Comparison of Mobility Management Protocols in IP Networks

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ABSTRACT

With recent advances in wireless communications technology, mobile computing and networking becomes an increasingly important research area. Enabling mobility in IP networks is a significant issue for making use of many portable devices appearing on the Internet. Several protocols and proposals, such as Mobile IP, Cellular IP, HAWAII, Hierarchical Mobile IP, SIP, etc, have been developed to support mobility. These mobility protocols will play an important role in the convergence of IP networks and telecommunication networks. In this paper, we address two important components of mobility management: location management and handoff management. Mainly, this paper reports a comprehensive comparison of each method qualitatively from various technical viewpoints.

Keywords: Internet, Mobile Network, Handoff, Location Management, Mobility Management.

1. INTRODUCTION

Wireless networks are rapidly evolving from 2G cellular telephony networks to 3G and beyond. Following the drastically expanding markets of cellular phone network and Internet services, mobile high-bandwidth data communication was becoming the next candidate of new targeting business. The current IP protocol version 4 (IPv4) [20] brings this world into the “Net-Era” stage. Both data and voice communications rely increasingly on IP-based techniques [1][24]. These trends are motivating a great deal of interest in making sure that these new all-IP systems allow end users to handoff within wireless access networks or roam between these networks while providing efficient data transfer services and seamless connectivity with the Internet or any other networks. All-IP wireless networks are such networks where IP is used end-to-end, from the mobile end-user station to a gateway connecting the wireless network to the Internet. To allow these evolutions, IP must obviously evolve to support users’ mobility [27]. Thus, a protocol that can support mobility is useful for future wireless networks [2][13].

Due to the different manner of the research communities, there seems to be some mismatches in the terminology used. In general, according to the mobility capability, the mobility management protocols that support terminal mobility in IP-based networks or telecommunication systems are classified into three categories: *micro-mobility*, *macro-mobility* and *global-mobility*. Micro-mobility is the movement of a mobile node (MN) within or across different base stations or access points within a single administrative domain or geographical region. Micro-mobility protocols are designed for use in mobile environments where the MNs change their locations frequently [2]-[5][23][25]. Micro-mobility protocols manage local movement of mobile hosts without interactive with the Mobile IP enabled Internet [27]. This effectively reduces transmission delay and packet loss during handoff and eliminates registration between MNs and distant home agents when MNs remain inside their local coverage areas. Eliminating global registration in this manner reduces the signaling load experienced by the core network in support of mobility. On the other hands, macro-mobility protocols are designed for the movement of MNs from one administrative domain to another. In such a case, the relevant domains must collaborate to ensure their connectivity to moving terminals. Global-mobility or roaming is the movement of an MN among different networking systems such as GPRS and WLAN. Obviously, in current mobile environments nowadays, global-mobility will not be involved frequently.

IP mobility [27] working on OSI layer 3 is intended to provide mobile hosts with the Internet connectivity when they move away from their home network to a visiting network. Internet Engineer Task Force (IETF) formed the IETF Mobile Working Group to draw up a standard of mobility support for IPv4, called Mobile IP (MIP) [16]. The MIP technique is the most common solution for offering seamless handoff to mobile devices over the Internet. There are a number of problems associated with the MIP, such as triangular routing, needing a home IP address and a temporary unfixed address i.e., Care-of-Address (CoA), for each host, tunneling management, etc. [16]-[12].

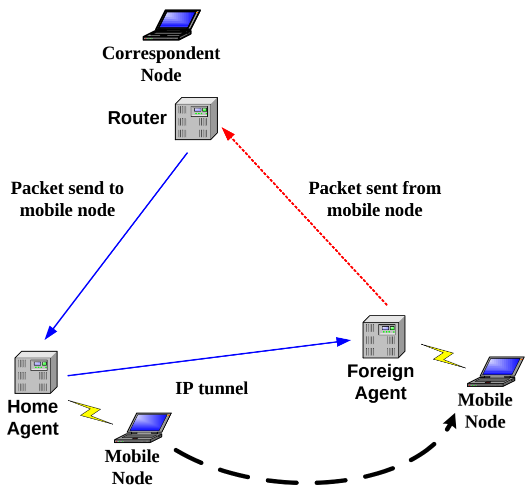

Fig. 1. Mobile IP protocol.

