A STUDY OF MICRO-MOBILITY MANAGEMENT USING CELLULAR IP PROTOCOL

Pratik Murali
Department of Computer Science, University of Texas at Arlington
pmurali@cse.uta.edu

Abstract

A brainchild of the collaborative efforts of the COMET research lab at Columbia University and Ericsson Research, Cellular IP is a micro-mobility paradigm, which seeks to enhance wireless access to the Internet by offering seamless mobility support. Cellular IP shows excellent results in handoff management in environments where mobile nodes exhibit a very high migration frequency. Driven by the current industrial prognosis about ubiquity of wireless access to the Internet and the prevalence of IP as the technology of choice for the next generation mobile networks, this term paper, seeks to explain the concepts behind Cellular IP and compares its performance with other existing micro-mobility protocols and concludes by describing the applicability of Cellular IP for Micro-mobility management in 3G networks and beyond.

Keywords: Cellular IP, Micro-mobility, Wireless Access Networks, And Fast Handoffs

1 Introduction

As wireless technology improves at a brisk pace, mobile devices for every situation and user are being created. From visual phones to communicators and hand held PDA's, technology is getting smaller and smarter, allowing the user to incorporate technology into everyday life more than ever before. These devices have increased the pervasiveness of wireless Internet access necessitating the need for enhancements to Mobile IP infrastructure. High-speed wireless access to the Internet entails "seamless mobility" [2] which is defined as the ability of a network to support fast handoff between base stations with low delay and minimum or zero packet loss. As the base station density increases, so will the handoff rates, thus placing significant demands on future mobile network architecture, protocols and services to support seamless mobility. To alleviate the handoff latencies resulting in packet losses, three contemporary protocols have been proposed, Cellular IP (CIP) [1], Handoff Aware Wireless Access Internet Infrastructure (HAWAII) [4] and Hierarchical Mobile IP protocol [5]. Mobile IP optimized for macro-mobility increases the handoff latency by repeatedly communicating with a distant home agent. The objective therefore is to minimize communication with the Home Agent by localizing handoffs concerning host mobility within a subnet and at the same time to efficiently inter work with Mobile IP to provide wide area mobility support.

2 Cellular IP Overview [2]

Cellular IP envisages a wireless Internet [2] with a lot of wireless subscribers, with an ability to actively communicate most of the time. The wireless IP communicators will be in be switched on and ready for service, constantly reachable by the wireless Internet. Analogous to "*paging*" in cellular telephony networks, it will be sufficient for the wireless Internet, only to know the approximate location of the population of its population of "*idle*" users. When data needs to be forwarded to these users, the network needs to efficiently search and find these users in a timely scalable manner.

A scalable location management scheme is proposed with a support for *"passive connectivity"*. According to this concept, the wireless Internet, needs to handle location tracking of active and idle users, this involves a significant decrease in signaling and hence reduces the load over the air interface and the core network. Reducing control signaling over air interfaces helps in preserving battery reserves of the mobile hosts.

2.1 Cellular IP Protocol

Cellular IP inherits cellular systems principles for mobility management, passive connectivity and handoff control, but is designed based on the IP paradigm. The universal component of a Cellular IP network is the *base station*, which serves as a wireless access point but at the same time routes IP packets and integrates cellular control functionality traditionally found in Mobile Switching Centers (MSC) and Base Station Controllers (BSC). The base stations are built on regular IP forwarding engines, but IP routing is replaced by Cellular IP routing and location management. The Cellular IP network is connected to the Internet via a *gateway* router. Mobile IP manages Mobility between gateways while Cellular IP handles mobility within access networks. Mobile hosts attached to the network use the IP address of the gateway as their Mobile IP care-of address

Assuming Mobile IPv4 and no route optimization, packets will be first routed to the host's home agent and then tunneled to the gateway. The gateway removes the packets from the tunnel and forwards them toward base stations. Inside the Cellular IP network, mobile hosts are identified by their home addresses and data packets are routed without tunneling or address conversion. The Cellular IP routing protocol ensures that packets are delivered to the host's actual location. Packets transmitted by mobile hosts are first routed to the gateway router and from there on to the Internet.

