Location update and routing scheme for a mobile computing environment

By Anna Hać and Yujing Huang

We present a new hierarchical location update and routing scheme for a wide area mobile computing environment with scalability of network hierarchy. Our scheme provides nearly optimal routing for most communication bypassing the mobile host’s home network and home agent. We use simulation to compare our scheme with other schemes in both non-hierarchical and hierarchical network architectures. Copyright © 2000 John Wiley & Sons, Ltd.

Introduction

Mobile host protocols support host mobility in conventional internetworks. The major difference between these protocols is the way in which the location information is propagated into the network to trace a mobile host and how packets are routed to destination mobile hosts. The main problems for mobile computing are how to distribute location information efficiently into the network and how to utilize the location information to efficiently route packets to mobile hosts. In this paper, we propose a new location update and routing architecture. A modified infrastructure and flow of messages for our scheme is examined. New functionality needed for the new architecture to complete location update and to route packet to its destination mobile host is added to basic operations. Simulation is performed to show the efficiency of our scheme over existing location update schemes, triangle routing and static update.

—Static Network Infrastructure and Routing Scheme—

In conventional network architecture such as TCP/IP and the OSI seven-layer model, the network address of a host denotes its identification as well as its location. The IP address scheme, as an example of current address schemes, assumes that a host’s IP address uniquely identifies a host’s point of attachment to the Internet. An IP address consists of two parts: a network number that identifies the network to which the host is attached, and a host number that identifies a given host within that network. IP packets are routed based on the network number. Therefore, a host must be located in the network indicated by its IP address in order to receive packets, otherwise packets destined for the host are undeliverable. Routing a packet to its final destination can be accomplished by using both direct and indirect routing.

When the packet source and destination are on the same physical network, i.e. are not separated by a router, the packet is routed directly in the local
network without the use of a router. If the packet is destined for another network, it must be routed through a router, a term referred to as indirect routing. The decision whether the packet has to be directly or indirectly routed is made based on the network address assigned to the network host. A network address consists of two parts: a network number that identifies the network of host attachment, and a host number that identifies a given host within the network. A packet source compares a packet's destination network number to the source network number. If the network number portion of the destination network address matches its own address, the packet can be routed directly in the local network, without the use of a router. Once the decision is made, the source looks up its ARP table to map the network address to a physical MAC address. If the destination's address is not in the ARP cache, the ARP request process is invoked. If the network number portion of the destination network address does not match the source's address, an indirect routing is used. An indirectly routed packet gets to its destination network, and is directly routed to its final destination.

—Overview of Related Work—

Since host migration results in a change in its network address, network addresses returned by name servers cannot identify migrating hosts. Therefore, the packets bound for the host changing its point of network attachment, without losing its ability to communicate, must be delivered with an extra redirection support. A number of mobile host routing architectures supporting host mobility within a conventional environment have been proposed. The architectures can be different, and they all provide migration transparency services to support host mobility. The basic ideas for the architectures are very similar. A permanent (home) address is assigned to the mobile host, which is a logical identifier of the mobile host. A forwarding (current) care-of address associated with its current physical location is obtained by the mobile host dynamically when it moves around and registers with a new mobility agent. Association between the mobile host's home address and its care-of address is known as its 'mobility binding', which can be used to resolve the mobile host's current physical location.

The base mobile IP protocol allows any mobile host to move around, changing its point of network attachment to the Internet, while being addressed by the same home address. Source hosts sending packets to a mobile host address them to the mobile host's home address in the same way as to any stationary destinations.

While a mobile host is connected to the network away from its home network, all packets addressed to the mobile host are routed using the routing mechanisms to the mobile host's home network, where they are intercepted by the mobile host's home agent, which then tunnels each packet to the mobile host's current care-of address. The outgoing packets from the mobile host use its current foreign agent as default router but require no other special redirection routing.

The base mobile IP protocol presented in reference 8 does not provide route optimization. Without route optimization, all packets destined for the mobile host must be routed through that mobile host's home agent, which then tunnels each packet to the mobile host's current location. This results in a 'triangle routing' (Figure 1) for every packet addressed to the mobile host even when the source is in the same network as the mobile host. In Figure 1, suppose mobile host (MH) changes its point of network attachment, and registers with a foreign agent (FA). A source host (SH) somewhere in the network sends packets to MH. SH addresses packets to MH's home address. Packets are routed to MH's home network and are intercepted by MH's home agent (HA). HA tunnels packets to FA currently serving MH. FA locally delivers packets to MH. The outgoing packets from MH use FA as its default router. Therefore, the packets going between SH and MH form triangle routes.

Intermediate routers are introduced in references 2, 3 and 13 to achieve an optimal or suboptimal route bypassing the home agent. However, location information is arbitrarily given to intermediate routers along the way to the mobile host. Thus, efficiency achieved by the introduction of intermediate routers greatly depends on the location of intermediate routers in the network. Another drawback is that the location cache size is proportional to the number of mobile hosts in the network, which can be very large with the growing population of mobile users. An important feature
of the protocols in references 2, 3 and 13 is the introduction of a special tunnel packet to avoid routing loops. A special tunnel packet is a tunnel packet whose encapsulation destination address is the same as the original destination address, which is always routed to the mobile host’s home agent without redirection.

Four mobile host protocols are compared in reference 7. Among them the Columbia MHP (Mobile Host Protocol)\textsuperscript{16} has fewer compatibility problems with existing networks. Columbia MHP uses definition of a virtual mobile subnet created by placing a small number of cooperating mobile subnet routers (MSRs) wherever mobile hosts can be connected to the network. The MSRs have a similar functionality to the foreign agents introduced in other schemes, however, the mobile hosts do not have their respective home agents. When a mobile host migrates, it detects and registers with an MSR at its new location. The mobile host informs its previous MSR, which still caches its location information. When the MSR receives a packet addressed to a mobile host, it looks for the mobile host’s current location in the cache table. The appropriate entry can usually be found in the cache. However, if no cache entry exists for the mobile host, the MSR sends a broadcast message to the other MSRs asking for the mobile host’s current location. The MSR caches the returned answer for future use and forwards the packet using encapsulation. However, this procedure is only appropriate for a small number of MSRs, thus the mobile host’s mobility is limited.

In the local area network and small campus environments, the Columbia MHP offers a better solution. It provides close to optimum routing to and from mobile hosts in the local area in a manner that is robust and makes minimal demands on the existing network.\textsuperscript{7} However, in wide area networks, the Columbia MHP offers a workable but unsatisfactory solution.

Extensions made to the Columbia MHP provide better scaling properties to wide area networks and large campus environments.\textsuperscript{4} A special form of routing protocol, called the Mobility Support Border Router (MSBR), is introduced. Special mobility functions are introduced into the OSPF (Open Shortest Path First) Area Border Routers. MSBR is essentially the same as an OSPF Area Border Router and serves as the second level of the mobile routing and tracking hierarchy. Path-reversal techniques are used to retrieve the OSPF area border router address at the other end of the active communication path, thereby minimizing the expensive wide area traffic due to mobile-related location information propagation. Update and propagation of the location information are accomplished in a distributed and hierarchical manner.
Location update schemes proposed in references 2–4 and 13 do not consider routing efficiency. Location notification is sent when one mobility entity determines that another entity may have an incorrect location binding for a mobile host. However, the memory size to cache the location information of mobile hosts is proportional to the number of mobile hosts in the network, and the network is flooded with notifications.

