MOBILE INTERNETWORKING PROTOCOLS FOR WIRELESS NETWORKS WITH ATM BACKBONES

Subhashini Rajagopalan
Ravi Jain
Li Fung Chang

Applied Research
Bellcore
331 Newman Springs Rd, Red Bank, NJ 07701
{subha, rjain, lfc}@bellcore.com

ABSTRACT

Protocols for the interoperable implementation of Internetworking Protocols (IP) and Asynchronous Transfer Mode (ATM) address the issues of address resolution and routing of IP datagrams in an ATM environment to support stationary hosts. To provide mobile computing a protocol, called Mobile IP allows users to move around in the network and yet maintain continuous network connectivity. Mobile IP and IP over ATM protocols have been designed for commercial networks, with less stringent quality and survivability requirements than military networks. In this work, we discuss the limitations of the Mobile IP and IP over ATM protocols for tactical military network applications. It is our effort to define solutions for providing mobility support to mobile IP hosts in an integrated network environment comprised of IP and ATM networks. We present a solution interworking Mobile IP and a specific IP over ATM protocol - Next Hop Resolution Protocol (NHRP) for an initial architecture with wireless access to ATM backbones.

1. INTRODUCTION

Protocols for the interoperable implementation of Internetworking Protocols (IP) and Asynchronous Transfer Mode (ATM) technologies are currently being developed in the ATM Forum and the Internet Engineering Task Force (IETF). These protocols provide mechanisms to support stationary hosts in an environment with IP and ATM networks. To support mobile computing in the IP network environment, a new protocol, called Mobile Internetworking Protocols or Mobile IP, is being standardized in the IETF. Mobile IP will allow users to change their point of attachment to the network and yet maintain transparent and continuous network connectivity. It is our effort in this work to define solutions for providing mobility support to hosts in a heterogeneous network environment comprised of IP, ATM and wireless networks. Specifically, we will address issues pertaining to tactical networks. In this section, we provide an overview of Mobile IP and IP over ATM protocols, followed by the motivation for our work.

A Mobile IP scheme [1] has been adopted by the IETF for standardization in IP version 4 (IPv4). Mobile IPv4 allows IP stations to change their point of attachment to the network while maintaining continuous network connectivity. A *Mobile Station* (MS) is a mobile host or a router with a permanent IP address, called the *home address*, which identifies the mobile's home network and does not change with the location of the station in the network. When the mobile moves to a foreign network, it is assigned a temporary *Care of Address* (COA), which changes as the mobile changes its point of attachment to the network. Agent functionalities, usually located in IP routers, provide mobility support to the user. A *Home Agent* (HA) is a router functionality in the mobile station's home network that maintains the current location of the MS in the network. While a mobile is located in a foreign network, a *Foreign Agent* (FA) forwards datagrams to and from the mobile station. A host communicating with a MS is called a *Correspondent Host* (CH). A key feature of Mobile IP is the use of triangle routing to route datagrams to the MS. All packets destined to the MS are routed through the HA, which encapsulates the original datagram and tunnels it to the MS at its foreign location in the network.

Efforts are underway in the IETF and the ATM Forum to provide mechanisms to address the issues of address resolution and routing of IP datagrams in an ATM environment. The ATM Forum is currently working on three approaches - Local Area Network Emulation (LANE), Multi-Protocol Over ATM (MPOA) and Integrated Private Network-to-Network Interface (I-PNNI). The IETF has proposed two protocols - Classical IP and ARP over ATM model that follows the classical LAN paradigm and the Next Hop Resolution Protocol or NHRP.

The LANE protocol [3] configures ATM as just another MAC layer protocol to look and behave like an existing LAN technology. It's basic function is to translate Media Access Control (MAC) addresses to ATM addresses. Classical IP and ARP over ATM model [4], on the other hand, proposes an enhanced ARP scheme, called ATMARP, which maps IP addresses of hosts and routers directly to their ATM addresses. Both LANE and Classical IP and ARP over ATM protocols provide address resolution only within a logical subnet. Multiple router hops are required to connect hosts in different logical subnets, making these protocols susceptible to scaling and performance limitations.

