IP Micro-Mobility Protocols

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The IETF Mobile IP Working Group is discussing a number of enhancements to the base protocol to reduce the latency, packet loss and signaling overhead experienced during handoff. In this article, we discuss a number of "micro-mobility protocols" that extend Mobile IP with fast handoff and paging capabilities. The aim of this article is not to provide an exhaustive survey of these protocols. Rather, we discuss the motivation behind micro-mobility, present common characteristics that a number of proposals share and briefly describe some of the key contributions discussed by the working group. In the longer term there is a need to understand the differences between many of the micro-mobility proposals discussed in this article in terms of, complexity of the design choice, and performance differences. As part of that process we have recently made available the Columbia Micro-mobility Suite (CMS). The CMS software is freely available from the web (comet.columbia.edu/micromobility) and includes ns source code extensions for Cellular IP, Hawaii and Hierarchical Mobile IP.

I. Introduction

Wireless access to the Internet may outstrip all other forms of access in the near future. It is likely that mobile users will expect similar levels of service quality as wireline users. Such a vision presents a number of technical challenges for Mobile IP in terms of performance and scalability.

Recently, a number of *micro-mobility protocols* have been discussed in the IETF Mobile IP Working Group that address some of these performance and scalability issues. Micro-mobility protocols are designed for environments where mobile hosts change their point of attachment to the network so frequently that the basic Mobile IP protocol [1] tunneling mechanism introduces network overhead in terms of increased delay, packet loss and signaling. For example, many real-time wireless applications (e.g., voice-over-IP) would experience noticeable degradation of service with frequent handoff. Establishment of new tunnels can introduce additional delays in the handoff process causing packet loss and delayed delivery of data to applications. This delay is inherent in the round-trip incurred by Mobile IP as the registration request is sent to the home agent and the response sent back to the foreign agent. Micro-mobility protocols aim to handle local movement (e.g., within a domain) of mobile hosts without interaction with the Mobile IP enabled Internet. This has the benefit of reducing delay and packet loss during handoff and eliminating registration between mobile hosts and possibly distant home agents when mobile hosts remain inside their local coverage areas. Eliminating registration in this manner reduces the signaling load experienced by the core network in support of mobility.

As the numbers of wireless users grow so will the signaling overhead associated with mobility management. In cellular networks registration and paging techniques are used to minimize the signaling overhead and optimize mobility management performance. Currently, Mobile IP supports registration but not paging. An important characteristic of micro-mobility protocols is their ability to reduce the signaling overhead related to frequent mobile migrations taking into account a mobile host's operational mode (i.e., active or idle). When wireless access to Internet becomes the norm then Mobile IP will have to provide efficient and scalable location tracking in support of idle users, and paging in support of active communications. Support for "passive connectivity" to the wireless Internet balances a number of important design considerations. For example, only keeping the approximate location information of idle users requires significantly less signaling and thus reduces the load over the air interface and in the core network. Reducing signaling over the air interfaces in this manner also has the benefit of preserving the power reserves of mobile hosts.

In this article we discuss a number of micro-mobility protocols. Our aim is not to provide an exhaustive survey of the field. Rather, we discuss the motivation behind the work, present some common characteristics that a number of proposals share and briefly describe some of the key contributions discussed in the Mobile IP working group over the past several years.

II. Motivation

Micro-mobility protocols aim to support fast handoff control with minimum or zero packet loss, and to minimize signaling through the introduction of paging techniques thereby reducing registration to a minimum. These enhancements are necessary for the Internet to scale to support very large volumes of wireless subscribers. In this section we discuss a number of issues that motivate the design of micro-mobility protocols.

Fast Handoff. Support for fast handoff, which reduces delay and packet loss during handoff, is an important attributed of micro-mobility protocols. A number of design choices influence handoff performance including handoff control, buffering and forwarding techniques, radio behavior, movement detection and prediction, and coupling and synchronization between the IP and radio layers. Tighter coupling between layers, for example, may minimize handoff latency but may impact the general applicability of the solution.