In reference 5 two concepts, ‘local region’ and ‘patron hosts’, are developed to utilize the locality properties of a mobile host’s pattern of movements and access history. For each mobile host, a local region is a set of designated networks within which the mobile host often moves, and the patron hosts are the hosts from which the majority of traffic for the mobile host originates. Introduction of these two concepts provides efficient location update and routing. Location update is limited to the local region and to those hosts which are the most likely to communicate with the mobile host.

The problem of the scheme proposed in reference 5 is difficulty of local region maintenance for a mobile host. Each time the mobile host changes its moving regions, the new local region has to be set up with the help of network administrators. Also, since the patron service is invoked only when the mobile host crosses in and out its local region, the scheme is only suitable for the Boring Professor Mobility Model, but not for the Traveling Salesman Mobility Model and the Pop-up Mobility Model. In the Boring Professor Mobility Model, mobile hosts tend to have a relatively unchanging mobility behavior. Mobile users choose some locations that they visit more often than other. In the Traveling Salesman Mobility Model, the users have an epicenter in their movement patterns. The zone of movement is specified by the number of hops from the epicenter. The Pop-up Mobility Model corresponds to the case when the mobile user has a tendency to pop-up at different points in the network. The new location has no relation to the previous movements of the mobile host. This mobility model can be considered as an extension of the Traveling Salesman Model.

Another location update scheme opposite to triangle routing is the static update scheme. This is an improved strategy proposed for high call-to-mobility ratios, where the mobile host actively informs a set of remote sources, which are most likely to communicate with the mobile host, of its current address. The performance of the static update scheme at high call-to-mobility ratios can serve as a benchmark, and performance of various location management schemes can be compared against the static update scheme.

—Proposed Scheme—

The concept of the patron host is introduced in reference 5 to take advantage of mobile host traffic pattern locality. In our proposed scheme, we further define the concept of patron area. The patron area is the OSPF area where one or more patron hosts reside. We place redirection agents, similar to the intermediate routers in references 2, 3 and 13, at the OSPF area border routers. We update location information in the redirection agents of the patron areas whenever the mobile host moves in non-hierarchical architecture, or the mobile host crosses the OSPF area boundaries in hierarchical architecture. Thus, source hosts within the patron areas, whether they are patron hosts of the mobile host or not, all benefit from location update.

Our proposed location update and routing scheme differs from the static update scheme and the scheme presented in reference 5. Our scheme uses the definition of the concept patron area and the update of redirection agents in those patron areas instead of an individual patron host. We call the OSPF routing area, where the mobile host’s home network is located, the mobile host home area, which is unrelated to the mobility models. The difference between our scheme and the schemes proposed in references 2, 3 and 13 is that instead of using the arbitrary update of intermediate routers along the way to the mobile host, we limit the location update to a small set of patron areas from where the communication requests to the mobile host most likely originate. The special tunnel packet introduced in reference 2 is used in our scheme. We compute the redirection agent address in another OSPF area from a node’s network address in that area by using a path-reversal technique described in reference 4.

Our new location update and propagation scheme has the advantages of limiting location updates to a set of designated patron areas, and provides almost optimal routing for most communications while increasing network and host scalability. Comparing with the scheme in
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reference 5, our scheme has the advantage of releasing the patron host from storing the calling list. Also, our scheme has no restriction on the model’s mobility. Since the number of patron areas is smaller than the number of patron hosts, we reduce the storage space required to store the patron list in each mobile host. Though more routers are involved, our scheme provides more suitable architecture for mobile networks in the future, such as temporarily setting up local area networks. Hierarchically distributed storage of location information in our scheme is also the preferred design in today’s networks.

We simulated and compared our scheme with the other location update schemes, triangle routing and static update. From simulation results, we can conclude that triangle routing is the most efficient for low call-to-mobility ratios. However, with the increase in the call-to-mobility ratio, triangle routing becomes less efficient than other schemes. The average cost needed to route a packet to the mobile host is lower for our scheme than for the static update scheme. Our location update scheme is more efficient than static update under both non-hierarchical and hierarchical architectures, and over all tested ranges of call-to-mobility ratios.

In the next section, we describe our architecture in detail. A modified infrastructure and flow of messages for our new scheme is examined. New functionality needed for the architecture to complete the location update and to route a packet to its destination mobile host is added to basic operations.

### New Location Update and Routing Scheme

Our proposed new location update and routing scheme is examined in this section. A modified infrastructure and flow of messages for our scheme are presented. By introducing mobile functionality into the OSPF Area Border Routers, we can bypass the mobile hosts’ home network and home agents whenever it is possible which results in optimal or nearly optimal routing for most communications. The functionality needed in our location update and routing scheme is presented.

All the mobility agents follow the rules, defined in later sections, to forward packets addressed to mobile hosts. Several informal messages are exchanged between the mobile host and related mobility agents when the mobile host moves to a new region, and registers with a new current foreign agent. Possible mobile host movements and subsequent message exchanges are also examined later.

In our scheme, we place a redirection agent in the OSPF area border router. Each OSPF area has at least one redirection agent. We use the term home area to refer to the OSPF area where the mobile host’s home agent resides. Besides the concept of patron hosts, we further define the concept of patron areas to simplify the presentation. A patron area is the OSPF area where one or more patron hosts reside. The number of patron areas cannot be greater than the number of patron hosts. The discussion of the scheme focuses on hierarchical architecture. A simulation model and the results for both non-hierarchical and hierarchical architecture will be presented in a later section.

### New Scheme Description

In this section, we describe design motivation and locality traffic pattern, and introduce our new scheme. Simulation results are described in later along with analysis and comparison of triangle routing, static update and our scheme.

**Design motivation** — In a mobile computing environment, a routing decision is made based on location information of the mobile host. If a source host knows the current foreign agent serving the mobile host, the packet is tunneled directly to the foreign agent bypassing the mobile host’s home agent, which results in direct routing. The least efficient case is triangle routing, in which packets addressed to the mobile host must be sent to the mobile host’s home agent before being tunneled to the mobile host’s current location. Triangle
routing can cause a significant delay in packet delivery, and too many redundant searches while the call-to-mobility radio is high. When the mobile host is visiting a subnet, and the packets come from sources in the same subnet, the unnecessary burden on the networks and routers along the path caused by triangle routing becomes obvious.

Packet routing efficiency critically depends on the propagation of the mobile host’s location information into the entire network. More location information updates can result in optimal and nearly optimal routing of a packet to the destination mobile host, while insufficient location information updates lead to non-optimal routing. However, redundant location information propagation can waste network resources. Therefore, when designing a location update and routing scheme, it is important to trade off update and routing costs. We consider update and routing costs as a whole.

The goals in our scheme design are to provide optimal and nearly optimal routing for most communication to the mobile host, and fewer location updates by limiting location updates to a designated set of patron areas. These goals are achieved by introducing mobility functions into the OSPF routing area border routers to use them as redirection agents for those areas. Location updates are sent only to redirection agents in the mobile host’s patron areas. Communications from these patron areas to the mobile host benefit from location update and result in nearly optimal routing.