The NHRP [5] and the MPOA [8] protocols, on the other hand, provide "cut-through" or "short-cut" routes that take advantage of the underlying ATM technology. They provide address resolution mechanisms across logical subnets and hosts in different subnets can communicate across a direct ATM connection, bypassing traditional routers. In NHRP, *Next Hop Servers* or NHS maintain IP to ATM address mappings for a set of stations on the ATM network. MPOA integrates the solutions provided by LANE, Classical IP and ARP over ATM and NHRP, to develop a more unified approach. While MPOA provides an architectural approach to IP-ATM interworking, I-PNNI [9] is a new routing protocol, based on PNNI, which integrates IP routing with ATM. The development of I-PNNI is closely linked to the development of PNNI standards [10] which are not yet complete. It is also not clear if, in the near term, networks will abandon the existing routing protocols in favor of I-PNNI.

Of the existing IP over ATM protocols, either MPOA or NHRP can be used for inter-subnet address resolution. In our description of the protocols, we will use NHRP as an example protocol. While this choice affects the type of network elements in use and their functionality, we believe that it does not affect the development of our protocols.

1.1 Motivation

The networking challenge for tactical military operations is the need to support mobile hosts in a heterogeneous environment with legacy LAN, ATM and wireless network technologies. Protocols for next generation tactical military networks must provide mobility, interoperability, survivability, reliable multicast capability and guaranteed quality of service. Existing protocols for interworking IP and ATM and Mobile IP, developed for commercial networks, do not entirely meet these needs. In a tactical environment where wireless, IP and ATM technologies are major components of military communication networks, protocols must be engineered to ensure a highly efficient and survivable operation.

Although Mobile IPv4 supports mobile routers and hosts, triangle routing results in recursive and/or successive encapsulation for datagram delivery through mobile routers. The IETF has proposed an alternate scheme called Route Optimization [2] which allows CH's to communicate directly with the MH's without going through the HA. This eliminates some performance issues with recursive encapsulation, however, it has not been adopted for standardization with Mobile IPv4. Encapsulation is a protocol overhead, especially when one or more links in the path are wireless. Unlike the wired network, the wireless network is low-bandwidth and prone to interference, link loss and failure. Mobile IP specification provides support for one HA per MS. Also, to provide datagram tunnelling, the HA and the MS's they serve must belong to the same network ID. Together, these two issues pose serious survivability questions for tactical military networks. It is usually the case that each echelon of the military network is assigned a separate network ID. To support mobile hosts in the lower echelons of the network, the HA's, which could also be mobile, must be placed close to the front. Extending the Mobile IP protocol, to support multiple HA's for a MS without the restriction that HA and the MS share the same network ID, needs further study.

The IP over ATM protocols have been designed specifically for supporting fixed hosts. Although NHRP allows registrations from mobile hosts to be forwarded from a foreign NHS to the serving NHS, it's operation is not clear for mobile NHS's. Autoconfiguration and dynamic cache management issues need to be addressed for mobile NHS's.

As a first step to addressing the many issues pertaining to tactical networks, the two main drivers for the work described in this paper are mobility and interoperability. We consider an architecture interworking wireless, IP and ATM network technologies. In the next section, we describe a sample architecture with wireless access to ATM backbones. In Section 3, we present a protocol for interworking Mobile IPv4 and NHRP for this initial architecture. In Section 4 we describe the limitations of the protocols for the tactical military environment. We conclude with a summary in Section 5.

2. ARCHITECTURE

We consider a sample architecture, illustrated in Figure 1, with mobile hosts connected to the IP LAN segment through wireless Access Points (AP). There may be several AP's in a LAN segment. The AP's connect to fixed routers attached to an ATM backbone. The hosts may move across AP's in the same LAN segment or even change LAN segments. The AP's provide link layer handoff for movement within a LAN. When a mobile host (MH) is located in its home network, it behaves like an ordinary fixed host and deregisters with its home agent (HA). As long as the MH does not move out of its home network, packets will be routed to the MH using normal IP routing and Mobile IP is not required. However, when the mobile changes IP LAN segments, link layer handoff can no longer provide transparent and continuous network connectivity. Figure 1 illustrates this scenario, when the MH moves to a foreign network and accesses the wireline network through a different router. Mobile IP operation assigns a Care of Address (COA) to the MH to identify its new location in the network and registers it with the MH's HA.

