Ubiquitous Mobile Host Internetworking

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1. Introduction

With the increasing popularity of notebook and palmtop computers and the increasing availability of wireless networking interfaces such as radio and infrared, there is currently a great deal of interest in providing IP [6] networking support for "mobile hosts" in the Internet [1, 2, 3, 4, 9, 10, 11]. However, IP host addresses are composed of a *network number*, identifying the network to which the host is attached, and a *host number*, identifying the particular host within that network; IP expects to be able to route a packet to a host based on the network number contained in the host's IP address, but if a host changes its point of connection to the Internet and moves to a new network, IP packets destined for it will no longer reach it correctly. Changing the IP address of the host when it moves is difficult or impossible (particularly while keeping existing transport level connections open), and thus a solution is needed for correctly routing packets to the host in its current location given the host's (constant) IP address. This problem is in general also not unique to IP, since any packet switching protocol using a hierarchical addressing scheme based on geography or network topology faces similar problems in trying to integrate mobile hosts into the network.

The issue of mobile host internetworking is sometimes regarded as synonymous with wireless networking, or is considered to be important only for "small" portable machines. However, the distinction between workstations and portable computers is beginning to disappear in terms of both features and computational power, and mobile host users may equally well want to connect their machines to the Internet using a conventional wired interface such as Ethernet while visiting another site. This paper instead takes the view that there is nothing "special" about a mobile host; every host on the Internet should be a "mobile capable" host, and a "mobile host" is simply any Internet host that happens to be currently "away from home." In fact, even today's portable computers have a "home" location (probably in their owner's office) where they spend much of there time when their owner is not traveling, and any "stationary" host may someday need to be temporarily moved to a new network.

This position paper summarizes the main features of a protocol for transparently supporting this type of IP routing to mobile hosts operating in the Internet [3]. The protocol is simple and requires few changes to existing protocol software. In particular, no changes to non-mobile hosts or to backbone routers in the Internet are required. The protocol scales well to very large numbers of mobile hosts and adds little overhead to the network. The protocol allows any host running the appropriate software to become mobile at any time, yet there is no penalty for a host being "mobile capable," since the protocol

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automatically uses only the standard IP routing mechanisms and adds no overhead to IP when a mobile host is currently connected to its home network.

2. Overview

In the IP addressing scheme, the IP network number for a network is assigned by a central authority (the *Internet Assigned Numbers Authority*) to an organization requesting connection of its network to the Internet [8]. The assignment of host numbers within that network number is then delegated to the requesting organization. Mobile hosts owned by that organization should be assigned a permanent IP address within that network number. The mobile host will use this IP address whether attached to its "home" network or currently attached to some "foreign" network. This method of address assignment preserves the delegation of addressing authority for each organization and makes the current physical location of a mobile host transparent to other hosts.

Each organization with mobile hosts is responsible for providing a *Location Server* on its network that maintains a database of the current location of each of its own mobile hosts for which this is the home network. The Location Server may be the router (or routers) that connects that network to the rest of the Internet, or may be one or more separate support hosts on that network. When a mobile host moves to a new location in the Internet (connects to a new foreign network), it must notify its home Location Server, which updates its location database.

The "location" of a mobile host is represented as the IP address of the *Base Station* on the foreign network (wired or wireless) to which the mobile host is currently connected. The Base Station is normally the router (or routers) that connects this network to the rest of the Internet, but may also be a separate support host on that foreign network. IP packets are routed to the mobile host by delivering them first to the Base Station, which is then responsible for delivering them over its local network to the connected mobile host. The Base Station maintains a list recording the IP address of each visiting mobile host currently connected to that network. Any host or router that caches the Base Station IP address for some mobile host becomes a *Location Cache* for that mobile host. Any out-of-date Location Caches (because the mobile host has moved) will be automatically corrected when needed by the protocol.

3. Protocol Summary

3.1. Moving a Mobile Host

When a mobile host moves to a new location and connects to a new Base Station, it must notify its new Base Station, its old Base Station, and its Location Server. As a special case, if the host is moving from its home network, there is no old Base Station to be notified. Likewise, when a mobile host reconnects to its home network, there is no new Base Station to be notified.