Our architecture is also inspired by progress in the cellular telephone PCS network. Trends of PCS location management are to trace and locate a mobile user in a hierarchical manner. Location information of the mobile user is provided by a profile and stored in the network base stations hierarchically. The environment of mobile computing is similar to a PCS network. To reduce delay in delivering packets to mobile hosts, and consumed network resource, we propose a hierarchical update scheme. Location information of a mobile host is propagated into the network and stored in a four-level hierarchical architecture (Figure 2). For some packet routing, the local and home level are same, and hierarchy reduces to three levels. A more detailed description of each level functionality is given later.

![Figure 2. Mobile Host's Location Information Hierarchy](image-url)
mobile host communicates, the concept of patron hosts was used in reference 5 to refer to the set of hosts that communicate with the mobile host most often. A potential set of sources that can communicate with the mobile host is large, but the set of patron hosts is relatively small.

The locality of the traffic pattern of a mobile host exists not only on the host basis, but also on the network basis. That is, the set of networks that communicates most often with the mobile host is relatively stationary and small. Therefore, in our scheme, we introduce the concept of the patron area, which is the OSPF area where one or more patron hosts reside, and from where connection requests to the mobile host are generated most often, to further reduce update cost and enhance routing efficiency. Each patron area has at least one patron host of the mobile host, that is, the number of patron areas cannot be greater than the number of patron hosts. Thus, the number of messages exchanged per location update is reduced. Location information update is only propagated to the small selected set of patron areas, and avoids unnecessary use of wide area communication links.

Patron areas reflect the traffic pattern of a mobile host. The set of patron areas is relatively stationary, and can be configured by a mobile user.

**Scheme description**— A mobile host must initially register with a mobility agent, which is its home agent in a mobile host’s home network. A mobile host can communicate with the rest of the network using either the wired network or the wireless link.

Foreign agents must send out Agent Advertisements periodically to indicate their existence to the mobile hosts visiting their control areas. Upon receiving the Agent Advertisement, a mobile host can go under the control of a new mobility agent. A mobile host sends a registration packet, which includes the addresses of its home agent, the previous foreign agent (if applicable), and the redirection agent in both the mobile host’s home area and its own OSPF area. The registration procedure goes through normally, the mobile host receives a registration acknowledgment from the foreign agent confirming registration and permission to send or receive data packets. If there is a fault in the registration procedure, the mobile host will re-try the procedure until it times out.

In our scheme, location information is propagated to related mobility agents hierarchically. When a mobile host moves to a new region, it first identifies a new current foreign agent and registers with it. The foreign agent then updates the mobile host’s home agent, the redirection agents in both the mobile host’s home area and its own OSPF area, and other related mobility agents. The redirection agent in the current area updates the redirection agent in the mobile host’s last visited area if the mobile host crosses the area boundary.

We explain why we place our redirection agent at the OSPF area border router. OSPF is a link state routing protocol and is designed to be run internally to a single Autonomous System. Each OSPF router maintains an identical database describing the Autonomous System’s topology. From this database, a routing table is calculated by constructing the shortest path tree. OSPF allows collections of contiguous networks and hosts to be grouped together into an area. Each area runs a separate copy of the basic link state routing algorithm, which means that each area has its own topological database and corresponding graph. Hiding a complete topological database, the redirection agent (the OSPF area border router) is able to learn about other area redirection agents’ addresses. This is done by computing the packet reverse path until it reaches a redirection agent in another area. This also explains why it is the responsibility of the redirection agent to forward the registration packet to the mobile host’s last visited area. The router not participating in the OSPF Backbone routing algorithm simply does not know how to reverse the path to compute the redirection agent’s address in the mobile host’s last visited area from the address of the mobile host’s previous foreign agent in that area.

In our approach, the efficiency of location update and routing schemes is measured by the total cost to route a packet to its destination mobile host. This cost includes two parts: the update cost and routing cost. The update cost consists of both the registration cost and the patron update cost. The routing cost consists of the search cost and the hop counts between the nodes, in which the mobile host’s location binding is found, and the destination mobile host.

Our approach is to reduce the total cost to route a packet to the destination mobile host. Because the number of patron areas cannot be
greater than the number of patron hosts, we can reduce the number of messages needed to update the location information for the mobile host. The update is sent to redirection agents at the border of each patron area instead of the individual patron host within those areas. It costs less to update the redirection agent at the area border than to update the individual patron host within that area. Therefore, the cost of location update associated with the mobile host’s movement and network architecture is reduced. Further, because we update the mobility agents at the border of the OSPF areas, all the source hosts in those areas, either patron hosts of the mobile host or not, benefit from location updates. As a result, traffic from source hosts within those patron areas, either the hosts communicating with the mobile host on a frequent basis or infrequently, can always achieve nearly optimal routing even if the hosts are located far away from the mobile host. Figure 3 shows packet routing using both triangle routing and our routing scheme. In triangle routing, the packet sent by stationary host SH to mobile host MH traversing path SH-RA1-RA2-HA-RA2-RA3-FA-MH. In our scheme, the same packet traverses path SH-RA1-RA3-FA-MH. In triangle routing the packet traverses twice the diameter of the OSPF Backbone and twice the diameter of the area. In our routing scheme the packet traverses the diameter of the OSPF Backbone and the diameter of the area only once.

—Infrastructure—

In a static network, the network address returned by name servers denotes the physical location of the hosts. A migrating host changes its point of network attachment. Address returned by name servers cannot reflect the changes. Therefore, for a host to change its point of network attachment without losing its connectivity to the network a set of new entities with extra mobility functions must be defined. Packets bound for the mobile host are delivered with redirection support of these new functional entities.

A static network infrastructure is clearly inadequate to support host mobility. Our location
update and routing scheme consists of a set of functional entities: mobile hosts, mobility agents, and redirection agents. Mobility agents include home agents and foreign agents whose functions are similar to the home location registers and visitor location registers in a cellular telephone network. Redirection agents are the same as the OSPF area border routers in our scheme. This section defines each entity and describes its basic operations. Although they are defined separately, the functionality of several of these entities can be combined into a single node. Different functionality is shown by using a different network interface. Table 1 shows the mobility entities, their mobility bindings, and their main mobility functionality:

