

PERFORMANCE IMPROVEMENT OF MICROMOBILITY ROUTING WITH CELLULAR IPV6

H. N. Uzo, T. A. Nwodoh

*Department of Electronic Engineering
University of Nigeria.*

Abstract

This paper examines the core of the wireless access infrastructure problem, how to find, track, and send data to mobile Internet nodes. These issues come about because of mobile nodes roaming between Internet domains, often in power-down mode, along with the need to perform vertical handoffs for seamless coverage. The Internet, which has been designed for fixed nodes, needs real improvement in order to deal with this new wireless Internet trend. The main contribution of this paper is in the development of a new protocol, Cellular IPv6, to deal with wireless access routing, handoffs, and paging. First an overview of general wireless access routing technologies and techniques is given. The design of Cellular IPv6 is then examined in detail. Cellular IP Route Optimisation, a technique for improving Cellular IP performance, is also introduced in the paper. This modification to the Cellular IP standard solves triangle routing problems, improving performance in the presence of intra-domain traffic. Preliminary simulation results for this technique are presented and discussed.

Keywords: Cellular IP, Cellular IPv6, Route Optimization, OPNET.

1.0 Introduction

Cheap personal computers (PCs) have spread not only across developed countries, but also across developing countries. Now, digital cellular and short-range wireless technologies have become another revolution; wireless Internet. By enabling Internet services through portable wireless devices, the Internet has the possibility for even deeper penetration. Portable electronic devices such as mobile phones are becoming increasingly widespread even without Internet capability. Providing Internet access to those devices is now the key challenge for the Internet [1].

Although wireless Internet might sound like the ultimate solution, it turns out to be a real technical and administrative challenge. Widespread wireless technologies and ISPs are needed to provide the basic connection to end users. The inherent instability and mobility of wireless devices require new capabilities for the Internet Protocol. If the research, standardization, and deployment of these capabilities do not happen in the near future, wireless Internet may stagnate.

Wireless Internet research has been up to speed with these new trends. Many mobile wireless access technologies such as

WLANs, Bluetooth, and GPRS have reached the point of affordable, wide-spread deployment. The Internet Protocol version 6 along with Mobile IP (MIP) [2] has been standardized to handle addressing and roaming problems, although deployment has been problematic. Most interesting however, is the area of wireless access networks where research and standardization efforts have not yet come to agreement. The problems involved with wireless access networks are challenging. Routing, paging, handoff services must then be developed on top of the standards. The network layer is a good level for implementing these kinds of services, as the Internet Protocol provides addressing and routing. In addition, using the network layer has the advantage of enabling the use of heterogeneous wireless interfaces, for example mixing IEEE 802.11 and Bluetooth within the same access network.

The challenge of providing workable IP-based wireless access with new standards such as IPv6 is the motivation for the work in this paper. Cellular IP [3] is one such protocol that provides IP-based wireless access. Through its use in this research, it was found that the IPv4 based protocol could be improved with modifications that take

advantage of IPv6 and Mobile IPv6 [4]. A new protocol, Cellular IPv6 [5], based on the original Cellular IP was specified working with the original authors of [5]. In addition, Cellular IP version 6 (CIPv6) was implemented and released to the public as a proof-of-concept. Finally, live demonstrations were made at INET 2001[6], which is a major international Internet conference.

In addition to the development of CIPv6, it was found that many micromobility protocols have problems with triangle routing within a single domain. Research was carried out to find a solution for Cellular IP (CIP) to eliminate triangle routing, thus improving performance for traffic between nodes in the same domain. Route optimisation for CIP was developed as a result. This modification to the CIP specification has been published, simulated, and released with the CIPv6 implementation mentioned above.

CIPv6 was developed as a modification to the original CIP with changes for IPv6, mobility, and security. This protocol is examined in detail in this paper. The original Cellular IP protocol also contained other problems not addressed by CIPv6: namely, triangle routing is performed for traffic between mobile hosts in the same access network. This paper is limited to addressing the Cellular IPv6 protocol and route optimisation modifications. Cellular IP is only one part of Wireless Internet that provides scalable routing, handoff, and paging for wireless access networks. Other topics such as context-transfer, handoff algorithms, accounting, security mechanisms, and vertical handoffs are beyond the scope for this paper.