The working group has considered a number of contributions that cover a wide set of design choices. Many proposals discuss seamless handoff (i.e., zero or near zero loss) where data is forwarded between the old and new access points during handoff. Many of these approaches support fairly complex signaling, buffering and synchronization procedures. Layer three movement detection (e.g., eager cell switching) plays an important roll in handoff performance. The delay associated with recognizing and registering at a new access point can have a significant impact on mobility and data delivery. Signal strength based handoff schemes may provide better solutions. In this case layer three handoff control is triggered by a layer two event. Given the wide diversity of wireless devices it is difficult to define the operation and interaction of these radios in a global mobility aware network, without falling into link specific definitions. There is a need to define an open radio API that captures the essence of each wireless technology without exposing complex link specific details. This may help facilitate layer two "triggered" handoff across a variety of radio technologies. Support for hard handoff and variants of soft handoff are under discussion in the working group. Many proposals support mobile-controlled handoff schemes, while others, consider network-controlled handoff. Other important design issues relate to assumptions governing the detection/prediction of host movement between different access points, the level of coupling between layer two and three, and the degree of synchronization between radio handoff and Mobile IP registration process.

Paging. Typically, fixed hosts connected to the Internet (e.g., desktop computers connected to LANs) remain on-line for extended periods of time even though most of the time they do not communicate. Being "always connected" in this manner results in being reachable around the clock with instant access to Internet resources. Mobile subscribers connected to the wireless Internet will expect similar service. In the case of mobile hosts maintaining location information in support of being continuously reachable would require frequent location updates which would consume precious bandwidth and battery power. This signaling overhead can be reduced through the introduction of paging. Mobile hosts are expected to typically operate on batteries with limited lifetime. This makes it important to save idle mobile hosts from having to transmit frequent location update messages. This requires explicit support from networking protocols, such as the ability to track location approximately and the ability to page idle mobile hosts. Idle mobile hosts do not have to register if they move within the same paging area. Rather, they only register if they change paging area. Paging has been implemented by a number of micro-mobility protocols including Cellular IP [3] and Hawaii [4], and recently proposed as extensions to Hierarchical Mobile IP [8].

Fast Security/AAA. One of the goals of micro-mobility protocols is to support fast handoff control for mobile hosts that frequently handoff. The performance of network services that contribute to handoff latency should be optimized in support of this goal. Therefore, networking functions (e.g., security, billing, etc.) invoked during handoff should be designed to assist this real-time operation. While authenticating location update messages seems necessary in most cases, data encryption over the air interface or in the fixed network may be not always needed. User authentication for authorization or accounting may be required in some cases, while anonymous free access is sufficient in others. The extent to which various micro-mobility protocols support security and Authentication, Authorization and Account (AAA) [19] functions has a large impact on the practical applicability of the protocol. The security model adopted by micro-mobility protocols impacts network and device performance, quality of service, manageability and the interoperation with other (possibly global) AAA systems. Because mobile hosts need to be authenticated during handoff, the security mechanisms used need to be responsive to the handoff time-scale found in micro-mobility environments. In particular the traditional AAA model where security-aware servers are potentially located at far away locations may be not responsive enough to accommodate fast handoff. Session keys for example that may be used by mobile hosts to perform authentication must be promptly available at the new base station during handoff. Timeliness of the authentication process is critical in the case of micro-mobility due to the real-time nature of handoff. In contrast, global mobility solutions may have broader requirements such as user identification, bilateral billing and service provisioning agreements. These boarder requirements may out weigh the need to support fast handoff control where the scalability of the global AAA system is of more importance than handoff. One can envision, however, micro-mobility protocols that build on global AAA preferences by offering enhanced services (e.g., fast session key management) to aid fast handoff.

Micro-Mobile QOS. Micro-mobility protocols will have to support the delivery of a variety of traffic including best effort and real-time traffic. There has been very little work on a suitable QOS model for micro-mobility. Extending the differentiated services model to micro-mobility seems like a logical starting point. However, the differentiated services concepts such as aggregation, per-hop behavior, service level agreement and slow time scale resource management may be impractical in wireless IP networks. For example, it may be impractical to allocate resources at every base station in a wireless access network in support of a service level agreement that offers assured service, or to use traffic engineering techniques that promote under utilization of wireless links in support of some per-hop behavior characteristic. In Mobile IP a host acquires a new address each time it hands off to a new base station. A new reservation between the mobile host and its home agent would be triggered in this case. This would be rather disruptive in support of micro-mobility because most of the path between the home agent and mobile host would remain unchanged. Work on QOS support for micro-mobility is predicated on differentiated services first being resolved in the wired network.

III. Characteristics

Micro-mobility proposals can be characterized into a number of categories.