<table>
<thead>
<tr>
<th>Mobility entities</th>
<th>Mobility bindings</th>
<th>Main mobility functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile host</td>
<td>Patron list*</td>
<td>Answer ARP request from local network when at home, regular routing is used away from home, register with a foreign agent in the visiting area and obtain a care-of address</td>
</tr>
<tr>
<td>Foreign agent</td>
<td>Visitor list</td>
<td>Send out Agent Advertisement periodically</td>
</tr>
<tr>
<td></td>
<td>Forwarding list</td>
<td>Answer the registration packet from the mobile host, create/update visitor list, provide the mobile host with care-of address, update related mobility agents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Locally deliver packets to mobile hosts in visitor list</td>
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<tr>
<td></td>
<td></td>
<td>Answer patron service packet from mobile host, forward patron service update to redirection agents in mobile host’s patron areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Answer registration from other mobility agent, create/update forwarding list for mobile host that previously visited the area</td>
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<td></td>
<td></td>
<td>Forward packets to mobile host in forwarding list</td>
</tr>
<tr>
<td>Home agent</td>
<td>Home list</td>
<td>Answer initial registration from mobile host, create home list, forward registration to home area, redirection agent</td>
</tr>
<tr>
<td></td>
<td>Forwarding list</td>
<td>Maintain the most up-to-date location information for mobile host in home list</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Act also as foreign agent, maintain forwarding list for mobile hosts</td>
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<tr>
<td></td>
<td></td>
<td>Forward packet to mobile host using forwarding list</td>
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<tr>
<td></td>
<td></td>
<td>Delete forwarding list entry for mobile host back at home, inform home area redirection agent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provide Proxy ARP for mobile host in home list and away from home</td>
</tr>
<tr>
<td>Redirection agent</td>
<td>Redirection list</td>
<td>Maintain redirection list for mobile host away from home</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forward packet to mobile host using redirection list</td>
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<tr>
<td></td>
<td></td>
<td>Answer patron service update, update redirection list for mobile host</td>
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<tr>
<td></td>
<td></td>
<td>Notify mobile host of crossing area boundary movement, update mobile host’s last visited area</td>
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<tr>
<td></td>
<td></td>
<td>redirection agent</td>
</tr>
</tbody>
</table>

* Obtained by sending an initial registration packet to redirection agent in the home area.

Table 1. Mobility entities, their mobility bindings, and their main mobility functionality
their mobility bindings and main mobility functionality.

A mobile host can use either the wired network or the wireless link to communicate with the rest of the network. Because of the asymmetric wireless communication medium, transmission of messages from a mobile host consumes more power than receipt of messages. We assume an architecture where much of the responsibility for the location information propagation lies in the mobility agents, but not in the mobile host. When registering with a current foreign agent, the mobile host informs the foreign agent about the addresses of its home agent, the redirection agent in the home area, and the previous foreign agent, if applicable. The foreign agent tries to forward a registration packet to each of the corresponding mobility agents on behalf of the mobile host and passes only registration acknowledgment packet indicating the registration success to the mobile host.

**Mobile host**— A mobile host has additional software that allows the host to move within the network. The host movement is transparent to the user and to the protocol layers above the network layer within the host. A mobile host is assigned a constant, unique home address that belongs to a home network, in the same way as any other stationary hosts. The permanent (home) network address remains fixed regardless of host attachment, thus acting as the mobile host logical identifier.

A mobile host must initially register with its home network mobility agent as its home agent. The mobile host connecting to its home network is just another stationary host in the network. The care-of address of the mobile host provided by its home agent is set to its own home address. The mobile host answers the ARP requests from the local network. All packets destined to the mobile host use regular routing algorithms without packet redirection. Additional software in the mobile host supporting the mobility is not invocled.

When a mobile host is away from home, connecting to networks other than its home network, the mobile host must be able to determine that it has moved to a new network, and can identify the new current foreign agent connected to the new local network with which to register. The foreign agent is the default router for all outgoing packets from the mobile host. A care-of address is provided to the mobile host by a current foreign agent. The care-of address and its fixed home address form a location binding of the mobile host.

Each mobile host maintains a patron list, which contains the addresses of redirection agents in the mobile host’s patron areas from where the connection requests are most often made. The addresses of redirection agents in a mobile host’s patron areas are obtained when the mobile host initially registers with its redirection agent in the home area. The redirection agent computes the addresses, and returns them to the mobile host. When the patron host list changes, the mobile host has to obtain new set of addresses of the redirection agents in the mobile host’s patron areas by sending an initial registration packet to its redirection agent in the home area. Whenever a mobile host crosses the OSPF area boundary, the redirection agent in the mobile host’s current visiting area notifies it about this movement. The mobile host then sends a patron service packet, which includes all addresses of redirection agents in its OSPF patron areas, to its current foreign agent, which in turn forwards the patron service update to each of redirection agents.

**Foreign agent**— During the registration process, a foreign agent provides the mobile host with a care-of address, which is usually its own network address. The care-of address indicates the current point of network attachment of the mobile host. The association of a mobile host’s home address and its care-of address is known as ‘mobility binding’, which can be used to resolve the physical location of the mobile host in the network. Foreign agents must periodically send out Agent Advertisements to indicate their existence to mobile hosts visiting their control area to recognize them and register with them as their current foreign agents. Upon receiving registration packets from the mobile hosts, the foreign agent creates/updates a visitor list entry for these mobile hosts, and sends a registration acknowledgment packet to the mobile host if registrations went through smoothly. The foreign agent, upon completion of the registration process for a mobile host, has the responsibility to forward the registration packet to that mobile host’s home agent, the redirection agent in its home area, and any other
related mobility entities depending on the mobile host’s movement.

If the registration packet is forwarded to a redirection agent in the foreign agent’s own OSPF area, the foreign agent includes the address of the previous foreign agent of the mobile host (if applicable) in the forwarding registration packet. It is the responsibility of the redirection agent in the mobile host’s current visiting OSPF area to notify the mobile host about crossing area boundary movements.

The visitor list maintained by each foreign agent identifies all mobile hosts currently registered. When a foreign agent tries to deliver packets addressed to mobile hosts locally in its visitor list, the scenario is the same as in the case of local delivery of packets to a stationary host—MAC addresses are used to distinguish hosts in the local network. The MAC address of the mobile host can be provided by the mobile host during the registration process with a foreign agent.

When a foreign agent receives a registration packet addressed to a mobile host in its visitor list from another mobility agent, the mobile host has already moved out of foreign agent’s control area and changed its point of network attachment. The foreign agent creates a forwarding list entry, deletes the visitor list entry for the mobile host, and finally sends a registration acknowledgment packet to the mobility agent. The forwarding list is an array of pointers to foreign agents currently serving mobile hosts.

With forwarding list caching, the foreign agent can also work as a pointer to the foreign agent that currently serves a mobile host. When a foreign agent receives a data packet addressed to a mobile host in the forwarding list, which the foreign agent maintains, it tunnels the packet to the address indicated by the forwarding list entry, which is generally the foreign agent that currently serves the mobile host.

When the foreign agent receives a patron service packet from a mobile host in its visitor list, it sends the patron service update to each of the redirection agents in the OSPF patron areas listed in the patron service packet. These redirection agents’ redirection list entries for the mobile host are updated by the address of the mobile host’s current visiting OSPF area redirection agent. Upon receiving all acknowledgment packets from the patron areas, an acknowledgment packet is sent to the mobile host.

**Home agent** — A mobile host must initially register with its home agent, which is a mobility agent in its home network. When a home agent receives the initial registration packet from a mobile host, it forwards the registration packet to the redirection agent in the home area for the mobile host. Upon receiving the registration acknowledgment packet from the redirection agent, the home agent records the mobile host in its home list, which identifies all mobile hosts the home agent is configured to serve, and sends a registration acknowledgment packet to the mobile host.