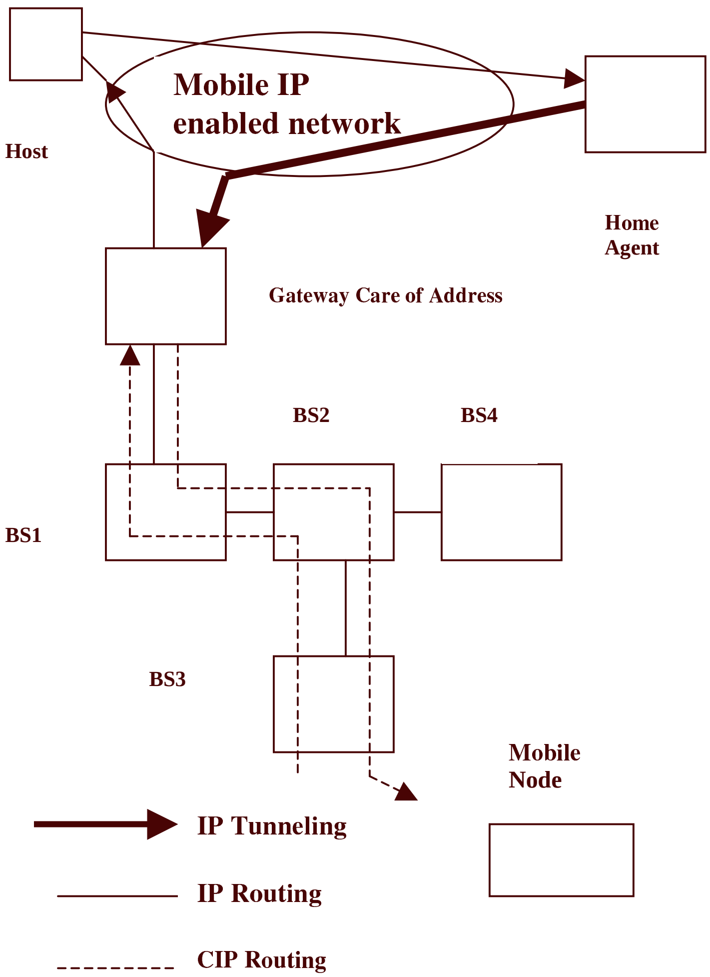

Figure 1: Cellular IP Access Network

In Cellular IP, location management and handoff support are integrated with routing. To minimize control messaging, regular data packets transmitted by mobile hosts are used to establish host location information. *Uplink* packets are routed from mobile to the gateway on a hop-by-hop basis. The path taken by these packets is cached in base stations. To route downlink packets addressed to a mobile host the path used by recent packets transmitted by the host is reversed. When the mobile host has no data to transmit then it periodically sends empty IP packets to the gateway to maintain its downlink routing state. Following the principle of passive connectivity mobile hosts that have not received packets for a certain period of time allow their downlink soft-state routes to timeout and be cleared from the routing cache. In order to route packets to idle hosts a Cellular IP mechanism called paging is used. The succeeding sections describe the various features of the protocol like routing, paging, handoff and location update, as presented in the paper by Valko, Campbell et al. [3].

2.1.2 Routing

In the routing functionality the gateway router, periodically broadcasts a flood of beacon messages to the access network. Base stations keep track of the most recent interface they received these Beacon messages from, and use it as the next hop address to route packets. The routing is shortest path, hop by hop routing. The shortest path algorithm used here is more complex in nature as it needs to determine the shortest path to all the nodes in the network. All packets transmitted by mobile nodes are routed through these paths. Routing is defined for the uplink direction, i.e. towards the gateway and in the downlink direction, i.e. from the gateway to the Mobile Node.

As each packet passes these nodes en route to the gateway, their route information is recoded as a quintuple of the IP address (IP) of the source, the interface of the previous hop (IC), and the MAC address of the originator node, the current time plus the route timeout (ET) and the arrival timestamp (TS) of the latest packet. This mapping {IP, IC, MAC, ET, TS} is stored in "*routing caches*" maintained by each base station. This mapping remains active for a configurable period called "*route-timeout*" and this period is refreshed by each packet that traverses the same base station after having originated from the same Mobile Node. A packet is dropped if it arrives from a neighbor different from what it's mapping indicates or if it has a timestamp older than the current timestamp.

In some cases the correspondent node might be a source of UDP traffic and the Mobile node will not have any ACK packets to transmit in the uplink path. In such cases the Mobile Node will transmit "*route update*" packets at regular time slots called "*route update time*". These packets refresh the routing caches and terminate at the gateway.