Hierarchical Mobility. Hierarchical mobility management reduces the performance impact of mobility by handling local migrations locally and hiding them from home agents. In this case the Internet address known by a home agent no longer reflects a mobile host's exact point of attachment. Rather, it represents the address of a gateway that is common to a potentially large numbers of network access points. When a mobile host moves from one access point to another one (which is reachable through the same gateway) then the home agent need not be informed. The role of micro-mobility protocols is to ensure that packets arriving at the gateway are forwarded to the appropriate access point. In order to route packets to the mobile host's actual point of attachment, micro-mobility protocols maintain a "location data base" that maps host identifiers to location information. Most micro-mobility protocols require hosts that participate in mobile routing to maintain a list of host entries and search this list for each downlink packet. List entries in these protocols are assigned timers and are removed after a pre-specified time unless refreshed. Each entry contains a pointer to the next node toward the mobile host's actual point of attachment. To forward a downlink packet, nodes must read the original destination address, find the corresponding entry and forward the packet to the next node. Two styles of hierarchical mobility are supported by micro-mobility, these are, "hierarchical tunneling" and "mobile-specific routing" techniques, as discussed in the next two sections, respectively.

Hierarchical Tunneling. In hierarchical tunneling approaches the location data base is maintained in a distributed form by a set of foreign agents in the access network. Each foreign agent reads the incoming packet's original destination address and searches its visitor list for a corresponding entry. If the entry exists then it contains the address of next lower level foreign agent. The sequence of visitor list entries corresponding to a particular mobile host constitutes the host's location information and determines the route taken by its downlink packets. Entries are created and maintained by registration messages transmitted by mobile hosts. These proposals rely on a tree-like structure of foreign agents. Encapsulated traffic from the home agent is delivered to the root foreign agent. Each foreign agent on the tree decapsulates and then reencapsulates data packets as they are forwarded down the tree of foreign agents toward the mobile host's point of attachment. As a mobile host moves between different access points, location updates are made at the optimal point on the tree, tunneling traffic to the new access point. These protocols sometimes require the mobile host to send new types of messages or to be aware that a hierarchical tunneling protocol is in use. Examples of micro-mobility protocols that use hierarchical tunneling include regional tunneling management [6] used by a number of Hierarchical Mobile IP proposals.

Mobile-Specific Routing. Mobile-specific routing approaches avoid the overhead introduced by decapsulation and reencapsulation schemes, as is the case with hierarchical tunneling approaches. These proposals use routing to forward packets toward a mobile host's point of attachment using mobile specific routes. These schemes typically introduce implicit (e.g., based on snooping data) or explicit signaling to update mobile-specific routes or they are aware that a routing protocol is in use. In the case of Cellular IP mobile hosts attached to an access network use the IP address of the gateway as their Mobile IP care-of address. The gateway decapsulates packets and forwards them toward a base station. Inside the access network, mobile hosts are identified by their home address and data packets are routed using mobile-specific routing without tunneling or address conversion. The routing protocol ensures that packets are delivered to the host's actual location. Examples of micro-mobility protocols that use mobile-specific routing include Cellular IP and Hawaii.

IV. Protocols

In what follows, we provide an overview of a number of micro-mobility proposals. Each protocol is identified as having one or more of the following protocol design attributes: **(h)** fast handoff, **(p)** paging, **(s)** fast security, **(m)** hierarchical mobility, **(t)** hierarchical tunneling and **(r)** mobile-specific routing. We use these design attribute to present a simple taxonomy.

Cellular IP (h,p,s,m,r). The Cellular IP (CIP) proposal [3] from Columbia University and Ericsson supports fast handoff and paging techniques. Location management and handoff support are integrated with routing in Cellular IP access networks. To minimize control messaging, regular data packets transmitted by mobile hosts are used to refresh host location information. Cellular IP uses mobile originated data packets to maintain reverse path routes. Nodes in a Cellular IP access network monitor (i.e., "snoop") mobile originated packets and maintain a distributed, hop-by-hop location data base that is used to route packets to mobile hosts. Cellular IP uses IP addresses to identify mobile hosts. The loss of downlink packets when a mobile host moves between access points is reduced by customized handoff procedures. Cellular IP supports two types of handoff scheme. Cellular IP hard handoff is based on simple approach that trades off some packet loss in exchange for minimizing handoff signaling rather than trying to guarantee zero packet loss. Cellular IP semisoft handoff exploits the notion that some mobile hosts can simultaneously receive packets from the new and old base stations during handoff. Semisoft handoff minimizes packet loss providing improved TCP and UDP performance over hard handoff. Distinguishing idle and active mobile hosts reduces power consumption at the terminal side. The location of idle hosts is tracked only approximately by Cellular IP. Therefore, mobile hosts do not have to update their location after each handoff. This extends battery life and reduces air interface traffic. When packets need to be sent to an idle mobile host, the host is paged using a limited scope broadcast. A mobile host becomes active upon reception of a paging packet and starts updating its location until it moves to an idle state again. Cellular IP also supports a fast security model that is suitable for micro-mobility environments based on fast session key management. Rather than defining new signaling, Cellular IP access networks use special session keys where base stations independently calculate session keys. This eliminates the need for signaling in support of session key management, which would inevitably add additional delay to the handoff process.

