ad Hoc Networking*, IEEE 7/96.
[16] Pahlavan, Kaveh et. al. *Handoff in Hybrid Mobile Data Networks*, IEEE 4/2000.
[17] Corson, Scott et. al. *Internet-Based Mobile Ad Hoc Networking*, IEEE 7/96.
[18] Johnson, David B. *Ubiquitious Mobile Host Internetworking*, IEEE 10/93.
[19] Peifang Zhou et. al. *Reverse routing: An alternative to MIP nad ROMIP Protocols*, IEEE 2/99.
[20] Perkins Charles and Jagannadh, Tangirala. *DHCP for Mobile Networking with TCP/IP*, IEEE 4/95.