Mobility Approaches for All-IP Wireless Networks

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***Abstract*--Several protocols and mechanisms have been developed to support inter-domain mobility and intra-domain mobility for multimedia services in the Internet. However choosing the right kind of mobility management which would meet the requirements and parameters suitable for a particular kind of application is of utmost importance. We review these approaches from the viewpoint of the protocol layers at which they operate and their applicability. We categorize them under the groups of network layer approaches and application layer approaches and compare each method qualitatively from various viewpoints. The motivation in doing such a classification is to identify mobility support methods that require significant network dependence and those that do not rely on knowledge of network elements. Each of these mobility management approaches is appropriate for different set of real-time and non-real-time services such as VoIP, multimedia streaming and file transfer.**

I. INTRODUCTION

Supporting mobility in the Internet is primarily intended to allow a mobile device to move between different cells, subnets and domains while keeping an ongoing multi-media session between the mobile device and its counterpart alive. This is not a trivial requirement to fulfill because IP addresses simply do not work outside the specific networks they belong to. Several protocols and mechanisms have been developed to support intra-domain and inter-domain mobility in the Internet, and several others are likely to follow, as this is an active research area. In this paper we review these approaches from the viewpoint of the protocol layers at which they operate. The motivation in doing such a classification is to identify mobility support methods that require significant network dependence and those that do not rely on knowledge of network elements. We categorize them under the groups of network layer approaches (Section II) and application layer approaches (Section III) and compare each method qualitatively from various viewpoints (Section IV). Section V briefly talks about MIPv6, section VI concludes the paper.

II. NETWORK LAYER APPROACHES

A. Mobile IP and its variants

Mobile IP is a mechanism developed for the network layer to support mobility [13]. Originally it was intended for travelers with laptops over wired networks, and later has been adopted by the wireless community. It supports transparency above the IP layer, including the maintenance of active TCP connections and UDP port bindings. A mobile host is associated with a fixed IP (home IP address). When it connects to a different network other than the one its IP address belongs to, its home network forwards packets to it. A router (or an arbitrary node) that is usually known as the home agent, on the user's home network delivers the packets. There are two different methods to deliver the packets to a mobile host when it is on a foreign network. With the first method, the mobile host adopts a second (temporary) IP address known as the care-of address and registers it with its home agent. When the home agent receives a packet for this user, it encapsulates the packet in another IP packet with the care-of address as the destination address and sends it to the foreign network [14], [15]. The care-of address in this method is said to be co-located and it can be acquired via services like DHCP (Dynamic Host Configuration Protocol) [3] or its optimized version such as DRCP (Dynamic Registration and Configuration Protocol). With the second method, the mobile host first registers with a foreign agent in the network it is visiting. The foreign agent sends (registers) its address to the mobile host's home agent as the care-of address of the mobile host. Packets that are intended for the mobile host are sent to the foreign agent after the home agent encapsulates them with the IP address of the foreign agent. After decapsulating these packets, the foreign agent delivers them to the mobile host. Encapsulating a packet within another packet until it reaches the care-of address is known as tunneling. Note that, encapsulation adds between 8 and 20 bytes of overhead, which adds a lot of overhead for rather small voice packets.

For the methods outlined above to be able to work, a mobile host should be able to know that it has moved from its home network to a foreign network. For this purpose, home agents and foreign agents advertise their presence periodically in their own broadcast domains. A mobile host can also solicit for agent advertisements in case these advertisements are absent. Fig. 1 illustrates the packet transfer between a mobile host and a correspondent host with the base form of Mobile IP (extensions and optimizations to this are described below). Packets from the correspondent host must first travel to the home agent, which are later forwarded to the mobile host either by way of the foreign agent or directly. Packets from the mobile host do not have to traverse the home agent; the mobile host sends them as usual with its home IP address as the source address, which is known as triangular routing.