Hawaii (h,p,m,r). The Hawaii protocol [4] from Lucent Technologies proposes a separate routing protocol to handle intra-domain mobility. Hawaii relies on Mobile IP to provide wide-area inter-domain mobility. A mobile host entering a new foreign agent domain it is assigned a collocated care-of address. The mobile node retains its care-off address unchanged while moving within the foreign domain, thus the home agent does not need to be involved unless the mobile node moves to a new domain. Nodes in a Hawaii network execute a generic IP routing protocol and maintain mobility specific routing information as per host routes added to legacy routing tables. In this sense Hawaii nodes can be considered as enhanced IP routers, where the existing packet forwarding function is reused. Location information (i.e., mobile-specific routing entries) is created, updated and modified by explicit signalling messages sent by mobile hosts. Hawaii defines four alternative path setup schemes that control handoff between access points. An appropriate path setup scheme is selected depending on the operator's priorities between eliminating packet loss, minimizing handoff latency and maintaining packet ordering. Hawaii uses IP multicasting to page mobile hosts when incoming data packets arrive at an access network and no recent routing information is available.

Hierarchical Mobile IP (h,p,s,m,t). The Hierarchical Mobile IP (HMIP) proposal [6] from Ericsson and Nokia employs a hierarchy of foreign agents to locally handle Mobile IP registration. In this protocol mobile hosts send mobile IP registration messages (with appropriate extensions) to update their respective location information. Registration messages establish tunnels between neighboring foreign agents along the path from the mobile host to a gateway foreign agent. Packets addressed to mobile hosts travel in this network of tunnels, which can be viewed as a separate routing network overlay on top of IP. The use of tunnels makes it possible to employ the protocol in an IP network that carries non-mobile traffic as well. Typically one level of hierarchy is considered where all foreign agents are connected to the gateway foreign agent. In this case, direct tunnels connect the gateway foreign agent to foreign agents that are located at access points. Paging extensions for Hierarchical Mobile IP are presented in [8] allowing idle mobile nodes to operate in a power saving mode while located within a paging area. The location of mobile hosts is known to home agents and is represented by paging areas. After receiving a packet addressed to a mobile host located in a foreign network, the home agent tunnels that packet to the paging foreign agent, which then pages the mobile host to re-establishes a path toward the current point of attachment. Paging a mobile node can take place using a specific communication time-slot in the paging area similar to the paging channel in second generation cellular systems. Paging schemes increase the amount of time a mobile host can remain in a power saving mode. In this case, the mobile host only needs to wakeup at predefined time intervals to check for incoming paging requests. Table 1 shows a simple comparison of CIP, Hawaii and HMIP.

Intra-Domain Mobility Management Protocol (h,p,m,r). The Intra-Domain Mobility Management Protocol (IDMP) [15] from Telcordia and University of Texas reduces handoff latency and signaling overhead of frequently roaming hosts by localizing mobility-related management within a wireless access domain. IDMP supports fast handoff with minimal packet losses and paging for reduced signaling. IDMP uses a hierarchical structure with a mobility agent at the top of the hierarchy with several child sub-network foreign agents interconnected to it. The top-level mobility agent functions as a gateway to the Internet. No global registration is necessary as long as hosts move within the agent's administrative domain. The home agent only needs to be updated when the mobile host changes administrative domains. Global and local addresses handle mobility. The global address points toward the current administrative top-level mobility agent. This address remains unchanged as long as the mobile host remains in the domain. In contrast, the local address is a pointer toward the visiting foreign agent and changes every time a mobile host hands off to a different child foreign agent.