2.0 Cellular IP

Cellular IP (CIP) is a micromobility protocol developed by the University of Columbia's COMET group and Ericsson [7]. The aim is to provide similar services as cellular mobile phone networks, such as power-friendly paging and smooth handoffs. Cellular IP works independently of Mobile IP by implementing a separate protocol [3]. A hop-

by-hop soft state routing technique is used to forward packets to mobile hosts (MH). Instead of specific signalling, uplink data packets from MHs are used to refresh the routing caches of CIP nodes. This minimizes signaling traffic. A semi-soft handoff procedure is employed to reduce the number of packets lost during a handoff. Finally, a built-in paging function allows nodes to stay in power-down mode, even while performing handoffs.

A CIP network contains a number of entities, as seen in Figure 1. The CIP Gateway acts as the default router for all mobile hosts in the wireless access network. It also functions as the Foreign Agent for MIP. Base Stations act as points of attachment for mobile hosts, they are responsible for broadcasting advertisements. Any number of CIP nodes can be arranged in a multi-level hierarchy between the gateway and base stations.

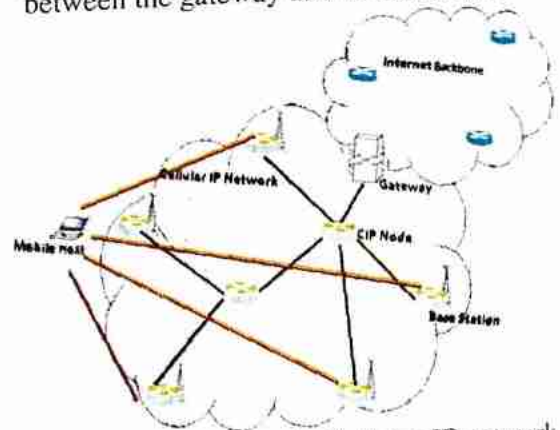


Figure 1: An example Cellular IP network.

The introduction of IPv6 provides benefits not only for MIP. The huge address space, optional header, built-in security, and lack of Mobile IP version 6 (MIPv6) Foreign Agents are also useful for micromobility protocols. These new features have inspired the introduction of Cellular IPv6, the main subject of this paper.

i. Routing

When a mobile host (MH) enters a CIP network, it listens for beacons transmitted by all base stations (BS). The MH then chooses the best BS (the one with the highest SNR) by sending an authenticated Route-Update (RU) message, which is then forwarded to the gateway. This initial message registers

the MH with CIP. All packets transmitted by the mobile host regardless of their destination address are routed towards the gateway using these route [3]. All CIP nodes, including the gateway and base stations, contain a routing cache to keep track of the next downlink hop of active CIP nodes. This is a soft-state routing cache, which must periodically be updated or the entry for a MH will become stale and be removed. The cache can be updated by any uplink data packets sent by the MH, or in the absence of those, by periodic route-update messages. Data and route-update packets are always routed from the base station on the shortest route to the CIP gateway. This ensures that the route-caches of all nodes along the path are updated. However, in the case of intra-domain traffic (i.e., between MHs in the same network) this is very sub-optimal. A solution for optimal CIP routing is discussed in Section 4.

ii. Paging

Cellular IP supports the tracking of idle mobile hosts through a paging mechanism. Paging [7] allows a reduction of signalling in the access network, and more efficient power usage for mobile hosts. Instead of forcing a MH to continually send RU messages to the network, it is allowed to go into an idle (power-down) mode. A CIP network is configured into blocks of Base Stations (BSs), known as paging areas. Within this paging area an idle node can roam without performing handoffs, and only very rarely sends a Paging-Update (PU) [8] message to the network. With many nodes allowed to enter idle mode, the scalability of an access network can be improved. Idle nodes are located through the paging mechanism where they are woken using a packet broadcast throughout their paging area when downlink traffic arrives.

In addition to the routing-cache kept by CIP nodes, some nodes can also keep a paging-cache to track idle MHs. It is recommended that the gateway, and possibly the first hierarchy of CIP nodes contain this secondary cache. The paging cache is updated by PUs sent by the MH when it enters idle mode, and then periodically

thereafter (on the scale of many minutes). Just as with the routing-cache, a paging-cache contains the next hop for each idle MH. If a MH moves to a new paging area (identified from the BS beacons), it must send a PU message immediately.