Optimizations and Extensions to Base Mobile IP Protocol

Mobile IP's routing of all incoming packets via the home network may cause additional delays and waste of bandwidth capacity. However if the correspondent host has the knowledge of where the mobile host is, it can send packets directly to the care-of address of the mobile host. This is achieved by route optimization [16], which is basically providing mobility binding updates to the corresponding host. Binding updates are sent from a home agent upon request, or can be sent upon receiving a warning message from a foreign agent if the mobile host changes location during a communication session. In the second case, the former foreign agent will keep forwarding packets to the new one until the correspondent host updates its mobility binding cache (known as smooth handoff). Although theoretically triangular routing could be avoided by letting the correspondent host know about mobile's new location, this requires the correspondent host to be able to encapsulate packets – which is not achievable without changes in the operating system of the correspondent host including authentication mechanisms.

Basically outgoing packets from the mobile host to a correspondent host do not have to be routed via the mobile host's home network. However, if sender's home IP address contained in the outgoing packets does not match the network the user is actually in (i.e., a topologically incorrect address), then firewalls may reject to forward such packets. To avoid this and due to some other considerations, reverse tunneling is defined as an extension to Mobile IP [12]. With reverse tunneling, all packets from a mobile host go through the home agent before reaching the correspondent host. Another optimization proposed is regional registration [8], which suggests locally registering within a visited domain. In base Mobile IP, a mobile host is required to register with its home agent each time it changes care-of address thus causing signaling delay for the registration if the mobile host is far away from its home agent. Regional registration attempts to decrease the number of registrations by keeping a hierarchical structure of foreign agents. As long as a mobile host's foreign agent is hierarchically under a so-called gateway foreign agent (GFA), it is unnecessary to relay registration messages back to the home agent since the home agent has already registered the GFA's address as the care-of address. One drawback of this approach is the reliability issue; failure of a GFA will bring down the whole hierarchy.

The base Mobile IP requires that a mobile host register with a foreign agent, and subsequently with its home agent. To make Mobile IP handoffs (i.e., the registration process) more suitable for real-time and delay-sensitive applications, two additional methods are proposed in [5]. With the first of these methods, called the Network Assisted, Mobile and Network Controlled (NAMONC) handoff method, the mobile host is informed (assisted) by the network that a layer 2 handoff is anticipated. It proposes to use simultaneous bindings (multiple registrations at a time) in order to send multiple copies of the traffic to potential movement locations before the actual movement. The other method, called the Network Initiated, Mobile Terminated (NIMOT) handoff method proposes extensions to the base Mobile IP so that foreign agents can utilize information from layer 2. Specifically, foreign agents use layer 2 triggers to initiate a pre-registration prior to receiving a formal registration request from the mobile host. Both methods assume considerable involvement of information from layer 2.

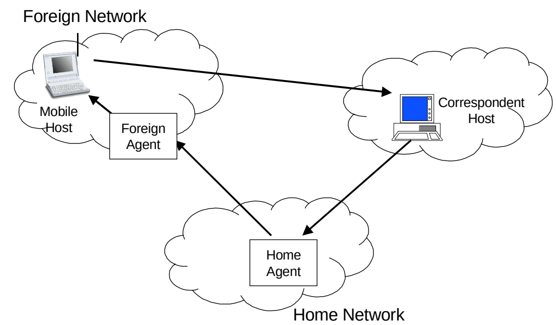

Fig. 1. Base Mobile IP packet flow

A common limitation to all of the Mobile IP approaches is the processing time to encapsulate and decapsulate packets, which might have undesirable effects on real-time sessions.

As Next Generation Internet is making a transition to IPV6 arena, Mobile IPV6 would be more applicable for Mobile Internet where the nodes would be changing their point of attachment very rapidly. Mobile IPv6 shares many features with Mobile IPv4, but the protocol is now fully integrated into IP and provides many improvements over Mobile IPv4, such as an integrated way of providing registration and Mobile IPv4 route optimization. It also makes use of IPv6 features to provide mechanism such as neighbor discovery and address auto-configuration so as to obviate the need for foreign agent. Details of Mobile IPV6 mechanism can be found in [24].

B. Cellular IP

Cellular IP approach [1], [22] separates local and wide area mobility (i.e. adopts a domain-based approach) and uses Mobile IP for inter-domain (wide area) mobility. The basic requirements for Cellular IP to be able to function are to isolate the wireless access network from the core of the Internet via a gateway that acts like a foreign agent and to deploy network elements (base stations) specialized for mobility management. Fig. 2 illustrates the basic architecture.