Suppose a mobile host moves back to its home area, and connects to its home network. A registration process goes on in the same way as when a mobile host registers with a new current foreign agent. When the home agent receives a registration packet directly from the mobile host that initially registers in home agent’s home list, the home agent knows that the mobile host returned. The home agent then deletes the entry for the mobile host in its forwarding list if it exists, and returns the home address of the mobile host as its new care-of address. The home agent forwards the registration packet to the redirection agent in its OSPF area, along with the address of the mobile host’s previous foreign agent. The home agent further notifies the redirection agent of the mobile host’s return by sending notification. With the mobile host’s previous foreign agent address, redirection agent can determine whether the mobile host has crossed its home area. When receiving notification of the mobile host’s return, the redirection agent deletes the redirection list entry for the mobile host. Redirection efforts are no longer needed to route the packets destined to the mobile host’s return.

After registering with a new foreign agent, when moving to a new location area, a mobile host must always register with its home agent through its current foreign agent. When a home agent receives a registration packet from a foreign agent addressed to a mobile host in the home list maintained by the home agent, the home agent creates a forwarding list entry (if there is no entry for that mobile host), or updates the forwarding list entry for that mobile host (if there is an entry), and finally sends a registration acknowledgment packet to that foreign agent. The home agent always caches the most recently updated location bindings for the mobile hosts initially registered.
with it as their home agent and must act as a foreign agent for other mobile hosts visiting its control area, and for mobile hosts initially registered with it.

When a home agent receives a data packet addressed to a mobile host in its home list and forwarding list, the home agent uses the forwarding list entry to tunnel the packet to the foreign agent currently serving the mobile host which is away from home. If the mobile host is in its home list but not in the forwarding list that means the mobile host is at home, no action is needed by the home agent, and the packet is delivered in the same way as the other packets.

The home agent must also provide the proxy ARP for those mobile hosts that initially register with the home agent and are away from home. When the mobile host is connected to its home network, the mobile host answers the ARP requests from local network. All packets destined to the mobile host use routing algorithms without any efforts of redirection. When a mobile host is not at home, connecting to networks other than its home network, the mobile host’s home agent must broadcast messages to all the source hosts in the local network to clear the ARP entries they held for the mobile host away from home. The home agent takes also the responsibility to answer the ARP requests from local network on behalf of the mobile host.

**Redirect agent (OSPF area border router)** — A redirection agent is a mobility router with the special functions of redirecting (tunneling) packets to or from a foreign agent. We place redirection agents on the border of an OSPF area. The redirection agent is essentially an OSPF Area Border Router with extra functionality to support tracking and delivery functions for intra-domain mobility scenarios. Each OSPF area has at least one redirection agent.

When a redirection agent receives a registration packet forwarded from a mobility agent, it updates the corresponding redirection list entry for the mobile host, and sends a registration acknowledgment packet to that agent. With the address of a mobile host’s previous foreign agent provided in the registration packet, a redirection agent can determine whether the mobile host has just crossed the OSPF area boundary. If the redirection agent (which is in the mobile host’s current visiting OSPF area) notices a crossing OSPF area boundary movement of the mobile host, a notice packet is sent to that mobile host to notify it of a boundary crossing. The current redirection agent forwards a registration packet to the redirection agent in the mobile host’s last visited OSPF area, whose redirection list entry for the mobile host is updated with the address of current redirection agent.

When the mobile host is back in the home network, the home agent sends a notification to the redirection agent in the home area. When the redirection agent receives a notification of the mobile host’s return, it clears the entry in its redirection list for the mobile host, and routing mechanisms are used to route packets to the mobile host.

When a redirection agent receives a patron service update forwarded from a mobility agent, the redirection agent updates the corresponding redirection list entry for the mobile host, and sends a registration acknowledgment packet to that mobility agent.

A redirection list preserves location information for mobile hosts and works as a pointer array pointing to the addresses of the foreign agents that currently serve mobile hosts. In a non-hierarchical architecture, when a mobile host moves, it must create/update mobility binding with redirection agents of its patron areas, including its home agent and previous foreign agent (if the mobile host had one). In a hierarchical architecture, every movement of the mobile host causes registration with its home agent and previous foreign agent, but only the movements across the OSPF area boundaries incur update of mobility binding with redirection agents in the mobile host’s OSPF patron areas. When a redirection agent receives a packet addressed to a mobile host in its redirection list, it uses the redirection list entry to tunnel the packet to the mobility agent that currently serves the mobile host.

---Packet Routing---

In Figure 2, location information about mobile hosts is distributed and stored in a four-level hierarchical architecture. With all the mobility agents working together, and location information cached at each level, packets are routed directly to the destination mobile host whenever possible,
without being routed through that mobile host's home network or home agent. To illustrate packet routing (tunneling), we describe how the packet traverses the mobile host's location information hierarchy and reaches its destination (Figure 4). The term packet used in this section refers to ununtunneled packet or the inner packet carried by the tunnel. A special tunnel packet, a special case of packet forwarding (tunneling), applies to all the mobility agents other than the home agent.

A special case in packet forwarding, used to avoid possible routing loops, occurs for a tunneled packet in which the destination of the tunnel is the same as the original destination of the packet. The tunneled packet is called a special tunnel packet, and is always forwarded to the destination mobile host's home network without redirection.

![Figure 4. Packet Traverses Through Location Information Hierarchy](image-url)
No location cache entries or visitor list entries can be used in routing a special tunnel packet; the packet must be routed using only regular packet routing, and reaches the destination mobile host’s home network, where it is intercepted by its home agent if the mobile host is away from home. A tunneling protocol must be designed so that a special tunnel can be detected after packet fragmentation.

We apply the special tunnel packet to our scheme. When a tunneled packet traversing through the second or third level of hierarchy is addressed directly to the node, and the network node (foreign agent or redirection agent) is unable to provide location information, the special tunnel is used to tunnel the packet to the mobile host’s home network. The special tunnel ensures that any loops can be easily and quickly detected and broken without having to rely only on the time-to-live field in the packet header.

Source hosts in the same network as the mobile host’s home network usually have an entry for the mobile host in their ARP tables. When these hosts send packets to a mobile host in the same network, and the mobile host is at home, the packet is directly routed in the local network. An exception is when the mobile host is not at home, in which case the local level is the same as the home level, and the ARP entry for the mobile host is actually its home agent’s MAC address. The packet is directly routed to the home agent, and tunneled to the mobile host’s current location using the forwarding list entry.

Source hosts in networks different from the mobile host’s home network do not have entries for the mobile host in their ARP tables. The packet is addressed to the mobile host’s home address and passed on to the default router in the network using packet routing.

If the mobile host is visiting the network and registers with the network’s default router as its current foreign agent, the current foreign agent has a visitor list entry for the mobile host. The packet destined for the mobile host is locally delivered. If the foreign agent is serving the mobile host at a remote level of information hierarchy, the foreign agent has an entry in the forwarding list for the mobile host. The packet is farther tunneled to the destination. If no location bindings for the mobile host are cached, the packet is passed on using normal packet routing, and reaches the OSPF area border router, which is also the redirection agent for that area and remote level of information hierarchy.