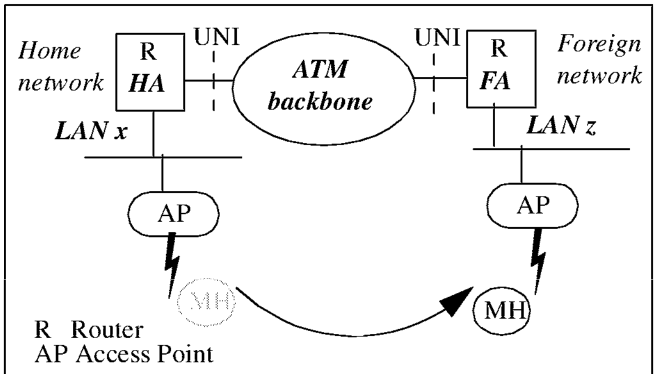

Figure 1 : Sample architecture

In this sample architecture, the routers connected to the ATM backbone implement HA and FA functionality. One of the requirements of NHRP is contiguous deployment of NHS's, i.e. routers that provide access to the ATM network must be configured as NHS's. Since there is only one ingress router to the ATM backbone in each of the IP LAN segments illustrated, these also implement the NHS functionality. They advertise reachability to the wireless hosts. The ATM User Network Interface (UNI) terminates at the routers. ATM cells are not transported over the wireless link. All ATM end stations, such as the HA, FA and the NHS are fixed entities.

In the next section we present a protocol to support mobile hosts in a mixed environment of legacy LAN, ATM and wireless network technologies, based on this sample architecture.

3. A PROTOCOL INTERWORKING MOBILE IP WITH ATM BACKBONES

We consider the base mobile IP protocol, RFC 2002 [1], and NHRP [5] in our protocol development. There are two main protocol components to interworking mobile IP and NHRP - Mobile IP and NHRP registration, and IP datagram delivery to and from MH's with NHRP address resolution.

3.1 Mobile IP and NHRP registration

Figure 2 illustrates Mobile IP and NHRP registration. The HA and the FA, implemented in routers, are ATM end-stations. They register their IP and ATM addresses with their serving NHS. The same router may implement the HA, FA and NHS functionality. For the purposes of discussion, Figure 2 shows the NHS functionality separate from the HA and the FA. If an NHS receives an NHRP registration request packet and it does not serve the station, it will forward the packet through one or more hops in the subnetwork to the serving NHS. The serving NHS records the station's IP and ATM address mapping in its next hop resolution cache and acknowledges registration by sending a reply directly to the served station across an ATM connection, if one exists. Otherwise, a new connection is setup.

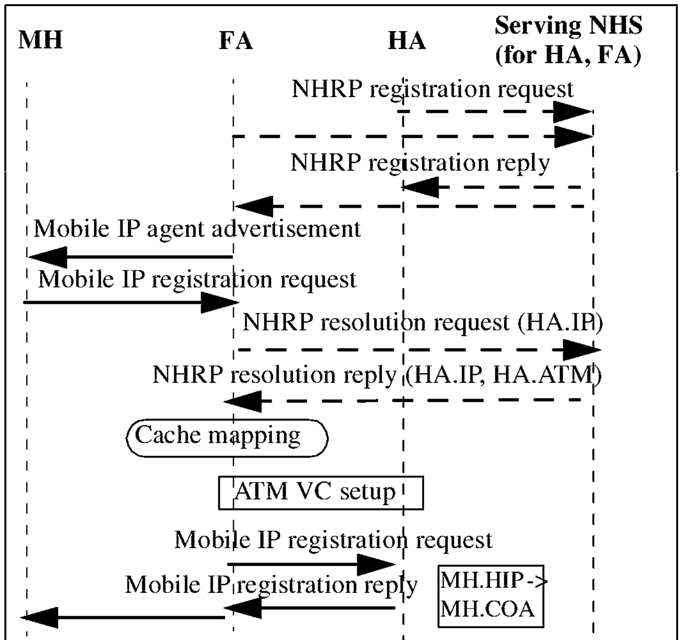

Figure 2 : Mobile IP and NHRP Registration

Mobile hosts located in a foreign network register their mobility binding with their HA, using Mobile IP. The MH determines whether it is at home or in a foreign network when it receives agent advertisement messages broadcast by the mobility agents. The MH may also send an agent solicitation message. If the MH determines that it is in a foreign network, the MH acquires a temporary care of address (COA) from the FA and sends a registration request with it's HA address (HA.IP). To forward the registration request to the HA, if the FA determines that the next hop to the HA is reachable across the ATM network, it obtains the next hop's ATM address either from its cache or through NHRP address resolution. The NHRP resolution request traverses the ATM network till it reaches the NHS serving the HA or till it reaches a transit NHS with a non-authoritative address mapping. In either case, the responding NHS returns the address mapping in an NHRP resolution reply packet. Since the destination host, in this case the HA, is attached to the ATM subnetwork, the reply packet has the ATM address of the HA. The FA sets up an ATM connection to the HA and forwards the mobile registration. While NHRP address resolution and ATM connection setup are in progress, the recommended approach is for the FA to forward the mobile registration request to the HA through normal IP routing. Alternatively, it can discard the packet or wait till it receives the NHRP reply. The HA returns the mobile IP registration reply to the FA.