Isolating the wireless access from the core is necessary since Cellular IP itself is the layer three routing protocol replacing IP in the wireless access network. Packets from a correspondent host are first sent to the mobile host's home agent and then tunneled to the gateway where they are decapsulated. Hosts are identified by their home addresses inside the Cellular IP cloud. Packets generated by mobile hosts are sent to the gateway and later to the correspondent host. Cellular IP base stations snoop actual data packets sent from mobile hosts to the gateway to cache the path taken by them (actually, base stations record only the host IP number and the neighboring base station from which the packet was received). To route packets from the gateway to the mobile host, base stations use the reverse of this path. Hosts that have not transmitted packets for a while are removed from the routing cache of the base stations. Location-tracking method of mobile hosts depends on whether the hosts are active or idle. An idle host is one that has not received or transmitted a packet for a specific time. The assumption is that, coarsely maintaining the position of idle hosts, as a distributed paging cache is enough.

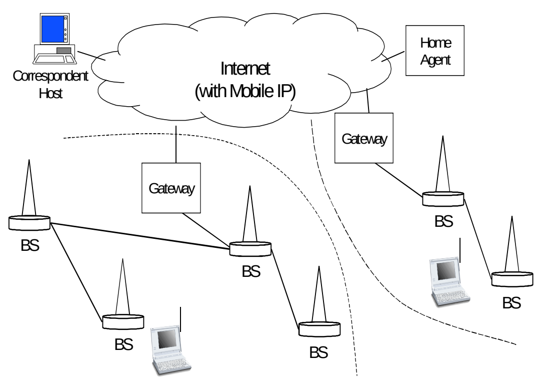

Fig. 2. Cellular IP basic architecture

To achieve this, a technique known as passive connectivity in cellular telephone systems is mimicked in Cellular IP layer. Base stations are geographically grouped into paging areas (a paging area may include more than one base station). Idle hosts send infrequent paging-update packets to the gateway. Note that, for active hosts, a distributed routing cache maintains the exact location of each host. Once a mobile host moves to another base station during a call, it sends a route-update packet back to the gateway. New base station(s) record this path accordingly.

C. HAWAII

Handoff-Aware Wireless Access Internet Infrastructure (HAWAII) is another effort to complement for Mobile IP's inefficiency in supporting intra-domain mobility [17], [18]. In that sense it is similar to Cellular IP, although it defines different set of techniques to achieve this. The basic assumption is that most user mobility occurs within a domain, therefore optimizing routing and forwarding for efficient support of intra-domain mobility will complement Mobile IP's inter-domain mobility support. Another assumption is that base stations are capable of IP routing.

HAWAII segregates the network into a hierarchy of domains. For each domain, on the top of the hierarchy, there is a domain root router. Packets addressed for a mobile host in a specific domain first reaches to the domain root router and are then sent to the mobile host. As long as the mobile host moves within a domain, it retains its IP address. Once the mobile host moves into another domain it is assigned a co-located care-of address, and the home agent in the home domain tunnels packets to this address. The path (route) between the mobile host and the domain root router is specific to that host. It is established (during power-up) and updated (during movement) for that mobile host in the domain root router and pertinent intermediate routers. This information is refreshed periodically by the mobile host, which allows the routers to maintain path state. Principally, the idea is similar to Cellular IP and the regional registration in Mobile IP: a physically distant home agent involvement is not desirable each time the mobile host moves. Four path setup schemes that can be used to re-establish path states when the mobile host moves within a domain are proposed. Two of them forward packets from the old base station to the new base station for a short period (i.e., until the relevant routers update their entries for the specific host). The other two methods do not forward packets during a handoff. Rather, they either bi-cast the packets to two base stations or unicast them for hosts that can simultaneously listen to two base stations. Obviously, HAWAII requires all routers in a domain to be augmented with mobility support so that they are able to handle host-specific path setup messages.

D. MIP-LR

Mobile IP with Location Registers (MIP-LR) is a scheme developed to avoid encapsulation of packets [6], [7] and to provide survivability. In MIP-LR, each subnet may contain a host that functions as a visitor location register (VLR) and/or a host that functions as a home location register (HLR). Each mobile host can be served by multiple HLRs. Each VLR advertises its presence on its local subnet using agent advertisement messages similar to Mobile IP. When a mobile host is located at its local subnet, it is not registered at either the HLR or the VLR. When it moves to a foreign network it obtains a care-of address (CoA) from the pool of addresses that VLR has. The mobile host registers with the foreign VLR using the CoA it has obtained, which in turn relays the registration to the mobile host's HLR. The HLR returns a registration reply containing the allowed lifetime for this registration; the VLR records the mobile host's CoA and the lifetime and forwards the reply to the mobile host.