In the original MIP mechanism as shown in Fig. 1, the triangular routing increases transmission delay, packet loss and additional signaling, which makes the network overhead more serious. Route optimization [7] was proposed by using binding update to inform the correspondent node (CN) its current IP address of the mobile node. However, route optimization technique still has several drawbacks [18][19] while dealing with the triangular routing problem and does not address the issue of micro-mobility management. [30] proposes an approach to avoid the triangular routing problem by optimizing routing path via an efficient handoff scheme in which a routing table, called Mobile Routing Table (MRT), is designed in each of edge routers such as home agent and foreign agent. A new handoff mechanism is designed mainly to reduce packet loss and handoff latency effectively. Furthermore, many network layer protocols, such as Hierarchical MIP [27][16], Cellular IP [4][27], and HAWAII [25], have been developed to reduce the overhead of MIP protocol. Alternatively, the application layer approach (specifically Session Initiation Protocol (SIP) [29]) aims to keep mobility support independent of the underlying wireless technology and network layer elements, thus may serve better mobility services.

Mobility management is the key to successfully enable seamless mobile services. It enables wireless or mobile networks to search and locate mobile devices for network communications and to maintain connections as the terminal device moves into a new service area [7]. Basically, mobility management consists of two major components: location management and handoff management [22]. Location management including update and paging enables the network to discover the current attachment point of the mobile user for call delivery. Handoff management enables the network to maintain a user's connection as the mobile terminal continues to move and change its access points or base stations to the network. In this paper, we address these two mobility management problems and comprehensively compare several well-known protocols, including Mobile IP, Hierarchical MIP, Cellular IP, HAWAII, and SIP on this issue.

Following the introduction in Section 1, the remaining of this paper is organized as follows. Section 2 shows the key design issues for location management. Section 3 presents the hand-off management. Finally, a conclusion is presented in Section 4.

2. LOCATION MANAGEMENT

Location management is a two-phase process that enables the network to discover the current point of attachment for MN. The first phase deals with location update (or location registration) that the MN periodically notifies the network of its new access point, allowing the network to authenticate the user and revise the user's current location. The second phase performs packet delivery. Here the network is queried for the user's location and the packets are forwarded to the current position of the MN.

2.1 Location Update

Current techniques for location management involve location architecture design and the transmission of signaling messages between various components of a signaling network. A number of criteria of protocol design choices influenced handoff performances including how to signaling the network about MN's location and where the location of current point of attachment is kept in. The performance of location update is determined by the following two factors.

A. How to Signal the Network About MN's Current Location

In MIP, after getting the Care-of Address (CoA), the MN has to inform the Home Agent (HA) by using the registration procedure. The MN sends a registration request with the CoA information by using the User Datagram Protocol (UDP). This information is received by the HA and, normally if the request is approved, it adds the necessary information to its routing table and sends a registration reply back to the MN. During the registration procedure, there is a need to authenticate the registration information.. Therefore, each MN and HA must share a security association. During this security association it is possible to use the Message Digest 5 [RFC1321], with 128-bit keys to create unaffiliated digital signatures for registration requests. Moreover, in the MIP protocol there are also other control message authentication methodologies, such as Secret Key, Public Key & Self-signed Certificates and Public Key & CA (Certification Authority) signed Certificates. Each of these authentication methods can use manual and/or dynamic key distribution approaches.

In MIP, an MN registers with its HA each time it changes CoA. If the distance between the visited network and the home network of the MN is large, the signaling delay for these registrations may be long. Hierarchical Mobile IP (HMIP) proposed a concept called regional registration [7]. The regional registration design introduces new MIP messages Regional Registrations, new MIP extensions to convey information between the MN, foreign agent (FA) and HA, and a new network entity: the Gateway Foreign Agent (GFA). Regional registrations reduce the number of signaling messages to the home network, and the signaling delay when an MN moves from one FA to another within the same visited domain. This will both decrease the load on the home network and speed up the process of handoff within the visited domain.

Cellular IP (CIP) and is intended to be applied on a local level, e.g., in a campus or metropolitan area network. CIP provides the micro-mobility capability within a CIP network and can inter-work with MIP to support wide area mobility, i.e., macro-mobility, between CIP Networks. The nodes used in the CIP networks are called CIP nodes. Each of the CIP nodes maintain two kinds of cache: the routing cache and paging cache. The routing caches are used to locate an active MN that is roaming in the wireless network and sends or receives IP packets frequently. For the location of idle MNs that do not send or receive packets frequently, paging caches are used.

For HAWAII approach, the network architecture is divided into a hierarchy based on domains. Each domain has a gateway, called the Domain Root Router (DRA), and each host registers with DRA to get an IP address. For Inter-domain mobility, in the situation that the MN moves into a foreign domain, the traditional MIP mechanism is used. The MN gets a co-located CoA from a foreign domain based on HAWAII. When the MN moves within the foreign domain, it retains its CoA. For intra-domain mobility, location is maintained by routing entries at router that are established by path setup messages.