3.2 IP datagram delivery

In mobile IP, packets from a correspondent host (CH) to the MH are addressed to the MH's home address. They are routed, using normal IP routing, to the MH's home network. If the mobile is at home, it receives the packet like an ordinary fixed host. If the mobile is located in a foreign network, packets are intercepted by the HA, encapsulated and tunneled to the MH's COA. If the next hop to the MH can be reached through the ATM interface, interworking of mobile IP protocols and NHRP is required.

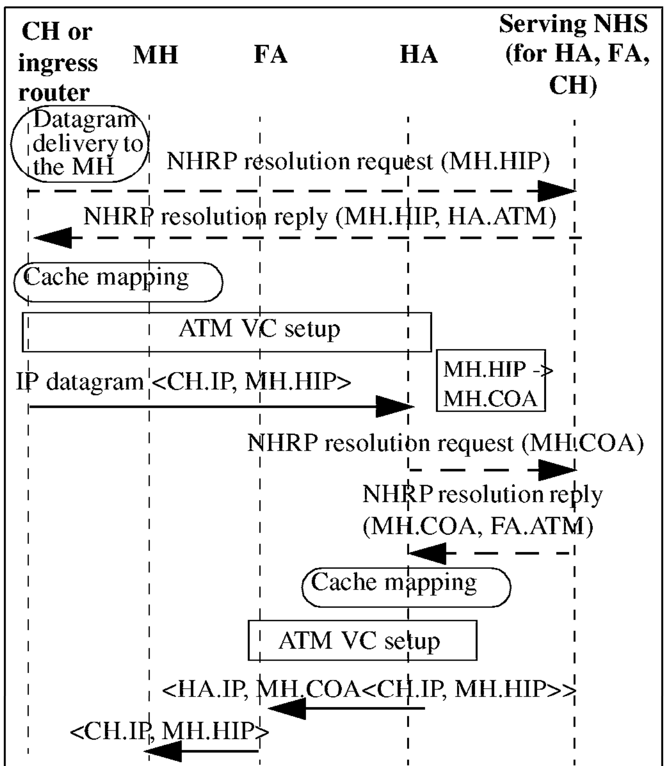

Figure 3 : IP datagram delivery to the MH

Figure 3 illustrates the protocol flow for IP datagram delivery to the MH. If the CH is a non-ATM host, it routes the IP datagram towards the MH using normal IP routing. If it is determined at any transit router that the MH can be reached across the router's ATM interface, the ingress router to the ATM network does NHRP address resolution. If the CH is an ATM end-station and it determines that the next hop to the MH can be reached across the ATM interface, it launches an NHRP address resolution request. Registration of mobile hosts in a NHS can be accomplished through several means. Through the exchange of routing information within the domain, the NHS knows that mobile hosts served by the HA can be reached through it. Alternatively, NHRP provides a mechanism that allows the HA to register it's own internetwork layer address and a equivalence class of addresses corresponding to the first prefix length of it's IP address with its serving NHS. Since the HA and the mobile hosts served by it share the same network ID, the HA can use this mechanism to register the mobile hosts, such that the prefix length will be mapped to the HA's ATM address.

When an NHRP resolution request packet reaches the NHS serving the HA, it responds with the ATM address of the HA. The CH or the ingress router caches the address mapping to avoid triggering NHRP for future packets to the same destination. It sets up an ATM connection to the HA and begins data transfer. While address resolution and ATM connection setup are proceeding, the CH or the ingress router may forward IP packets to the MH using normal IP routing. When the HA receives a packet addressed to the MH and the MH has registered it's mobility binding, the HA forwards the packet to the MH. If the HA determines that the next hop to the FA is reachable through it's ATM interface, it does NHRP address resolution and sets up an ATM connection to the FA.

Protocol for datagram delivery originated by the MH is similar. The MH is unaware of the presence of the ATM network. It launches an IP packet using IP routing. When the packet reaches an ATM router with NHRP implementation, the router will determine if the next hop to the CH can be reached through the ATM network.