A correspondent host, wishing to send a packet to the mobile host for the first time, issues a query to the HLR, which returns the mobile host's CoA as well as the remaining registration lifetime. The correspondent host then directly sends the packet to the mobile host's CoA. The correspondent host caches a binding for the mobile host's CoA and uses this binding for subsequent packets destined to the mobile host. The correspondent host must refresh its binding cache by querying the HLR again before the mobile host's remaining registration lifetime expires. In MIP-LR, unlike Mobile IP, HLR can be anywhere (geographically distributed). Also, the tunneling function is eliminated. After a mobile host moves, if the mobile host was previously registered at some other foreign VLR, the new VLR deregisters the mobile host at the old VLR. The deregistration is required so that the mobile host's old CoA can eventually be released for use by some other mobile host. If a VLR runs out of CoAs temporarily, it can still issue its own IP address as a CoA, and, when a mobile host registers using this CoA, inform the HLR accordingly.

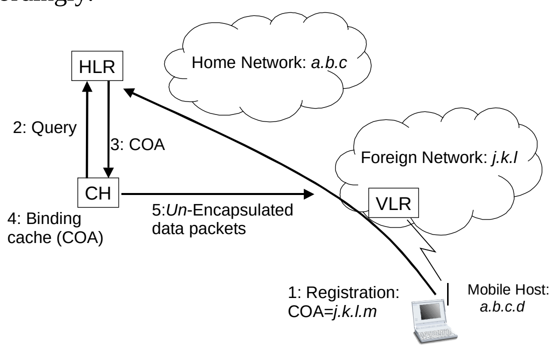

Fig. 3. MIP-LR basic operation

The HLR in turn informs any correspondent host which queries for the mobile host's CoA; the correspondent host then uses tunneling to send packets to the mobile host, and the foreign VLR must decapsulate such packets before delivering them to the mobile host. After a mobile host moves, the correspondent host will have an outdated mobility binding until the remaining registration lifetime expires and the correspondent host queries the HLR again. Since the remaining lifetime could be long, a mechanism is required to update the cache on the correspondent host. Three schemes are used for this: lazy caching, eager caching and tunneling from old foreign agent to the new one. In lazy caching the mobile host informs the old VLR which sends a warning message to the HLR. HLR, in turn, sends a binding update to the corresponding host. In eager caching, the mobile host issues a binding update to each correspondent host it has active sessions. With the third scheme, the old VLR can relay packets to the new VLR after a request by the mobile host.

E. TeleMIP

TeleMIP (Telecommunications-Enhanced Mobile IP), is an intra-domain mobility solution which uses two layers of scoping within a domain [2], [11]. It reduces the latency of intra-domain location updates by specifying an intra-domain termination point called mobility agent (MA). Intra-domain updates are sent only up to the MA, which provides a globally valid care-of address (CoA) to the mobile host. TeleMIP reduces the frequency of global update messages since the MA is located at a higher hierarchy than that of subnets, global updates (to home agent, correspondent hosts, etc.) only occur for inter-domain mobility. It also reduces the requirement of public addresses (IPv4) by adopting a two-level addressing scheme.

In TeleMIP network is divided into domains similar to Cellular IP and HAWAII. Domain identifiers are broadcast in agent advertisement / discovery messages. Network retains control of MA assignment. When a mobile host first moves into a domain, it obtains a global care-of address (mobility agent's address), as well as a local care-of address. MA's global CoA is sent in the registration message to HA. Mobile host also registers itself (with its local CoA) with its MA. Hierarchically, there are foreign agents/DHCP servers at the subnet level under a MA.