In Session Initiation Protocol (SIP) approach, suppose a user wishes to initiate a session, an invitation is directed to the SIP server, which in turn queries the location server for the current IP address of the mobile user's end system [29]. The SIP server sends the invitation to the called user. The invitation contains the IP address of the callee. If the mobile user moves, the location server is updated and new sessions will be set up to that new IP address.

B. Where the Location of Current Point of Attachment Is Kept In

For MIP, the location of current point of attachment is kept in the HA. For HMIP, the location of current point of attachment is kept in the GFA. For CIP and HAWAII approaches, the location information is kept in the Gateway [27] and the Router [25], respectively. However, the SIP protocol stores the location information in Location Server [29].

2.2 Packet Delivery

Current techniques for packet delivery can be categorized into two classes: tunneling and specific host route. The tunneling technique is used in MIP and HMIP while CIP, HAWAII and SIP all adopt the specific host route technology. In the following, we describe the packet delivery approaches used in each of the existing protocol in detail.

A. Tunneling

In MIP, tunneling to the CoA is accomplished by using an encapsulation mechanism. All mobility agents, i.e., HAs and FAs, in MIP must be able to use a default encapsulation mechanism included in the IP within IP protocol [RFC2003]. With this protocol, the source of the tunnel, i.e., HA, inserts an IP tunnel header into the front of the header of any original IP packet addressed to the

MN’s home address. The destination of this tunnel is the MN’s CoA. In the method of IP within IP there is one way to indicate that the next protocol header is again an IP header. This is accomplished by indicating in the tunnel header that the higher level protocol number is ‘4.’ The entire original IP header is preserved as the first part of the payload of the packet. By eliminating the tunnel header the original packet can be recovered. The tunneling procedure can also be performed by other types of encapsulation mechanisms. These mechanisms are included in different encapsulation protocols such as the minimal encapsulation protocol [RFC2004] and the Generic Routing Encapsulation (GRE) protocol [RFC1702].

In HMIP, registration messages establish tunnels between neighboring FAs along the path from the mobile host to a GFA [16]. Packets addressed to mobile hosts travel in this network of tunnels, which can be viewed as a separated routing network overlay on top of IP. Typically one level of hierarchy is considered, where all FAs are connected to the GFA.

B. Specific Host Route

In CIP, routing information is maintained by Routing Cache. Packets that are transmitted by MN are routed to the Gateway using regular hop-by-hop routing. Each CIP node that lies in the path of these packets will monitor and use them to create and update Routing Cache mappings. Once these Routing Cached chain mapping paths are created, they can be used to route the packets addressed to the MN along the reverse path on a hop-by-hop basis.

HAWAII protocol uses path setup message to support packet delivery. When the MN moves within its home domain, its IP address is retained. The packets that are sent to the MN can reach the domain root router based on the sub-network address of the domain. The received packets are then forwarded to the MN by using dynamically established paths. Three different path setup schemes [25] can be used to dynamically establish the paths followed by the IP packets from gateway to MN. In each of these schemes, the path setup update messages are sent to the gateway by the MN to create entries (used during the reverse path) in the intermediate nodes they pass. The first setup scheme is active during power up while the other two are active during handoff. In the situation that the MN moves into a foreign domain, the packets arriving at the home domain and destined to an MN away from home are tunneled by the MN’s HA to the CoA.

Since SIP operates in application layer, the packets are sent by using normal IP routing protocol. Accordingly, there is no need to modify current IP protocol.

3. HANDOFF MANAGEMENT

From the viewpoint of IP network, the handoff management concerns the management of the changes of base stations or access points during their moves. The handoff management is obviously a major issue in mobility management since an MN can experience several handoff during a single communication session. A well-designed handoff mechanism must be fast and smooth, i.e. they should be performed without significant delays and without loss of packets. A number of factors for designing an efficient mobility management protocol influence handoff performance including handoff control, packet loss and duplication, radio behavior, signaling overhead, path efficiency, passive connectivity and paging, etc.

3.1 Handoff Control

The handoff control contains the initiator of the handoff operation and handoff mechanism. In most of the mobility management protocols, MNs listen the signaling messages transmitted by base station or access point and initiate handoff based on signal strength measurements. Two kinds of handoff schemes, which have found importance so far, are soft handoff and hard handoff.