When the gateway receives a packet destined to a MH, it checks its routing-cache. If no entry exists, the paging-cache is then checked. The paging cache tells the next hop of any idle MH in that paging area. This procedure is followed for all downlink CIP nodes. If a node does not have a paging-cache, it then broadcasts the packet on all downlinks. The area covered by these downlink base stations makes up a paging area. It may also be that a CIP network contains only a single paging area, in which case the gateway contains no paging-cache, and all downlink packets with no routing-cache entry are broadcast. When a MH receives the downlink data packet, it enters active mode where it sends a RU and normal operation begins again.

iii. Handoffs

In order for MHs to roam in a CIP access network, while still correctly maintaining route-caches, two handoff procedures are provided by CIP: hard handoff and semi-soft handoff. Handoffs in CIP are always MH initiated [9], whereas in many traditional cellular paradigm handoffs are network initiated or network assisted. MHs in CIP are always monitoring the SNR levels of beacons received from BSs. When a sufficiently better BS is found than the current one, the MH simply sets it as the new default route and sends a RU to that BS. This updates its new location in all uplink CIP nodes. Because of the latency time for changing the routing-cache in uplink nodes, there may be a loss of packets if there is traffic destined to the MH during the handoff. If a node can listen to both BSs at the same time, it may be able to avoid losing packets [3].

In order to reduce the chance of lost packets, semi-soft handoff can be employed. In semi-soft handoff a new BS is pro-actively notified about a coming handoff before it

occurs. When ready to perform a handoff to a chosen BS, a MH first sends a RU with the S-flag set to the new BS. It then continues to use the current base station for a set latency time before starting to use the new BS. This RU will travel uplink until it reaches the crossover node where the old and new routes cross. This special RU with the S-flag adds a duplicate route to the crossover node's routing-cache. The node then bi-casts any traffic for that MH down both links. When the MH makes the handoff to the new BS it sends another RU without the S-flag. When this RU reaches the crossover node the old cache entry is removed. This handoff method does not guarantee a lossless handover (as a soft-handoff would), however it tries to minimise any packet losses and research results have shown it to work almost flawlessly [7, 8, and 10].

3.0 Cellular IPv6

The introduction of IPv6 to the Internet community has given a large boost to the support of Internet host mobility. Cellular IP was originally designed tightly around the specific capabilities of IPv4, for example the MIP Home Agent and IPv4 header format. With the introduction of IPv6, Cellular IP could also be improved to take advantage of the IPv6 mobility and security improvements.

The design and implementation of Cellular IPv6, an improved micromobility protocol for IPv6 wireless access networks, is detailed in [5]. The author of [5] is the main contributor for protocol design and oversaw the implementation of the protocol. Other research groups have also been involved with the design, publications, and implementation.

Design changes to CIPv6 from its predecessor, CIP, stem from new features in IPv6, IPSEC, and MIP. The new structure of IPv6 addressing gives the first improvement. IPv6 autoconfiguration can be used for a MH to acquire its care-of-address (CoA). The new IPv6 extended headers allow CIPv6 control messages to be included in the Hop-by-Hop extension header. Along with IPv6, built-in security is required with IPSEC. This

means that all IPv6 nodes include authentication capability. CIPv6 uses this built-in authentication for all control messages. Mobile IP for IPv4 required that a foreign agent be located in every network. With MIPv6 this is no longer a requirement, introducing changes to the CIP Gateway node. Finally, because semi-soft handoff required a wireless technology where two base stations can be contacted simultaneously, CIPv6 introduces an alternative. Indirect semi-soft handoff allows for semi-soft handoffs with other wireless interfaces. These differences are summarized in Table 1.

Table 1: Protocol differences between CIP and CIPv6

	Cellular IP	Cellular IPv6
Control Message Carrier	ICMP	IPv6 Hop-by-Hop extension header
Address Acquisition	MIP HA or DHCP	IPv6 Autoconfiguration
Host Identification	Home IP address	IPv6 care-of-address
Authentication	Proprietary	IPv6 authentication header
Handoff	Normal, Semi-soft	also Indirect Semi-soft

i. Signaling

CIPv6 base stations transmit their CIP network ID, base station ID, paging area ID, CIP gateway IP address, and IPv6 subnet prefix in a beacon packet. See Figure 2 for the format of this beacon packet. The beacon is periodically sent in an IPv6 destination options header to the IPv6 all-nodes multicast address (FF02::1). When a new CIP mobile host arrives within range of a CIP base station, this beacon is used to join the network. After the MH authenticates to the network, it uses IPv6 stateless address auto-configuration to form its IPv6 care-of-address.