They provide the mobile host with a locally-scoped address, which identifies mobile location within the domain. Mobility agent provides mobile host with a global care-of address that stays constant within the domain**.** Mobility agents are distributed within the domain. Multiple MAs can be provisioned for load-balancing and redundancy within the domain. Mobile host's location is globally known only up to the MA-level granularity. Mobile host retains the same MA (global care-of address) within the same domain. All packets from the global Internet are tunneled to the MA, which acts as a single point of enforcement/accounting. MA forwards packets to mobile host, using regular IP routing, by using the local CoA (co-located or FA) as the destination. On subsequent movement within the domain, mobile host only obtains a new local CoA. At that point there is no need to update the home agent or correspondent hosts. However, mobile host updates its MA with its new local CoA. With TeleMIP, if packets come from outside the domain, they have to be encapsulated twice thus causing some additional delay in the delivery of packets [25].

F. TCP with Migrate Option

Although cannot be categorized as network layer or application layer approach, another interesting end-to-end proposal that deserves to be mentioned in this section is the approach in [21]. It proposes a new set of migrate options for TCP to provide a pure end-system alternative to network layer solutions. With this extension, established TCP connections can be suspended by a TCP peer and reactivated from another IP address without a third party (except for the involvement of DNS updates). Obviously this approach requires changing the transport protocol in the end-terminals. Also, as hinted in [21], if both peers are moving simultaneously with this approach cannot locate each other, which can be taken care of by application layer approaches. easily.

III. Application Layer Approaches

A. Session Initiation Protocol (SIP)

The application layer approach (specifically SIP) aims to keep mobility support independent of the underlying wireless technology and network layer elements; thus may serve better for the purposes of service providers who do not own network facilities. SIP [9] is basically an application layer signaling protocol, which allows two or more participants to setup a multimedia session. Several wireless technical forums, such as 3GPP, 3GPP2, and MWIF have agreed upon SIP as the basis of the session management of the mobile Internet. Since it seems that SIP will eventually be part of the mobile Internet protocol architecture, it may make sense to leverage some of its inherently present mobility support functions. SIP can help provide personal mobility, terminal mobility, session mobility and service mobility. For the purposes of this paper, we will elaborate on the terminal mobility support, however a comprehensive discussion on other mobility types can be found in [19]. [4] discusses framework requirements for SIP based mobility for the Internet. Basically, supporting terminal mobility is to provide the ability to move while a session (call) is active. With SIP, being mobile does not require to modify (or add) capabilities to existing terminal's operating system. If the mobile host moves during an active session, first it receives a new address from a DHCP server (or a variant of it), and then sends a new session invitation to the correspondent host (Fig. 4). With this new invitation, it tells its new IP address (contact) so as to forward packets properly. Actually, this invitation is nothing more than updating the current ongoing session description. Then the mobile host also updates its registration with the home SIP server so that new sessions that would come can correctly be redirected to its new address. Basic advantage of using SIP for terminal mobility support is that the mobile host does not have to go through first registering with its home agent to tunnel the binding updates to the corresponding host as in Mobile IP.

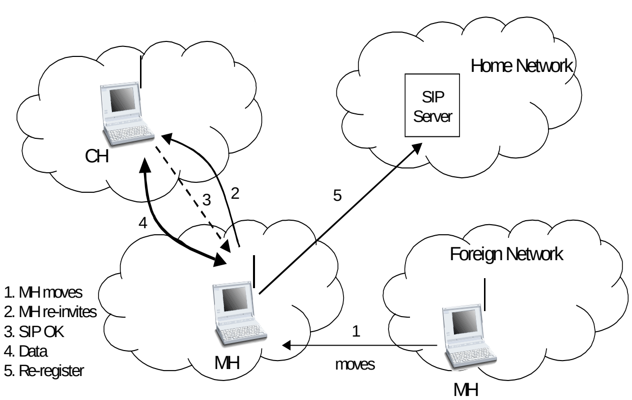

Fig. 4. SIP terminal mobility support

In addition SIP based mobility can take care of scenario for cases where both the communicating nodes move around. Note that the SIP mobility support approach does not necessarily exclude the Mobile IP approach, rather it may work to complement based on the kind of application such as real-time and non-real-time traffic. Although there are proposals to take care of TCP based application by using SIP signaling [26], SIP based mobility works best for RTP/UDP based application such as voice over IP and video streaming.

IV. QUALITATITIVE COMPARISONS

Table I shows qualitative comparisons of the approaches.