4. DISCUSSION

In our architecture, the mobile hosts are unaware of the existence of the ATM network. As long as the mobile hosts can be reached through normal IP routing and the ATM routers they connect to implement NHRP, existing mobile IP and NHRP protocols will work satisfactorily. Interworking becomes an issue when the routers become mobile.

NHRP provides support for hosts directly attached to the ATM network. When an ATM host moves, it can access an NHS in the foreign network using ATM anycast.The NHRP registration is forwarded to the NHS serving the MH. If a serving NHS moves, NHRP packets addressed to the NHS need to be tunnelled to it through it's HA. This involves recursive and/or successive encapsulation. Another issue is that if an ATM router is the only ingress point for hosts on a legacy LAN segment, hosts in the local LAN can no longer be reached through the ATM network and NHRP will fail. Also, since the NHS's participate in inter and intra-domain routing protocols to acquire network layer reachability information, when an NHS moves it must initiate auto-configuration mechanisms to make itself known to the network. In its present form, NHRP is used for host-host, host-router and router-host communication only [6]. Router-router communication is discussed in a separate document [7]. NHRP is not applicable when the routing information disseminated by the router is not stable which is likely to be the case for a mobile router.

It is also clearly evident that the base mobile IP protocol is not efficient for routing data packets to mobile hosts or routers. Triangle routing results in delay and with ATM interworking, two ATM VC's need to be setup for tunneling data packets to the MH - one between the CH and the HA and the other between the HA and the FA. This can be avoided with route optimization [2].

5. SUMMARY AND CONCLUSIONS

Existing protocols for IP over ATM and Mobile IP do not meet the needs of tactical networks. Protocols for next generation tactical military networks must provide mobility, interoperability, survivability, reliable multicast capability and guaranteed quality of service. In this work, we discuss the operation of Mobile IP and a specific IP over ATM protocol, NHRP, for tactical military applications. As a first step, this paper presents a protocol for supporting mobile hosts in a mixed network environment of legacy LAN, ATM and wireless network technologies. Mobility and interoperability are the two main drivers for this work. We consider an architecture with mobile IP hosts connecting to the ATM network through fixed routers. It is found that Mobile IPv4 and NHRP interwork satisfactorily with fixed ATM end stations. Interworking becomes an issue with mobile ATM devices, especially mobile routers. The base Mobile IP protocol with mobile routers results in protocol overhead due to tunneling and recursive encapsulation. Operation of NHRP is also not clear with mobile router-NHS's. This work is an initial step towards addressing many of these salient issues with regard to interworking in tactical military networks.

6. REFERENCES

[1] C. Perkins, "IP Mobility Support," *RFC 2002,* IETF, October 1996.

[2] D.B.Johnson, C.Perkins, "Route Optimization in Mobile IP," *draft-ietf-mobileip-optim-05.txt,* Internet draft of the Mobile-IP working group, IETF, November 1996, Work in progress.

[3] The ATM Forum Technical Committee, "LAN Emulation Over ATM: Version 1", *af-lane-0021.000,* LANE sub-working group, January 1995.

[4] M. Laubach, "Classical IP and ARP over ATM," *RFC 1577*, IETF, January 1994.

[5] J.V.Luciani, D.Katz, D.Piscitello, B.Cole, "NBMA Next Hop Resolution Protocol (NHRP)", *draft-ietf-rolc-nhrp-11.txt*, Internet Draft of ION Working Group, IETF, March 1997, Work in progress.

[6] D.H.Cansever, "NHRP Protocol Applicability Statement", *draft-ietf-ion-nhrp-appl-00.txt*, Internet draft of the ION working group, IETF, November 1996, Work in progress.

[7] Y.Rekhter, "NHRP for Destinations Off the NBMA Subnetwork," *draft-ietf-ion-r2r-nhrp-00.txt*, Internet draft of the Network working group, IETF, February 1997, Work in progress.

[8] The ATM Forum Technical Committee, "MPOA Baseline Version 1," *ATM Forum/96-0824r9,* Multiprotocol sub-working group, September 1996.

[9] The ATM Forum Technical Committee, "Issues and Approaches for I-PNNI," *ATM Forum/96-0355,* PNNI sub-working group, April 1996.

[10] The ATM Forum Technical Committee, "Private Network-Network Interface Specification V1.0 (PNNI 1.0)," *af-pnni-0055.000*, PNNI sub-working group, March 1996.