2.1.2.1 Route Maintenance Overhead

Presented here are the results of an analytical study of the route maintenance overhead, performed at Columbia University. The network operator will typically set the route-timeout to be a small multiple of the route-update time. This ensures that the mobile host's routing cache mappings remain valid even if a few route-update packets are lost. Let ***Tru*** denote the route-update time and ***αTru*** the route-timeout where is a small integer. To choose an optimal value for *Tru*, the following trade-off should time, packets addressed to this host continue to be delivered to the old base station increasing the network load and reducing network performance. A small value of ***Tru*** should be used to minimize this condition. On the other hand, an active host that has no data to send must transmit route-update packets at a rate of **1/*Tru***. This load increases with decreasing ***Tru.*** Let the cost of carrying a packet to or from the mobile host be defined as the size of the packet in bits. This model neglects differences in uplink and downlink cost due to different traffic conditions but is sufficient to characterize the ***Tru*** trade-off. Consider a mobile host that is receiving data at a constant rate r p denote the fraction of the time when it is not sending packets and is forced to transmit route-update packets instead. (We note that in some typical IP applications downlink traffic is considerably higher than uplink traffic. This, however, does not necessarily cause p to be high if acknowledgments are transmitted over the uplink.). The cost of transmitting route-update packets during

rupT/Tru where *Rru* is the size of a route-update packet in bits. During this time the mobile performs ***T/TH*** handoffs where ***TH*** (dwell time) is the mean time spent in a cell. After each handoff, the old route remains active for at most ***αTru***, the exact value depending on when it was last updated before handoff. Hence the mean cost of sending packets along the old route after handoff is **r*Tru*()2/1−α** and the total cost of misrouted packets during time ***T*** is ***rTTru()2/1−α /TH*** The optimal route-update time $\hat{T}_{ru}$ is the one that minimizes the sum of these costs and is calculated as

$$\hat{T}_{ru} = \frac{\sqrt{p R_{ru} T_h}}{\sqrt{r(\alpha - 1/2)}}$$

The parameters of the simulation carried out at Columbia were as follows: The mobile host performs handoffs every 30 seconds while it is receiving data at a rate of 128 kbps. The size of route-update packets is 102 bytes, is 3 and p associated with the mobility of an active host and is calculated as:

$$C_a = \frac{p R_{ru}}{\hat{T}_{ru}} + \frac{r \hat{T}_{ru}(\alpha - 1/2)}{T_H} = \sqrt{\frac{4 p R_{ru} r(\alpha - 1/2)}{T_H}}$$

The important thing to notice out here, is that the *cost is not proportional to the migrational frequency, but to its square root*. This shows Cellular IPs efficiency in supporting highly mobile hosts.

2.1.3 Paging

An *idle* mobile node is defined as a host that has not received any data packets for a system defined period called "*active state timeout*". Idle mobile hosts will allow their routing caches to time out thus conserving battery power. They periodically transmit control packets called "*paging-update*" packets at regular timeslots called "*paging-update -time*". These control packets serve to update data structures called "*paging caches"* maintained by all the Base Stations, in addition to the Routing Caches. Hence idle mobile hosts will have mappings in the Paging Caches, but not in the Routing Caches.

When a packet needs to be transmitted to a mobile host in idle state, the gateway router will find no route cache mappings in the downlink neighbors. This initiates the paging process. In case no paging cache mappings are found either, then a broadcast flood is initiated. On receiving a broadcast, the idle mobile host moves into active state and sends a routing update packet all the way to the gateway, thus updating it's routing path, and paves way for the next packet to arrive in the downlink But if paging caches do exist, these broadcast storms need not be initiated conserving memory and processing cost.