TABLE I

	Intra-domain encapsulation	Inter-domain encapsulation	Changes to end-systems	Triangle routing	Infrastructure change	Fast handoff
MIP	Yes	Yes	Yes	Yes	No	No
MIP-RO	Yes	Yes	Yes	No	No	No
MIP-RR	Yes	Yes	No	Yes	No	Yes
MIP-FF	Yes	Yes	No	Yes	Yes	Yes
CIP	No	Yes	No	Yes	Yes	Yes
HAWAII	No	Yes	No	Yes	Yes	Yes
MIP-LR	No	No	Yes	No	No	Yes
TeleMIP	Yes	Yes	No	Yes	Yes	Yes
SIP	No	No	No	No	No	Yes

MIP-RO: Mobile IP Route Optimization; MIP-RR: Mobile IP with Regional Registration; MIP-FH: Mobile IP with Fast Handoff Extensions; CIP: Cellular IP, SIP: Session Initiation Protocol

Note that, MIP-RR and MIP-FF do not cause triangle routing if they are used together with MIP-RO. However, change to end-systems would apply.

V. Mobile IPv6

As end-to-end communication becomes more prevalent there has been an increasing need to provide IP connectivity to each and every communicating device such as PDA, palmtop, many household appliances such as washing machine, refrigerator and car appliances. Its increased address space and inherent support for security and auto-configuration has made it an attractive candidate to support mobility for the next generation Internet. Mobile IPv6 [24] is the corresponding framework for IPv6. Since address auto-configuration is standard part of MIPv6, MH will always obtain a COA routable to the foreign network. Thus there is no need to have an FA in MIPv6 framework. When the mobile node moves to a new foreign network it acquires a temporary care-of-address using stateless auto-configuration or DHCP. While it provides a way of making sure the uniqueness of an address as the mobile moves to a new router space, it also adds delay for the binding update and binding acknowledgement. In order to support router optimization in a better way it also takes advantage of IPv6 destination option to provide binding updates and binding acknowledgements directly to the CH and HA. Compared to regular Mobile IP, there are inherent advantages in MIPv6. Route optimization is a standard feature of MIPv6, thus there is no need for the CH to be equipped with additional software as with MIP-RO. Explicit binding updates or MIP registrations are not needed, as the destination options are naturally piggy-backed on IP packets. For the on-going sessions it avoids triangular routing, thus packets from CH to MH need not be encapsulated but are sent directly to MH with its COA as the source route. However for the new sessions there is still a need for HA and the packets from CH need to travel to HA and get tunneled to the mobile host.

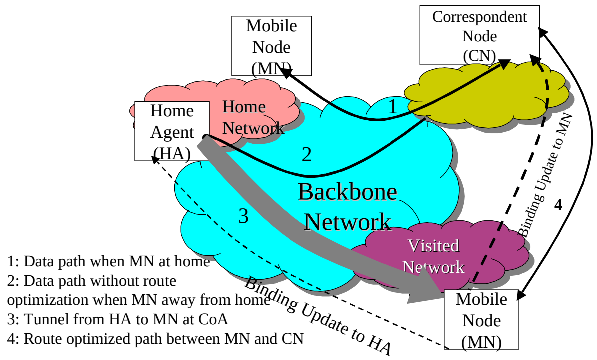

Fig. 5. Mobile IPv6

Although Mobile IPv6 can be termed as a network layer approach and one needs to install MIPv6 stack so as to support mobility in IPv6 space, in future any standard operating system vendor may like to include this as part of bundled software. In some way there is still a lot of similarity between SIP based mobility and Mobile IPv6 in terms of providing binding update. On the other hand a SIP based multimedia session can easily co-exist with Mobile IPv6 for supporting mobility. Comparison of SIP based mobility with MIPv6 is for future study.

VI. Conclusions

This paper illustrates some of the mobility approaches for supporting an all IP wireless network classified broadly into two categories such as network layer and application layer. All these approaches provide suitable mobility solutions for both intra and inter domain scenario. Although most of the approaches discussed here and comparison there of are related to Mobile IPv4, this paper also provides a brief over-view of MIPv6. MIPv6 is an extension of MIP-RO and has a lot of similarity with SIP based application layer mobility.

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