3G Wireless (h). The 3G wireless proposal [18] from members of the 3GPP2 consortium describes a Mobile IP based micro-mobility management protocol for third generation cdma2000 wireless networks. Enhancements to Mobile IP include mobility management support between radio access networks and the Internet. The work focuses on the connectivity between mobile hosts and foreign agents at the link layer. A feature of cdma200 networks is that the physical layer terminates at a radio network node while the administrative foreign agent resides at a separate serving node. The serving node is responsible for controlling the link layer operations of mobile hosts. This includes establishing, maintaining, and terminating connections to and from mobile hosts. The 3G wireless proposal also minimizes the disruption experienced by mobile hosts during handoffs between radio access networks.

Edge Mobility Architecture (h,m,r). The Edge Mobility Architecture [10] proposed by British Telecom, Ansible-Systems and the University of Maryland presents a general framework that supports host mobility in wireless access networks. The authors argue that edge based routing protocols need to be more responsive to host mobility and further conjecture that exist routing protocols developed for highly dynamic environments (e.g., mobile ad hoc networks) are very applicable. The edge proposal discusses the use of the TORA routing protocol in this context. However, the approach supports a generic framework where other fast routing algorithms could support micro-mobility. Edge mobility supports transparent handoff between access routers using different wireless technologies through information exchanged between access routers. Edge mobility does not advocate any specific layer two functions. Rather, it presents a common interface to hide the details of different wireless technologies from the higher layers. A mobile host acquires an IP address within an address block allocated to the access router. An access router advertises the IP address prefix associated with an address block using an intra-domain routing protocol. Here the intra-domain routing protocol uses longest prefix match to overrule or overwrite the standard prefix routing of allocating access routers. During handoff a host redirect route is introduced to forward packets from the old to the new access router.

Proactive Handoff (h,m,t). The foreign agent assisted hand-off proposal [12] from Sun Microsystems and the University of Illinois allows one or more foreign agents to forward packets prior to receiving a Mobile IP registration request from a mobile host. After detecting that a mobile host is about to perform a handoff to a different location, the mobile node's serving foreign agent sends a binding update request to the "new" foreign agent prior to handoff. This proactive binding update contains the mobile host's home address, security related information, as well as the serving gateway foreign agent's address. The proposal assumes that foreign agents can detect the direction of movement of mobile hosts by taking advantage of link layer and radio specific information. Upon reception of the binding update, the new foreign agent sends a handoff request toward the gateway foreign agent, which in turn towards packets to all foreign agents registered by the

Table 1: Simple Comparison of Cellular IP, Hawaii and Hierarchical Mobile IP

	Cellular IP	Hawaii	Hierarchical MIP
OSI Layer	L3	L3	“L3.5”
Nodes Involved	all CIP nodes	all routers	FAs
Mobile Host ID	home addr	c/o addr	home addr
Intermediate Nodes	L2 switches	L2 switches	L3 routers
Means of Update	data pkt	signalling msg	signalling msg
Paging	implicit	explicit	explicit
Tunneling	no	no	yes
L2 Triggered Handoff	optional	optional	no
MIP Messaging	no	yes	yes

mobile host. The proactive protocol completes the layer two handoff and forward data to the mobile host before the Mobile IP registration proceeds. In essence, proactive handoff delivers IP packets to the mobile host via the new base station before Mobile IP can “handoff”.

Anchor Handoff (h,s,m,t). The anchor handoff proposal [11] from Cisco and Rensselaer Polytechnic Institute reduces handoff latency attributed to Mobile IP registration and security related settings. Anchor handoff proposes a number of enhancements to ease local registration and global indirect registration. A mobile host authenticates with its home agent during global registration and establishes a secure tunnel between the home agent and foreign agent. The foreign agent then acts as anchor foreign agent for future registrations. This proposal assumes mobile hosts and foreign agents can establish a shared key through a mechanism that can be used to authenticate a mobile host with a foreign agent. In this scheme, only a local registration is necessary after handoff. This rule holds as long as the mobile host moves within the same domain between the visiting foreign agent and the anchor foreign agent.