2.1.3.1 Paging overhead

The paging-update time T_{pu} is subject to a similar trade-off as T_{ru}. A selected value that is too small will result in very frequent paging-update packets being sent by idle mobile hosts. On the other hand, considering that the paging-timeout is a small multiple of the paging-update time, increasing T_{pu} will result in an increase in the number of cells that an idle mobile host is paged in. Paging is initiated when a new data session starts by a downlink packet, for instance a TCP connection is initiated *to* the mobile host. Let λP denote the arrival rate of such sessions and RP the mean amount of traffic (bits) sent in paging packets. The paging packets are delivered to all the cells to which the mobile host has valid paging cache mappings. Let us first assume that all base stations have paging caches and that the probability of immediately revisiting a cell is negligible. Paging occurs in the 'primary' cell that the target mobile host resides in plus any other 'secondary' cells where the mobile host has valid paging cache mappings. Secondary cells represent cells that the mobile host has recently visited and that have valid paging cache for the target mobile host. Paging secondary cells is a waste of transmission resources and reflects the cost of our paging scheme. The mean number of secondary cells paged is $(\beta - 1/2)Tpu/TH$ where β is the ratio between the paging-timeout and the paging-update time. The optimal paging-update value is the one that minimizes the sum of paging-update traffic and wasted paging traffic and is obtained as $\sqrt{\frac{R_{pu} T_H}{\lambda_p R_p (\beta - 1/2)}}$ where R_{pu} is the size of the paging update packet in bits. The total cost associated with the mobility of an idle host is given by: $C_i = \sqrt{\frac{4 R_{pu} \lambda_p R_p (\beta - 1/2)}{T_H}}$. The significance of this result is that, the downlink data rate **r** $\lambda_P R_P$ though largely dependant on the application will still be a lot lower than **r,** which is the mobility cost of active users. This forms the basis for "*passive connectivity*".

2.1.4 Handoff

Cellular IP protocol, offers two handoff variations called "*Hard Handoff*" and "*Semisoft Handoff*". Mobile Hosts initiate handoff by listening to Beacon signals emanating from the Base Stations and decide their next access point based on the signal strengths

To perform a handoff a mobile host has to tune its radio to the new base station and send a route-update packet. This creates routing cache mappings en route to the gateway hence configuring the downlink route to the new base station. Handoff latency is the time that elapses between the handoff and the arrival of the first packet through the new route. For *hard handoff* this equals the round-trip time between the mobile host and the *crossover point*, which is the gateway in the worst case. During this time, downlink packets may be lost. The mappings associated with the old base station are not cleared at handoff, rather, they timeout as the associated soft-state timers expire.

Semisoft handoff on the other hand exploits the notion that mobile hosts can simultaneously receive packets from old and new base stations. In a semisoft mechanism, route cache mappings for the new base station are created before the actual handoff procedure. Before a mobile host hands off to a new access point, it sends a semisoft packet to the new base station and immediately returns to listen to the old base station.

The semisoft packet establishes new route cache mappings between the crossover and the new base stations. During this route establishment phase, the Mobile Node will still be connected to the old base station. After a time lag called "*semisoft period*" the Mobile Node performs a regular handoff. The semisoft delay can be an arbitrary value, which is proportional to the mobile-to-gateway round-trip delay. This delay ensures that by the time, the mobile host finally tunes its radio receiver to the new base station; its downlink packets are being delivered to both the old and new base stations.

According to [3], while the semisoft packet ensures that the mobile host continues to receive packets immediately after handoff, it does not, however, fully assure smooth handoff. Depending on the network topology and traffic conditions, the time to transmit packets from the crossover point to the old and new base stations may be different and the packet streams transmitted through the two base stations will typically not be synchronized at the mobile host. If the new base station "lags behind" the old base station, the mobile host may receive duplicate packets. Reception of duplicate packets in this case is not disruptive to application operations. If, however, the new base station "gets ahead" then packets will be deemed to be missing from the data stream observed at the receiving mobile host. The second component of the semisoft handoff procedure is based on the observation that perfect synchronization of the two streams is not necessary. The condition can be eliminated by temporarily introducing into the new path a constant delay sufficient to compensate, with high probability, the time difference between the two streams. This can be best achieved at the cross-over switch that understands that a semisoft handoff is in progress due to the fact that a semisoft packet has arrived from a mobile host that has a mapping to another interface. The mapping created by the semisoft packet has a flag to indicate that downlink packets routed by this mapping must pass a "delay device" before transmission. After handoff, the mobile host will send data or route-update packets along the new path, which will clear this, flag and cause all packets in the delay device to be forwarded to the mobile host

3 Comparison of existing Micromobility protocols.

This local mobility can be solved by more efficient procedures called local or micro mobility protocols, which should be deployed in scoped networks, called access networks to reduce the delays and the extent of route updating. The assumption is that a local protocol can address these goals better by limiting its applicability to a smaller domain (such as an intranet - e.g. WLAN, and not the entire Internet as in the case of Mobile IP) and reverting to Mobile IP for the general case of internet mobility support. This assumption may require that the scope of a local mobility protocol be restricted to the case of mobility support
of a mobile host whose routable IP address does not change.