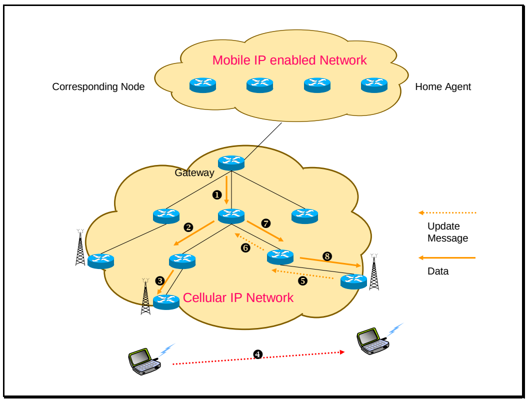

Fig. 2. Cellular IP hard handoff scheme.

CIP and HAWAII support both hard and soft handoff schemes, while HMIP and TeleMIP support only hard handoff scheme. DMA and SIP support only soft handoff scheme. In CIP or HAWAII, though the MN maintains a single CoA while changing subnets within an administrative domain, but this idea may have the possibility of increasing signaling complexity for establishing mobile-specific routes.

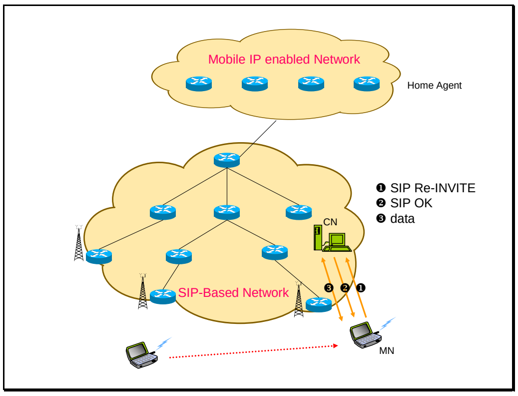

Fig. 3. SIP-based mid-call handoff scheme.

3.2 Packet Loss and Duplication

For smooth handoffs, packet losses would be minimized. There are several ways to reduce packet loss during handoff. One approach relies on interaction between the old and new base stations during handoff. In this case the new base station notifies the old base station of the pending handoff. Packets that arrive at the old base station after notification of handoff are forwarded to the new base station and onto the MN. Another approach relies the ability of MN that is able to listen and transmit to two or more base stations simultaneously for short duration. Both of the CIP semi-soft handoff and HAWAII handoff schemes support MN to listen and transmit to two or more base stations simultaneously but may result in packet duplication. Other protocols including HMIP and SIP may result in packets loss and will not receive duplicate packets.

3.3 Radio Behavior

To perform a handoff, an MN should turn its radio to a new base station and sends related update messages. Radio behavior distinguish the abilities of MN that can listen and transmit to two or more base stations simultaneously or not.

HAWAII supports four variants of handoff schemes: Multiple Stream Forwarding (MSF), Single Stream Forwarding (SSF), Unicast Non-Forwarding (UNF) and Multicast Non-Forwarding (MNF) where UNF and MNF used to provide different radio behaviors. The UNF scheme is optimized for networks where the MN is able to listen and transmit to two or more base stations simultaneously for short duration, as in the case of a WaveLAN or Code Division Multiple Access (CDMA) network. The MNF scheme is optimized for networks where the MN is able to listen and transmit to only one base station, as in the case of Time Division Multiple Access (TDMA) network.

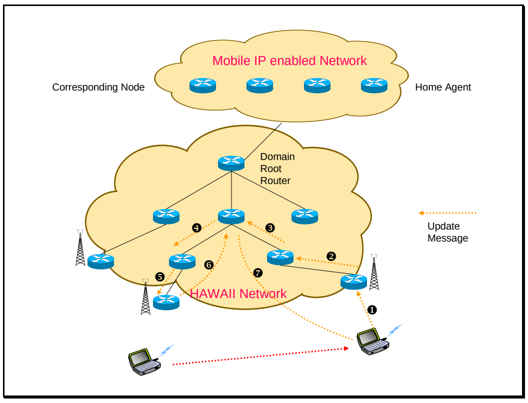

Fig. 4. HAWAII MNF scheme.

CIP also supports two kinds of handoff schemes for the environments in different radio behavior. The semi-soft handoff scheme is optimized for networks where the MN is able to listen and transmit to two or more base stations simultaneously for short duration which is the time that the MN spends in overlap area. The hard handoff is used for networks where the MN is able to listen and transmit to only one base station.

SIP works in application layer rather than network layer, therefore it is independent of the radio behavior.

3.4 Signaling Overhead

A well-designed handoff mechanism should be fast, smooth, and low signaling overhead. Signaling overhead can be minimized to ensure better scalability and loss power consumption of MNs by paging. By tracking idle hosts, MNs need not have to update their location after each handoff, which extends the life of the battery and also reduces air traffic interface. Both basic Mobile IP and HMIP have higher signaling overhead by tunnel mechanism, while the other mobility management protocols generate lower signaling overhead.