If the redirection agent at the area border has location binding for the mobile host, that is, the mobile host is in the redirection agent’s redirection list, the packet is tunneled to the mobile host’s current location using the redirection list entry. However, if no location bindings are found, the packet is passed on to the mobile host’s home network using packet routing.

If no location binding is cached for the mobile host along the way to its home agent, or a special tunnel packet is formed by the second or third level mobility agent, the packet gets to the mobile host’s home agent. The mobile host’s home agent always caches the mobile host’s most up-to-date location information. If the mobile host is at home, the packet is delivered there, otherwise, the home agent tunnels the packet to the mobile host’s current location and a triangle route is formed.

—Mobile Host Movements—

Our location update and routing scheme can be implemented in both non-hierarchical and hierarchical architecture. In non-hierarchical architecture, the patron service update is invoked for every move of the mobile host, even movements inside the same OSPF area; while the patron service update is invoked only when the mobile host moves across the OSPF area boundaries in hierarchical architecture. In this paper we are interested in hierarchical implementation.

In Figure 5, we show examples of registration and informal message exchange. A mobile host MH moves around the network. The MH currently registers with foreign agent FA1. MH’s previous foreign agent is FA2. HA and RA are MH’s home agent and redirection agent in the home area, respectively. RA2 and RA3 are redirection agents in the MH’s current visiting area and last visited area, respectively, when applicable. Registration and informal message exchange flows are different and depend on the MH’s movement.

In a hierarchical architecture, a mobile host does not need to declare its movements within an OSPF area, that is, movements within an OSPF area do not have to be known to the outside world. This greatly facilitates mobility in the OSPF area. If the
mobile host continues to move within the OSPF area, then all that is needed are local transfers of control information.

If the OSPF area is the mobile host’s own OSPF area (we call it the home area of the mobile host), and the MH is away from home, then after identifying its new foreign agent FA1, the MH registers with FA1. Foreign agent FA1 currently serving the MH propagates a registration packet to the MH’s home agent HA, previous foreign agent FA2 (if the mobile host has one), and the redirection agent RA1 in MH’s home area.

If the OSPF area is an area other than the mobile host’s home area, whenever the MH moves, it registers with a new foreign agent FA1. Registration packets are propagated to MH’s home agent HA, previous foreign agent FA2, and both redirection agent RA1 in MH’s home area and redirection agent RA2 in the present visiting OSPF area.

When a MH leaves its home area and joins a mobility agent in another OSPF area, the MH registers with a new current foreign agent FA1 in that OSPF area. The current foreign agent FA1 propagates a registration packet to the MH’s home agent HA, previous foreign agent FA2 (which must be in an OSPF area other than the OSPF area, in which the mobile host is, since we discuss the situation when the mobile host has crossed the OSPF area boundary), and redirection agents in MH’s home area RA1 and in the present OSPF area RA2. Upon receiving a registration packet, with the address of the MH’s previous foreign agent FA2 provided in the registration packet,
redirection agent RA2 in the MH’s current visiting OSPF area can determine that the MH has just crossed the OSPF area boundary, and redirection agent RA2 informs the MH about the movement by sending the MH notification packet. Redirection agent RA2 also propagates a registration packet to redirection agent RA3 in the MH’s last visited area. Upon receiving the notification packet, the MH sends a patron service packet to its current foreign agent FA1, which in turn forwards a patron service update to each redirection agent in the patron areas listed in the patron service packet. The individual patron host of the mobile host is not aware of the movement.

The mobile host registers with a mobility agent within its home area as its current foreign agent. The foreign agent sends registration packets to the home agent and the previous foreign agent of the mobile host and redirection agents within the home area. The redirection agent in the home area notices the mobile host crossing the home area boundary. The redirection agent forwards a registration packet to the redirection agent in the mobile host’s last visited OSPF area, and notifies the mobile host about the movement. Upon receiving notification, the mobile host sends out a patron service packet.

Simulation Results and Analysis

We simulate three routing schemes: triangle routing, static update, and our location update and routing scheme, in both non-hierarchical and hierarchical architectures. Connection requests generated from stationary hosts to one mobile host within a certain time interval are traced. Connection requests to the mobile host are represented by a Poisson random process. The mobile host moves around in the network, and the movement is associated with two exponential random variables. The amount of time the mobile host stays with a foreign agent is described as short-stay, and the amount of time the mobile host moves within an OSPF area is long-stay. The value of long-stay is greater than the value of short-stay.

—Simulation Model—

We compare the average cost to route a packet to a mobile host by using three different schemes in the internetworks, and to compare the efficiency of these schemes for various traffic models. For the purpose of simulation, the following sets of OSPF areas are considered. The network is represented as an undirected graph. Each OSPF area is represented as a network node in an undirected graph. Network nodes are assumed to be geographically distributed.

Since the OSPF area is a collection of continuous networks or hosts grouped together, the network node representing an OSPF area can be seen as the epicenter of a single large network or several smaller administrative networks. Thus, each network node consists of several smaller networks and represents a larger movement region for mobile hosts. The network configuration inside each network node (an OSPF area) is shown in Figure 6. We assume that the network configurations inside each OSPF routing area are the same. Each OSPF routing area has a direct connection link with every other OSPF area through the OSPF backbone network. The OSPF area border router RT 1 is the only access point to other OSPF routing areas.

In Figure 6, router RT 1 is the area border router and, in our scheme, also acts as a redirection agent for that OSPF routing area. The mobile hosts can connect to networks N2, N3, and N4 by using either wireless link or wired networks. Routers RT 2, RT 3, and RT 4 can act as both home agents and foreign agents for mobile hosts. Mobile hosts and stationary hosts can only connect to networks labeled N2, N3, and N4.

The purpose of simulation is to compare the average cost to route a packet to a mobile host by using various schemes. The average cost, including the update and routing costs, to route a packet to a mobile host is used to measure the efficiency of different schemes. Simulation results are obtained for one mobile host in the network. Connection requests are generated by stationary source hosts, which are connected to networks labeled N2, N3, and N4 in each OSPF routing area.

The traffic models used in our simulation reflect the mobile host locality traffic pattern. Most of the communication requests originate from patron hosts and from patron areas. Three traffic models are simulated as follows.

- Traffic Model 1: All the connection requests are only from patron areas.
Traffic Model 2: Connection requests from OSPF areas other than patron areas are also considered.

Traffic Model 3: Connection requests are only from non-patron host within patron areas.

Simulation of the third traffic model shows the benefits of non-patron hosts within patron areas gained from location updates in redirection agents at the area border. For simplicity of simulation, the connection requests from the mobile host’s home area are not considered. We also assume that connection requests are not generated from the area where the mobile hosts are.

In the internetworks, it is desirable to minimize the overall number of hops traversed by the packets to the mobile hosts, since this minimizes the cost of router processing and consumed link bandwidth. Therefore, in our work, to minimize network resource consumption, the cost measures are computed based on the hop count. The cost of sending a packet between any pair of source hosts in the network is taken to be the hop count between these two hosts. It is assumed that the cost of notifying the mobile host about across-area boundary movement is negligible.