By providing a local mobility scheme that localizes mobility management signaling can be kept to a minimum; thereby reducing handover latency. This should allow for improved scalability and reliability with handover of a mobile node between different access routers. Deployment of such a scheme may be easier as it is done locally and no requirements would be imposed outside the micro-mobility domain. Based on this motivation, a lot of micromobility protocols were proposed in the IETF Mobile Working group. Three key protocols that came into existence before the advent and progressive deployment of IPV6 were:

- Cellular IP
- Handoff Aware Wireless Access Internet Infrastructure (HAWAII)
- Hierarchical Mobile IP

The HAWAII protocol [4] developed by lucent technologies proposes a separate routing protocol to handle intra-domain mobility. Here, a Mobile Node entering a new Foreign Agent domain is assigned a collocated care-of address. The mobile node maintains its care-of address while roaming in the foreign domain, hence the Home Agent need not be involved unless the Mobile Node changes domains. Every node in a HAWAII subnet is essentially a Layer 3 router and executes a generic IP routing protocol and also maintains mobility-specific routing information as per host routes added to legacy routing tables. HAWAII also defines four alternative path setup schemes that control handoff between access points. The appropriate path setup scheme is selected depending on the operator's priorities between eliminating packet loss, minimizing handoff latency, and maintaining packet ordering. IP Multicasting is used to page idle mobile hosts when incoming data packets arrive at an access network and no routing information is available.
Ericsson and Nokia developed Hierarchical Mobile IP [5] and it 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 the mobile host 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 (GFA). 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 [5] allowing idle mobile nodes to operate in a power saving mode while located within a paging area. The location of mobile hosts is known by 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 the packet to the paging foreign agent, which then pages the mobile host to re-establish a path toward the current point of attachment. The paging system uses specific communication time-slots in a paging area. This is similar to the paging channel found concept found in second generation cellular systems. In this paper the authors purport a generic micromobility management protocol, centered on the concept of a *Mobile Routing Point (MRP),* which is a common feature for all three protocols. In case of Cellular IP, the MRP is a L3 node and all CIP nodes are MRPs, in the case of Hawaii, it is a L3 node and all autonomous system routers in Hawaii subnet are L3 nodes and in the case of Hierarchical Mobile IP all MRPs are Foreign agents and are classified by the authors as "L3.5" switches (because they are tunneling endpoints).

Based on the simulation studies [3], the results were classified into handoff quality, route control messaging and deployment considerations. Each wired connection was modeled (in ns-2) as a 10 Mbps duplex link with a 2 ms delay. Mobile hosts connected to the access points using the ns-2 carrier sense multiple access with collision avoidance (CSMA/CA) wireless link mode, where each Access Point (AP) operates on a different frequency band. The simulation results were obtained using a single mobile host, continuously moving between APs at a speed that could be varied during simulation. Such a movement pattern was followed to ensure that the Mobile Node always goes through the maximum overlapping region between two radio cells. The simulation accommodated both TCP and UDP traffic. UDP probing traffic was directed from CH to MH and consists of 210 byte packets transmitted at 10 ms intervals. TCP sessions represented greedy downloads from the corresponding host to the mobile node using Reno congestion control.

The first observation was that results for Cellular IP hard handoff and Hawaii were very similar. In both cases handoff delay is related to the packet delay between the APs and the crossover node. When the mobile host moves between AP1 and AP2 the delay is small. If the crossover distance is larger, the handoff delay increases with an extra packet delay of 2 ms for each additional hop. The authors purport that the results are a direct consequence of the similarity between these two protocols, particularly in the way in which the protocols build up the route between a crossover node and new AP.

In contrast to Cellular IP and Hawaii, Hierarchical Mobile IP updates routing only when registration messages reach the GFA. Therefore, Hierarchical Mobile IP cannot benefit from the fact that a crossover node is topologically close to the APs. performance in the case of the maximum crossover distance for Cellular IP and Hawaii. crossover distance for Cellular IP and Hawaii.

For route control messaging, based on the results of the simulation, the authors [3] concluded that protocols that do not identify the crossover Mobile routing point would have no ability to discard update messages before the gateway. Cellular IP is one such protocol that cannot support such behavior. Thus micromobility protocols have the following design options with respect to route control.