Fast Handoff (h,m,t). The fast handoff proposal [21] from Ericsson assumes that the serving foreign agent anticipates the movement of mobile hosts by sending multiple copies of the traffic to potential neighbor foreign agents. “Bicasting” is used to support data forwarding to the previous and new foreign agents while the mobile host is moving between the old and new access points. Fast handoff predicts the movement of mobile hosts through coupling with layer two functionality that, it is argued, is dependent on the type of access technology used. Bicasting uses simultaneous bindings, where the mobile hosts sets the ”S” bit in the registration request. Depending on the networking model (i.e., flat or hierarchical model) the receiving agent (home agent, gateway foreign agent or regional foreign agent) will add a new binding for the mobile host. As in the case of proactive handoff, the fast handoff proposal also assumes that it can anticipate the movement of mobile hosts in advance of handoff. Fast handoff completes the Mobile IP handoff prior to establishing layer two connectivity or forwarding data. The total delay for fast handoff is limited to the time needed to perform a layer two handoff.

Session Initiation Protocol Mobility (h,m,t). The Session Initiation Protocol (SIP) mobility proposal [9] from Telcordia, Toshiba and Columbia University enhances SIP to support multimedia sessions for mobile devices in wireless access networks. SIP is gaining widespread use as a signaling protocol for handling multimedia applications and telephony in the wired Internet. The proposal covers roaming support for both real-time and non-real-time applications. Similar to most micro-mobility protocols, SIP mobility considers partitioning the network along the lines of other micro-mobility proposals. Mobility management encompasses domain handoff and sub-network handoff leaving the link layer to deal with cell-to-cell handoff. The proposed SIP mobility framework can support TCP applications by spoofing addresses through the use proxy servers. General support for authentication, accounting, quality of service management and SIP registrations for mobile users is also discussed.

Unified Hierarchical Mobility (h,m). The Unified Hierarchical Mobility model (UHM) from INRIA [14] presents a framework for interoperability between different types of micro-mobility protocols. The authors argue that different micro-mobility protocols will be implemented in the Internet and that there will be a need for mobile hosts to handoff between access networks running different micro-mobility protocols (e.g., Cellular IP and Hawaii). UHM decomposes mobility management into three protocol components. An access protocol specifies a standard approach to registration between mobile hosts and domains. A micro-mobility protocol manages local mobility that can vary from one domain to another depending on which protocol is supported (e.g., Hawaii, IDMP, HMP, etc). A macro-mobility protocol based on Mobile IP manages mobility between domains. Mobile node registration is independent of the micro-mobility protocol operating within a specific domain. The nature of the mobility support is therefore very much dependent on which micro-mobility protocols are deployed.

Paging Extensions for Mobile IP (p). The paging extensions for Mobile IP (P-MIP) [17] developed by Columbia University, Fujitsu and Broadcom is designed to reduce signaling load in the core Internet and power consumption of mobile hosts. Active mobile nodes operate in exactly the same manner as in Mobile IP. When a mobile host changes its point of attachment, it registers with a new foreign agent. In contrast, idle mobile hosts do not register when they move in a same paging area. An idle mobile host is forced to register only when it moves to a new paging area. When packets are destined to mobile hosts then home agents forward data packets to registered foreign agents. A registered foreign agent first checks if it has the mobile host’s information on record. If it has a record, then it checks if the mobile host supports paging or not. If paging is supported then the registered foreign agent checks the mobile host's state. If the mobile node is in active mode then the registered foreign agent decapsulates and forwards packets to the mobile host, as in the case of Mobile IP. In contrast, if the mobile node is in idle mode, the registered foreign agent sends a paging request message to other foreign agents in the same paging area as well as transmitting the message on its own access network. When a mobile host receives a paging request, it registers through the current foreign agent to its home agent. After receiving a registration request, the mobile node sends a paging reply back to its registered foreign agent through its current foreign agent to inform the register foreign agent of its current location. When the registered foreign agent receives a paging reply, it forwards any buffered packets to the mobile host.

Hierarchical Mobile IPv6 (h,m). There has been a number of recent Internet drafts addressing fast handoff and paging issues for MIPv6. The Hierarchical Mobile IPv6 (HMIPv6) [13] proposal from INRIA uses the IPv6 address space and neighbor discovery mechanisms to support flexible, scalable and robust mobility management. HMIPv6 uses anchor points called mobility servers and supports two or more levels of hierarchy. The simplest implementation of HMIPv6 supports two levels of hierarchy (e.g., a micro-mobility protocol and Mobile IP). The micro-mobility protocol in HMIPv6 is based on one or more mobility servers. When a mobile host moves into a new domain it acquires a global and a local address. Mobile hosts only need to change their local address while moving within a domain, their global address remains unchanged. Packets addressed to a mobile host's global address are routed to the domain, intercepted by the mobile server and encapsulated and tunneled toward the mobile host's actual location, as defined by its local address. The global address does not represent the address of the mobile server. Rather, it is an address associated with the mobile server's sub-network. This operation allows HMIPv6 to dynamically change the mobile server without changing the global address. This feature supports load balancing and robustness.