At the Location Server, the notifications of a mobile host's movement are used to maintain a database of the current location of the mobile host, giving the IP address of the current Base Station for each mobile host for which this is the home network. The database may be maintained in the memory of the Location Server host, but for reliability, should also be recorded on disk to survive any crashes and subsequent reboots of the Location Server. When the Location Server receives notification that a mobile host is disconnecting from its home network, the Location Server also arranges to intercept any IP packets sent to the mobile host over the home network. This may be done, for example, with "proxy" ARP [7].

When the old Base Station receives notification that a mobile host is disconnecting, the old Base Station normally caches a "forwarding pointer" to the new Base Station's IP address by becoming a Location Cache for this mobile host. This forwarding pointer is only a cache, though, and is treated the same as other Location Caches. The Base Station may optionally instead simply remove its record of the visiting mobile host, which will then cause any packets addressed to the mobile host that are subsequently received by the old Base Station to be forwarded to the mobile host's home network and to its Location Server.

When the new Base Station receives notification that a mobile host has connected to the local network, the new Base Station creates an entry for that host in its list of local mobile hosts. When the Base Station receives an IP packet for routing, if the destination IP address of the packet is in this list, it sends the packet over its local network rather than routing the packet based on the destination IP address.

3.2. Locating a Mobile Host

When sending an IP packet to a mobile host, the sender initially does not know (or need not know) that the host is mobile. The packet is sent and routed exactly the same as any other IP packet, and thus reaches the home network of the mobile host. If the mobile host is currently connected to its home network, the packet is delivered there directly to the host without extra overhead.

If, instead, the mobile host is not currently connected to its home network, the packet is intercepted by the Location Server on that network. The Location Server forwards the packet to the mobile host through the Base Station currently recorded in the Location Server's database, and returns an ICMP "mobile host redirect" message to the original sender of the packet. This new type of redirect message is similar to the standard ICMP host redirect message [5] and is sent from the Location Server to the original sender of the packet. It includes the IP address of the mobile host to which the original packet was sent, and the IP address of the Base Station on the network to which the mobile host is currently connected.

Any host or router is free to cache the current location of a mobile host at any time, but is never required to do so. In particular, the original sending host or any router that sees this mobile host redirect message may become a Location Cache for this mobile host by caching the IP address of the Base Station for this mobile host. This IP address may be recorded in the same table already required within IP to handle the existing host-specific ICMP redirect messages. Before transmitting an IP packet, a host or router must currently search this table to find the correct first-hop router address to use for this destination IP address. By saving the IP address of a mobile host's Base Station in this same table (with a different type field on the table entry), the correct Base Station address for sending to a mobile host can be found in the cache with little or no additional cost. This table can also be used by a Base Station to store a table entry for each visiting mobile host currently attached to that Base Station, and to recognize that a packet which it is routing must be transmitted locally to a visiting mobile host.

3.3. Routing IP Packets to a Mobile Host

To cause IP packets destined for a mobile host to be routed through the Base Station currently serving that host, a new *tunneling* protocol, called the *Mobile Host Routing Protocol (MHRP)*, is used [3]. The original IP packet is transformed into a new IP packet addressed to the Base Station, and then uses only normal IP routing for delivery to the Base Station; once received there, the packet is transmitted by the

Base Station to the locally visiting mobile host. The tunneling may be initiated by the sending host itself, if it is running IP software that supports the MHRP protocol and if it is currently a Location Cache for the destination IP address. The tunneling may also be initiated by the sender's first-hop router or by any other router that handles the packet and is currently a Location Cache for the destination IP address. If no Location Caches are encountered, the packet will be routed at each hop according to the normal IP routing algorithms and will eventually reach the mobile host's home network, where the packet will be intercepted by the mobile host's Location Server. The Location Server will then tunnel the packet using MHRP to the Base Station, and will return an ICMP mobile host redirect message to the original sender, as described in Section 3.2.

The MHRP protocol adds a new header to the packet between the IP header and any existing transport-level header such as TCP or UDP. The original IP destination address (the mobile host) is copied into the MHRP header, and is replaced in the IP header by the address of the Base Station. Likewise, the original IP protocol number (such as TCP) is copied into the MHRP header, and is replaced in the IP header by the IP protocol number indicating MHRP. The original IP source address in the IP header is replaced by the address of the Location Cache or Location Server tunneling the packet, and a list is kept in the MHRP header of the previous IP sources addresses for this packet. If the Location Cache or Location Server building the MHRP header is the original source of the packet, then this list is empty, and the length of the constructed MHRP header is only 8 bytes; otherwise, the length of the constructed MHRP header is 12 bytes.