- Send all handoff and update messages to the gateway.
- Ensure that old entries are always removed in the network and let MRPs identify themselves as crossover nodes based on this property.
- Explicitly determine the crossover MRP at handoff.

4 Relevance of Cellular IP in 3G Networks and Beyond

With 3G systems just beginning to be deployed it is necessary to consider how they will evolve to include a much wider range of users, applications and economic deployment. There is no industry consensus on what “Systems beyond 3G “ will look like but, as far as the network is concerned, ideas and concepts often quoted

- Transition to an “All-IP” network
- Ad-Hoc sub-networks as part of future networks
- Addition of micro-cellular technologies (such as WLANs)
- Software Radio –allowing a single terminal to connect to multiple access technologies

- Multi-homed terminals – capable of vertical hand-over between different access technologies (eg Cellular to WLAN)

Fixed-mobile convergence – whereby users access the same services and applications but these are adapted to their current terminal/location

In order to support these developments a much more flexible network architecture will be required than has been the case with traditional mobile networks. In particular:

- The close integration between the air interface network protocols and signalling must be reduced and transformed into an interface that can be used with any air interface.
- The future mobile network must use IP natively – meaning that network layer functions – such as QoS and mobility are handled by IP protocols within the network.

In order to cope with any application or service the network should simply be a basic, QoS-enabled, IP packet delivery service. All other functionality should be provided at the edge of the network (including, possibly, at the end terminals

Within such an evolved IP network there are two types of mobility that are commonly differentiated:

- Personal mobility – where users access the same services from different terminals (in IP SIP has been proposed as a technology to support personal mobility)
- Terminal mobility – where a user on a single terminal moves within and between networks.

Terminal mobility [14] can further be broken down into macro and micro mobility. When a terminal moves from one IP domain to another it is a significant network event – usually a new IP address is required, security plus re-authentication is needed and the air interface technology may change, this is termed macro mobility. Mobile IP is an IP protocol that supports macro mobility.

Since, Mobile IP in its base form is not capable of supporting real time hand-over between base stations with in the same network. This is essentially because the home agent, responsible for tunnelling the packets to the moving user, may be located even in another continent and the delay of the users registering with a new foreign agent and that being communicated with the home agent is considerable – during which time many packets can be lost., this increases the relevance of micromobility schemes like Cellular IP et al.

The 4G systems called the systems beyond the third generation focus on a scenario where multimedia services are provided by a mobile Internet, to provide theses services the Internet is evolving as well. The evolution introduces the concept of flows, or soft-state connections, in the connectionless IP network. Hence when a multimedia session starts, the network recognises this and an prepares an end-to-end soft-state connection, this is called Layer 3 Switching, with MPLS as one of the proposals to solve this problems. With requirements for real time, high fidelity services, quality of service becomes a big issue, here there will be a need to tune the losses caused by handovers, like packet loss and jitter. Hence cellular IP will play a huge role in micrombility management in 3G networks and beyond.

5 Discussion and Conclusion

Finally, though Cellular IP was marketed as a great solution to the micro-mobility problem, during the course of writing this paper, this technology has its own drawbacks, which have not been addressed by the authors in [3]. In Cellular IP, not accounting for the gateway, the solution is not scalable. The routers in the network must keep track of all the individual systems in their area. Thus instead of routing by the network address, each individual host requires a dedicated entry in the routing tables. Also source routing is required for the uplink. Current routers are equipped to deal with plain routing only and all other options like source routing, result in performance degradation. Finally all upstream datagrams must be inspected at all routers to record the actual location of the mobile terminal. Thus route update procedures are called for these packets, which result in severe performance degradation. Also the semisoft handoff scheme for cellular IP is optimised for networks where the Mobile Node is able to listen/transmit to two or more base stations simultaneously for a short duration- the time that the mobile host spends in the overlap area- as in the case of a WaveLAN or a code division multiple access (CDMA) network. This scheme improves the efficiency of handoff in terms of packet loss but with more delay.

As regards the comparison between the micromobility protocols, the longer handoff delay in the HAWAII handoff scheme causes more packet loss then in Cellular IP. Comparing packet loss numbers for Cellular IP and HAWAII at higher handoff rates the performance of both the forwarding and non forwarding schemes in HAWAII is worse than that of all the handoff schemes in Cellular IP.