3.5 Path Efficiency

The operation of CIP and HAWAII is different when the network topology is not a tree, however. In HAWAII, path setup messages are directed toward the old base station, while CIP route update packets are sent toward the gateway. For non-tree topologies this difference will often result in different nodes being used as the cross-over point. In HAWAII the cross-over node lies at the intersection of the old downlink path and shortest path between the old and new base stations. As a result, the new downlink path will not necessarily be the shortest path between the domain root router and the new base station. Hence, HAWAII may generate suboptimal routes after handoff. This suboptimal routing problem represents a generic trade-off associated with handoff control signaling in micro-mobility management protocols

3.6 Passive Connectivity and Paging

The mobile devices have a very limited power capacity and their batteries must be spared by reducing the mobiles transmissions to the minimum required. An ideal solution would be that the MN emits exclusively when it has data to transmit and nothing during the rest of the time. Unfortunately, if a MN is not emitting and proceeding handoff, it will be impossible to forward an incoming packet destined to it as we do not know where the MN is located.

A standard solution adopted in GSM networks is to divide the network in geographical areas called paging areas. When the MN has no data to transmit, it emits only when changing of paging area. This implies that the network only knows the approximate location of the MN. An incoming packet destined for an idle MN triggers the network to perform a paging in order to deliver the packet. Mobility Management protocols including HMIP, CIP, HAWAII, Intra-Domain Mobility Management Protocol (IDMP) [27] support paging. A major difference between HMIP, CIP and HAWAII is the ability of HAWAII to distribute the burden of paging between all stations of the network.

4. CONCLUSION

This paper investigates several mobility management protocols such as Mobile IP, Cellular IP, HAWAII, Hierarchical Mobile IP and SIP and presents a comprehensive comparison of these mobility management protocols. Most of the micro-mobility protocols including CIP and HAWAII work in conjunction with the MIP.

The most important problem in IP mobility is the handoff management. To reduce the risk of packet losses, this handoff must be as fast and as efficient as possible. Handoff management introduces some types of latencies such as routing update latency. In MIP, the IP routing update is performed through a registration process. This can take a long time but the micro-mobility approach such as HMIP allows to perform only one registration with the HA when connecting for the first time to an administrative domain.

The IETF solutions do not take various wireless network architecture, however the IETF solutions are not complete solution for IP mobility management. A combination of different mobility management protocols could result in a complete IP mobility solution.

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Table. 1. Comparative chart for well-known mobility management protocols

		Mobile IP	Cellular IP	HAWAII	Hierarchical Mobile IP	SIP
Proposed		1996	1998	1999	1996	1999
OSI Protocol Layer		L3	L3	L3	“L3.5”	L7
Mobility	Management	Macro	Micro	Micro	Micro	Macro
	Method	Tunnel	Host Route	Host Route	Tunnel	-
	Agents	HA/FA	Gateway	Routers	HA/GFA/FA	-
	Topology	-	Tree-Style	Tree-Style	Tree-Style	-
	Re-encapsulation	Yes	No	No	Yes	No
	Device	Yes	Yes	Yes	Yes	Yes
	Personal	No	No	No	No	Yes
Resource	Extra Hardware	No	Yes	Yes	No	No
	Extra Software	Yes	No	No	Yes	No
	CPU	High	Low	Low	High	Low
	Memory	High	Low	Low	High	Low
Path Optimization		No	Yes	Sub-Optimal	No	Yes

		Mobile IP	Cellular IP	HAWAII	Hierarchical Mobile IP	SIP
Traffic	Bi-Casting	No	Yes	Yes	No	No
	Buffering	No	No	Yes	No	No
Handoff	Initiator	MN	MN	MN	MN	MN
	Control	Hard	Hard/Soft	Hard/Soft	Hard	Soft
	Fast	No	Yes	Yes	Yes	Yes
	Triangle Routing	Yes	Yes	Yes	Yes	No
	Latency	High	Low	Low	High	High
	Packet Loss	High	Low	Low	High	High
	Packet Duplication	No	Yes	Yes	No	No
	Message	Registration	Update	Update	Registration	Re-INVITE
	Addressing	CoA	Home	CoA	CoA	-
	Address Change	Yes	No	No	Yes	Yes
	Signaling Overhead	High	Low	Low	High	Low
Location	Signaling with	Registration	Update	Update	Registration	Re-INVITE
	Kept in	HA	HA/Gateway	HA/Router	HA/GFA	Server
Security	AAA	Yes	No	No	No	No
	Fast	No	Yes	No	No	No
IP Paging Support		No	Yes	Yes	No	No