If the mobile host has moved to a new Base Station since previously using this Base Station, the destination mobile host will not be in this Base Station's list of locally visiting mobile hosts. If the Base Station has a forwarding pointer (a Location Cache) to the new Base Station, it tunnels the packet there; otherwise, the old Base Station tunnels the packet to the mobile host's IP address, so that it will be intercepted by the mobile host's Location Server and tunneled to the correct new Base Station.

The list of previous IP source addresses for this packet in the MHRP header is used to update any out-of-date Location Caches that are used, and to recover any Base Station that "forgets" about a locally visiting mobile host, such as when the Base Station is rebooted. Also, although no routing loops can be created by a correct implementation of this protocol, in a system as large as the Internet, with many independent interoperating implementations of each protocol, some incorrect implementation could accidentally create a loop of Location Caches; such a loop would cause a packet to be forwarded continuously until its IP "time-to-live" expired. The MHRP router list may also be used to easily correct any such loop that may be formed. In general, by sending an ICMP mobile host redirect to the addresses in this list, each of the Location Caches or Base Stations that have handled the packet can receive updated location information, or can be instructed to delete a possibly incorrect cache entry.

3.4. Overhead and Scalability

The protocol adds no overhead to normal IP routing and delivery when a mobile host is "at home," connected to its home network, and normally adds only 8 (or 12) bytes to each IP packet destined for a mobile host when connected to a foreign network. If the sending host or the sender's first-hop router supports the protocol, optimal routing is used for packets sent to a mobile host (after the first packet sent through the Location Server, which initializes the Location Cache), and if some router near the sender supports the protocol, near-optimal routing is used. No support, however, is *required* at or near the sender, and packets are still delivered correctly to the mobile host through its Location Server.

The protocol uses no broadcast or multicast for finding the location of a mobile host, and requires no temporary assignment of a new IP address within the foreign network being visited by a mobile host. The location information provided by a Location Cache is only an optimization, and the contents of the (finite) cache space provided by a host or router may be maintained by any local cache replacement policy. If an out-of-date Location Cache is used to tunnel a packet, the packet will in turn be forwarded to the correct new Base Station for that mobile host, and that Location Cache will be automatically updated by the protocol.

Each organization that owns mobile hosts manages the assignment of IP addresses to those hosts in the same way as the assignment of IP addresses to other hosts in the Internet. In addition, each organization manages its own Location Servers to support the routing of IP packets to the mobile hosts owned by that organization. For example, if that organization requires increased reliability of service for its own mobile hosts, it can replicate the Location Server function on several support hosts on its own network or may install additional links connecting its network to the Internet at more than one point to provide continuous connectivity to its Location Server in case one of its links to the Internet is temporarily down.

4. Related Work

As mentioned, there is currently a great deal of interest in providing IP support for mobile hosts in the Internet [1, 2, 3, 4, 9, 10, 11]. Each of the protocols proposed by different researchers shares some features in common and differs in other features. The protocol presented here is unique, though, in its support for ubiquitous mobile host internetworking, in treating all Internet hosts as "mobile capable" hosts and adding mobile host routing overhead *only* when a host is currently away from its home network. The protocol is also unique in allowing a first-hop router to support the tunneling of IP packets to mobile hosts for all (unmodified) senders on a local network, rather than requiring each sender to be modified or to forward all packets to a mobile host through a server on the mobile host's home network. Finally, the protocol is unique in its simple and effective method of correcting any out-of-date cached location information for a mobile host, of supporting the recovery of a Base Station when it "forgets" about a locally visiting mobile host, and of detecting and correcting any "forwarding pointer" routing loops that may be formed by incorrect implementations of the protocol.

5. Conclusion

This position paper has argued that being a mobile host (or a mobile capable host) should be a standard property of all hosts in the Internet, and has summarized the design of a new protocol for transparently allowing these mobile hosts to interoperate in the Internet using IP. A mobile host may move from one network to another at any time, while always using only its "home" IP address. Any host may be configured to be a "mobile host" simply by running the appropriate software on it, and there is no penalty for this configuration, since the protocol automatically uses only the standard IP routing mechanisms, adding no overhead to IP, when a mobile host is currently connected to its home network. The protocol scales well to very large numbers of mobile hosts and adds little overhead for packets sent to a mobile host currently connected to a foreign network. The protocol is currently being implemented within the Berkeley networking code and is expected to be available shortly to interested groups outside Carnegie Mellon.

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