In a Cellular IP network, the number of hops from source to destination is a constant since all the routing update packets must reach the gateway. However in HAWAII, nodes upper than the crossover router are not involved when the handover is happening. In this aspect HAWAII is more reliable compared to Cellular IP and has less control signaling in the nodes higher than the crossover nodes as compared to Cellular IP.

The future wireless Internet infrastructure is headed the all-IP way, a scenario where IP along with MPLS will be used to build a mobile operators infrastructure, and with the advent of services like video-on-demand, vide conferencing and other delay intolerant real time services, the demand for an effective micromobility management scheme is going to be the need of the hour, will it be Cellular IP? Or is there going to be a route optimization support in Cellular IPV6, which will handle micromobility management? It remains to be seen.

6 References

[1] A. Valkó, "**Cellular IP: A New Approach to Internet Host Mobility**," *ACM SIGCOMM Comp. Commun. Rev.*, vol. 29, no. 1, Jan. 1999, pp. 50–65.

[2] A. T. Campbell, Gomez, J., Kim, S., Turanyi, Z., Wan, C-Y. and A, Valko "**Design, Implementation and Evaluation of Cellular IP**, IEEE Personal Communications, Special Issue on IP-based Mobile Telecommunications Networks, June/July 2000

[3] A. T. Campbell, Gomez, J., Kim, S., Turanyi, Z., Wan, C-Y. and A, Valko "**Comparision of IP Micromobility protocols**" IEEE Wireless Communications Magazine, Vol. 9, No. 1, February 2002

[4] R. Ramjee *et al.*, "**HAWAII: A Domain-Based Approach for Supporting Mobility in Wide-area Wireless Networks,**" *Proc. IEEE Int'l. Conf. Network Protocols*, 1999.

[5] E. Gustafsson, A. Jonsson, and C. Perkins, "**Mobile IP Regional Registration**," Internet draft, draft-ietfmobileip-reg-tunnel-03, work in progress, July 2000.

[6] Chiussi, F.M.; Khotimsky, D.A.; Krishnan, S. "**Mobility management in third-generation all-IP networks "** IEEE Communications Magazine, Volume: 40 Issue: 9, Sept.2002 Page(s): 124 -135

[7] Teughels, M.; Van Lil, E.; Van de Capelle **Mobility control beyond 3G system,** A Communications and Vehicular Technology, 2000. SCVT-200. Symposium on, 2000 Page(s): 28 -33

[8] Veres, Campbell, A. T, Barry, M and L-H. Sun, "**Supporting service differentiation in wireless packet using distributed control"** *IEEE Journal of Selected Areas in Communications (JSAC)*, Special Issue on Mobility and Resource Manegement in Next-Generation Wireless Systems, Vol. 19, No. 10, pp. 2094-2104, October 2001

[9] A. Campbell, J. Gomez, C-Y. Wan, Z. Turanyi, A. Valko, "**Cellular IP**" Internet Draft, draft-valko-cellularip-01.txt, October 1999

[10] A. T. Campbell, S. Kim, J. Gomez, C-Y. Wan, Z. Turanyi, A. Valko, "**Cellular IP Performance**" draft-gomez-cellularip-perf-00.txt, October 1999

[11] Z. D. Shelby, D. Gatzounas, A. T. Campbell, C-Y. Wan, **"Cellular IPV6"** draft-shelby-seamoby-cellularipv6-00.txt, November 2000.

[12] S. Kim, C-Y. Wan, W. B. Paul, T. Sawada, A. T. Campbell, J. Gomez, A. G. Valko, **"A Cellular IP Demonstrator"** Sixth IEEE International Workshop on Mobile Multimedia Communications (MOMUC'99), San Diego, California, November 1999.

[13] A. G. Valko, J. Gomez, S. Kim, A. T. Campbell, **" On the Analysis of Cellular IP Access Networks"** IFIP Sixth International Workshop on Protocols for High Speed Networks (PfHSN'99), Salem Massachusetts, August 1999

[14] Charles Perkins, editor, ``**IP Mobility Support,**'' Internet RFC 2002, October 1996

[15] David B. Johnson, Charles Perkins, "**Route Optimization in Mobile IP**," Internet Draft, draft-ietf-mobileip-optim-07.txt, November 1998