We simulate three types of traffic models. The traffic models and the parameter settings reflect the mobile host locality traffic pattern. In the first traffic model, all the traffic is from patron areas only. The probability of a connection request being generated by patron hosts is 0.7, and the remaining probability of 0.3 connection requests are generated by non-patron hosts within patron areas.

In the second traffic model, connection requests generated by patron hosts and non-patron hosts within patron areas are 0.7 and 0.2, respectively, leaving 1% of the connection requests generated by the source hosts outside patron areas.

In the third traffic model, all the connection requests are generated by non-patron hosts within patron areas.

We assume that the mobile host we are tracing has 10 patron hosts. The number of patron areas cannot be greater than the number of patron hosts.

—Results and Analysis—

The efficiency of location update and routing schemes is measured by the total cost to route a packet to its destination mobile host. The total cost to route a packet to its destination mobile

![Network Configuration within the OSPF area](Image)
host is contributed by two parts, the update cost and routing cost. Update cost in turn consists of both registration cost and patron service update cost, while routing cost consists of search cost and hop counts between the node in which the mobile host’s location binding is found and the destination mobile host.

In Figures 7 and 8, we show the average update cost for three routing schemes. Update cost shown in those figures is for Traffic Model 2. In both non-hierarchical and hierarchical architectures, we can see that triangle routing scheme has the lowest average update cost. The cost for our scheme is between the cost of triangle routing and static update.

Figure 7. Non-hierarchical Traffic Model 2 Update Cost

Figure 8. Hierarchical Traffic Model 2 Update Cost

In our analysis, the update cost consists of registration cost and patron service update cost. In the triangle routing scheme there is no patron service update cost and there are fewer mobility agents involved in the registration procedure: this scheme has the lowest cost. Our scheme differs in that the static update scheme updates individual patron host’s within patron areas, while our scheme updates the redirection agent at the border of each patron area. The cost is lower for the update redirection agent at the area border than to the update individual patron host within that area. The average update costs shown in Figures 7 and 8 are for the case in which the number of patron areas equals the number of patron hosts. Messages needed per patron service update are the same for both static update and our scheme. This way, we gain patron service update cost saving in our scheme. Update cost consists of two parts: registration cost and patron service update cost. The cost saving for our scheme in Figures 7 and 8 mainly comes from patron service update cost. Therefore, our scheme has a lower update cost than static update.

The update cost for hierarchical architecture is lower than for non-hierarchical architecture. This is due to the fact that patron service update is invoked with every move of the mobile host and even with the movements within the same OSPF area in non-hierarchical architecture, while only across-area boundary movements cause the patron service update in hierarchical architecture. This results in a slow movement rate across OSPF area boundaries. The mobile host stays within an OSPF area for a longer time than with a foreign agent. In hierarchical architecture, the mobile host tends to update related mobility agents less frequently, which is as if the effective call-to-mobility ratio was significantly lowered.

The efficiency of routing a packet to its destination mobile host depends on two parts of the cost: update and routing. We consider the total cost as a whole and show the total average cost to route a packet to its destination mobile host for both non-hierarchical and hierarchical architectures in Figures 9 and 10. The results shown in these figures are for Traffic Model 2, in which connection requests are from both patron areas and non-patron areas. In hierarchical architecture, the total average cost is lower than in non-hierarchical architecture. Our scheme has lower costs than
static update over all the call-to-mobility ratio range. Partial simulation results for Figures 9 and 10 are shown in Tables 2 and 3. The lower the cost, the more efficient is the scheme. Our scheme has more than 17.67% cost saving over static update in non-hierarchical architecture, and more than 4.76% cost saving in hierarchical architecture. When the call-to-mobility ratio is higher than 7.6 in non-hierarchical architecture, and 2.4 in hierarchical architecture, our scheme has lower costs than triangle routing. The same situation exists between static update and triangle routing. When the call-to-mobility ratio is higher than 19.0 in non-hierarchical architecture, and 4.1 in hierarchical architecture, static update has lower costs than triangle routing.

From the results shown in Figures 9 and 10 the triangle routing scheme is most efficient when the call-to-mobility ratio is low (i.e. relatively high mobility), since it incurs minimal update overhead and there are not many redundant searches. However, when the call-to-mobility ratio increases, the overhead due to redundant searches increases. Triangle routing therefore results in high average cost.

Cost saving for our scheme comes from two parts. First is the update cost saving as shown in Figures 7 and 8. Second is from the search cost saving for non-patron hosts within patron areas. Since we update redirection agents at the border of patron areas, all source hosts within these areas benefit from location update, whether they are patron hosts of the mobile host or not.

From Figures 9 and 10 we can see that both static update and our scheme benefit from network hierarchy. As shown in Tables 2 and 3, for the same call-to-mobility ratios, hierarchical schemes have lower cost than their respective non-hierarchical schemes.

We plotted the average cost saving percentage for three traffic models in Figures 11, 12, 13, and 14. We only considered connection requests from non-patron hosts within patron areas in Traffic Model 3, to show clearly the non-patron hosts benefits within patron areas gained from location update. From the curves shown in the figures, we can see

<table>
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<th>Non-hierarchical average cost (hops)</th>
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<td>Static update</td>
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<td>Percentage saving (%)</td>
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<td>Our scheme</td>
<td>4.76</td>
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<td>Percentage saving (%)</td>
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*Percentage saving = 1-cost of our scheme/cost of static update.
Table 3. Hierarchical traffic Model 2: average cost comparison (static update and our scheme)

<table>
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<tr>
<th>Call-to-Mobility ratios</th>
<th>Hierarchical average cost (hops)</th>
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<th>Our Percentage saving(^*)</th>
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<td></td>
<td></td>
<td></td>
<td>(Our scheme over static update)</td>
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<tr>
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<td>41.20</td>
<td>5.65</td>
<td>5.38</td>
<td>4.76</td>
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\(^*\) Percentage saving = \(1 - \text{cost of our scheme}/\text{cost of static update}\).

that Traffic Model 3 has the highest percentage cost saving among the three traffic models.

Our scheme over triangle routing plots (Figures 11 and 13) shows a consistently better performance over triangle routing. The average cost saving percentage increases with the increase of the call-to-mobility ratio. Partial simulation results for Figures 11 and 13 are shown in Table 4. Our scheme over static update plots (Figures 12 and 14) indicate the difference for each traffic model. The average cost saving percentage decreases with the increase of the call-to-mobility ratio. Partial simulation results for Figures 12 and 14 are shown in Table 5. Our scheme has more than 37.77%, 17.67%, and 19.10% cost saving over static update for Traffic Models 3, 2, and 1, respectively, in non-hierarchical architecture, and 16.84%, 4.76%, and 6.53%, respectively, in hierarchical architecture.

The highest percentage cost saving for Traffic Model 3 indicates the non-patron hosts benefits within patron areas gained from location update in redirection agents at the borders of these areas. In the triangle routing scheme, a packet has to go to the mobile host’s home agent before it is tunneled to the mobile host’s current location. In a static update scheme, since the packet is generated from the non-patron hosts, it has to go to the mobile host’s home network, and is tunneled to
the mobile host’s current location by either the redirection agent in the home area or the mobile host home agent.