Mobile IPv6 Handoff (h,m). The Mobile IPv6 handoff proposal [20] from Sun Microsystems addresses latency and packet losses issues associated with MIPv6 handoff. This proposal allows mobile hosts to send IPv6 binding updates with multiple care-of-addresses. These include the care-of-address of the mobile node's current location as well as the care-of-address of other access points in the neighborhood that the mobile node may handoff to. This "neighborhood" is established on a per mobile basis and is based on the network layout and the direction the mobile host in moving in. A new routing header extension allows home agents and corresponding hosts to route packets toward a mobile node's last known recorded position, and if not there, to the other care-of-addresses defined by the binding update. To some extent this proposal leverages ideas used in paging where the location of mobile host is approximately tracked via paging areas.

V. Conclusion

In this article we have presented a brief overview of the micro-mobility protocols discussed in the Mobile IP Working Group over the last two years. The working group is in the process of consolidating all contributions with the idea of having one standard for fast handoff. As part of the filtering process the working group eliminated any proposals that did not support tunneling and Mobile IP messaging. A design team was formed to discuss four proposals. After the design team completed their work they were left with the proactive and fast handoff proposals discussed above. The working group is in the process of discussing the pros and cons of these two proposals.

There are many similarities between the fast and proactive handoff proposals. Both proposals aim to limit handoff delay to the time needed to perform a layer two handoff. While neither proposal advocates a particular link layer technology each proposal couples layer three and two to minimize handoff delay. Both proposals predict the movement of mobile hosts anticipating new points of attachment. Differences exist, however. The proactive proposal first completes layer two handoff, then starts to forward data to the mobile host, and finally, allows layer three registration to proceed. Handoff control is driven by the network as opposed to mobile hosts. The fast handoff proposal anticipates the movement of a mobile host allowing the mobile host to register with the "new" foreign agent or gateway foreign agent prior to layer two connectivity being established. This allows packets to be forwarded by the receiving agent to the old and new foreign agents prior to, or synchronized with, establishing connectivity at layer two. Some form of synchronization is required so that layer three registration completes before the mobile host is instructed to perform layer two handoff.

A number of open issues remain. What is the minimal coupling between the IP and radio layers to facilitate fast handoff? Here the challenge is to keep the "interface" as simple and radio independent as possible. Both proposals call for some degree of coupling and synchronization. However, this is not clearly spelt out in the proactive and fast handoff Internet drafts. Both the proactive and fast handoff proposals rely on predicting new access points in advance. Is this assumption reasonable? What styles of handoff control should be supported? The proactive proposal advocates network-controlled handoff while fast handoff is mobile initiated. The proactive draft requires some extra support from the network elements but allows for vanilla MIP client implementation, which may be an issue with the fast handoff proposal.

In summary, the proactive and fast handoff proposals being discussed by the working group make a number of assumptions regarding handoff control, radio behavior, movement prediction, layer coupling and protocol synchronization. Any limitations associated with these design choices need to be understood to determine if there is any hidden cost or lack of generality of the two schemes. The process of consolidating these two proposals has recently resulted in a single proposal for fast and low latency handoff for Mobile IPv4 networks. A similar consolidation has also resulted in an Internet-Draft for Mobile IPv6 fast handoff and paging.

Other recent developments in the area of micro-mobility in IETF include the formation of a new working group to look at solutions that possibly adopt per-host routing techniques in support of fast and localized handoff. The Seamoby Working Group is formulating problem statements for IP paging, context transfer (including QOS state) and micro-mobility.

Finally, there is a growing need to best understand the differences between many of the micro-mobility proposals discussed in this article in terms of, complexity of the design choice and performance differences. As part of that process, we have recently made available the Columbia Micro-mobility Suite (CMS). The CMS software is freely available from the web (comet.columbia.edu/micromobility) and includes ns source code extensions for Cellular IP, Hawaii and HMIP.

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