---Comparisons with Other Schemes---

The scheme proposed in reference 5 has limitation to mobility models since patron service is invoked only when the mobile host crosses in and out local region, and the scheme is suitable only for Boring Professor Mobility Model. Because of definition of the local region, location update is limited to local region, and less update is needed. The scheme presented in reference 5 should be more efficient than our scheme for Boring Professor Mobility Model. However, for other mobility models, no location information of the mobile host is provided in reference 5 when the mobile host moves outside its local region, which is equivalent to triangle routing. Therefore, for Traveling Salesman and Pop-up Mobility Models, our scheme performs more efficiently than the scheme in reference 5.

<table>
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<th>Traffic Model 3</th>
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</table>

* Percentage saving = (cost of triangle routing – cost of our scheme)/cost of triangle routing.

---Table 4. Average cost saving percentage* (our scheme over triangle routing)---

<table>
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<tr>
<th>Call-to-mobility ratios</th>
<th>Traffic Model 1</th>
<th>Traffic Model 2</th>
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<td>16.84</td>
</tr>
</tbody>
</table>

* Percentage saving = (cost of static update – cost of our scheme)/cost of static update.

---Table 5. Average cost saving percentage* (our scheme over static update)---
The schemes presented in references 2, 3 and 13 update the mobile host’s location information in intermediate routers which are randomly selected routers in the network. How efficient the scheme is greatly depends on the intermediate routers, location. Also, the cache size to cache the location information of the mobile hosts is scaled to the number of mobile hosts in the network which can be very large with an increase of mobile host population. In our scheme the size of the redirection list, which each redirection agent at the area border maintains, is not the network scale but only proportional to the number of mobile hosts with which the source hosts within that area communicate. Where to locate the intermediate routers in the network to enhance routing efficiency can be another research area.

**Conclusion**

We presented a location update and routing scheme with the scalability of network hierarchy. Our scheme provides nearly optimal routing for most communications bypassing the mobile host’s home network and home agent. Our scheme achieves fewer location updates by limiting the location updates to a designated set of redirection agents at the border of patron areas, from where communication requests most often generate.

The networks and source hosts within a domain are grouped into OSPF areas. An OSPF area can be seen as the epicenter of a single large network or several smaller administrative networks. Utilizing the locality property of the mobile host’s traffic pattern, the concept of patron hosts is defined in reference 5. The locality of the mobile host’s traffic pattern exists not only on a host basis but also on a network basis. We then further defined the concept of patron areas to take advantage of the locality properties of the mobile host’s traffic pattern, and introduced redirection facilities into the OSPF area border routers. The location information of the mobile host is hierarchically distributed and stored in the network. The information propagated into the network is cached in the mobility agents in a four-level hierarchy. The current foreign agent of the mobile host serves as the local level of the mobile host routing and tracking hierarchy, while redirection agents in patron areas serve as the remote level. Source hosts in a mobile host’s home network holding an entry for the mobile host in their ARP table serve the host level, and the mobile host’s home agent is the home level. The path-reversal technique is used to compute the redirection agent’s network address in the mobile host’s last visited area. It is the responsibility of the redirection agent in the mobile host’s current visiting area to determine whether the mobile host crossed the area boundary, and to notify the mobile host about the movement.

The efficiency of location update and routing schemes depends on how the efficiency of location information is distributed in the entire network. In this paper, the efficiency of location update and routing schemes is measured by the total cost to route a packet to its destination mobile host. The total cost to route a packet to its destination mobile host is contributed by two parts: update cost and routing cost. Update cost in turn consists of both registration costs and patron service update cost, while routing cost consists of search costs and hop counts between the node in which the mobile host’s location binding is found and the destination mobile host.

When we only consider the update cost, triangle routing is the most efficient scheme. However, when we look at the total cost as a whole, triangle routing is efficient as the call-to-mobility ratios are relatively low. Triangle routing is the most efficient scheme among the three schemes when the call-to-mobility ratio is low.

In both non-hierarchical and hierarchical architectures, our scheme performs better than static update over all ranges of call-to-mobility ratios. In non-hierarchical architecture, our scheme has at least 17.67% cost saving over static update; while in hierarchical architecture, it has at least 4.76% cost saving over static update. Triangle routing is the most efficient when call-to-mobility ratios are low. However, with an increase of the call-to-mobility ratio, triangle routing becomes the least efficient. Triangle routing incurs the minimal update overhead and not many redundant searches are involved when call-to-mobility ratios are relatively low. However, when call-to-mobility ratios increases, the overhead due to redundant searches increases and results in a less efficient routing scheme.

Both static update and our scheme benefit from hierarchical organization of the network by specifying the OSPF area border routers as location
servers for the routing area. This hierarchical network organization also facilitates movement of the mobile host within an OSPF area, incurs only local information update within that area, and avoids unnecessary use of wide area links. Update cost is therefore reduced, especially when the cost of updating a regional location server is insignificant.

In our scheme, more network routers are involved to accomplish the task of routing packets to destination mobile hosts. However, involvement of network routers is unavoidable if we wish to resolve the host mobility problem while preserving backward compatibility. Triangle routing and static update seem to offer better solutions over other schemes since minimal requests are put in existing networks. However, our scheme offers a better solution while the population of mobile hosts increases and mobile networks become popular. From the similarity between a mobile computing environment and a cellular network, the reason can be clearly seen from the progress in cellular telephone and PCS networks. The trend of current PCS networks is to provide a profile for each subscriber to reduce tracing and routing costs. The use of the concepts of patron hosts and patron areas in our scheme provides profiles in which the areas where most of the communication requests generate are recorded. The profile is used to reduce updating cost, therefore enhancing routing efficiency. Information storage in PCS networks has changed from centralized information centers to hierarchically distributed location centers. Even in current conventional static networks, routing information is also hierarchically distributed in the network. OSPF areas used to separate routing information from the outside world are examples of this hierarchy. Our scheme provides a good hierarchical organization of the mobile hosts’ location information.

Although our scheme requires some caching overhead for the mobility bindings at the redirection agents, the cache size of the redirection list is not dependent on the network scale, but is limited to the total number of mobile hosts with which the source hosts within that area communicate.

By limiting location updates to a small set of redirection agents in patron areas, fewer update events are propagated into the network while still achieving nearly optimal routing for most communication by using a redirection facility. Location updates are efficiently managed to notify only redirection agents in patron areas where one or more patron hosts reside when mobile hosts cross OSPF area boundaries in a hierarchical architecture. All source hosts within patron areas benefit from location update whether the host is a patron host of the mobile host or not. The number of patron areas cannot be greater than the number of patron hosts, and compared with the static update, fewer location update messages are needed. Also, it costs less to update redirection agents at the area border than to update individual patron hosts within that area.

Our location update and routing scheme still does not perform well over all ranges of the call-to-mobility ratios. When the call-to-mobility ratio is low, it is less efficient than triangle routing (the negative percentages in Table 4). In future, to reduce the total costs of location management and to scale well when the call-to-mobility is low, it is possible for the mobile host to dynamically generate its patron hosts and patron areas, and trade off the routing and update costs according to the call-to-mobility ratio dynamically.

References

17. Rajagopalan S, Badrinath BR. An adaptive location management strategy for mobile IP. Available from Internet, 1996.

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