Instead of using ICMP packets for sending route-update and paging-update control messages, CIPv6 uses built-in IPv6 headers. Update messages are sent in the hop-by-hop IPv6 extension header. The destination of this packet is always the gateway. Route- and paging-update packets are identical to those in CIP except for an additional I-flag

used for indirect semi-soft handoffs. These control messages are authenticated using the IPSEC authentication header. In the original CIP control messages were authenticated using a proprietary method.

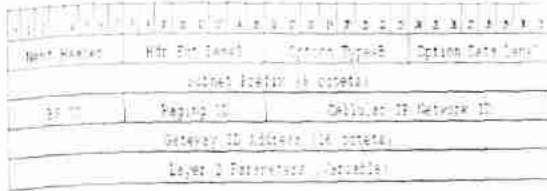


Figure 2: The Cellular IPv6 beacon format.

Routing

Routing in CIPv6 is performed identically as was described for CIP in Section 2. Uplink packets from a mobile host are always forwarded along the shortest route to the Gateway. Downlink packets are forwarded on a hop-by-hop basis by each CIP Node along the path. If a CIP node receives a packet for a node it does not have any valid route or paging cache entry for, it is broadcast on all downlink interfaces. This performs the paging mechanism, identical to that in CIP. However, the specification for paging is more precise in the CIPv6 specification with regard to the placement of paging caches. The new indirect semi-soft handoff method is explained below.

Indirect Semi-soft Handoff

The CIP semi-soft handoff method requires that a MH has the capability to listen to the current BS while sending a route-update packet to the new BS. Not all wireless technologies have this capability (as is the case for Bluetooth). For this reason, an alternative method is introduced for CIPv6: indirect semi-soft handoff.

When a mobile host decides to make a handoff, instead of sending a route-update packet to the new BS directly (as it cannot), it sends the packet to the current BS. This packet will have as a destination IP address, the IP address of the new BS.

Unlike in a standard semi-soft handoff the I-flag will be set to indicate an indirect semi-soft handoff [9]. The current BS will forward this uplink to the Gateway normally.

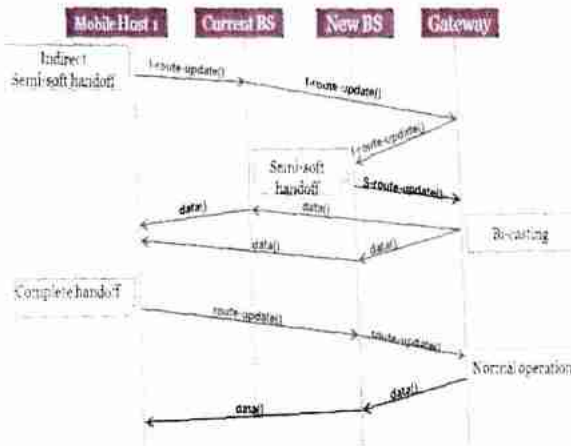


Figure 3: Example of indirect semi-soft handoff.

The Gateway then uses normal IP routing to deliver the packet to the new BS. When the new BS receives the indirect handoff route-update, it creates a semi-soft route update packet with the IP address of the mobile host. It is then forwarded uplink. Data destined to the mobile host is then bi-cast from both the current and new base stations in order to assure that no packets are lost. The mobile host then completes the handoff by sending a normal route-update packet to the new BS. This route-update ends the bi-casting function. See Figure 3 for a sequence diagram of indirect semi-soft handoff.

4.0 CIP Route Optimization

Cellular IP performs very well in networks where almost all mobile host traffic is coming from or going to outside the network. However, when intra-domain traffic exists (between MHs or a MH and a local network entity) the forced route through the gateway is far from optimal [11]. Data packets take needless extra hops, and congestion problems arise at the gateway. In order to optimise the handling of intra-domain traffic with Cellular IP, the author in [9,12] has helped develop a proposed route optimisation for CIP.

i. Algorithm

This technique is a modification to the original CIP specification and is equally applicable to CIPv6. The goal of the algorithm is to route intra-domain traffic on the shortest path, while still sending the necessary signalling messages to maintain

the soft-state routing caches of uplink nodes. The central entity for performing the algorithm is a cross-over node, which is a common uplink for 2 or more base stations. The performance of this technique improves as the number of hierarchical levels in the network increases. When there is only a single level, i.e. a gateway connected directly to base stations, there is no performance improvement as the gateway is the optimising node in this case.

The changes to the specification affect mobile hosts in active mode and any CIP nodes which are located at common crossover points between BSs. See Figure 4 for a visualization of route optimisation. No new architectural entities are added and soft-state routing is maintained. The optimisation function is transparent to mobile hosts.

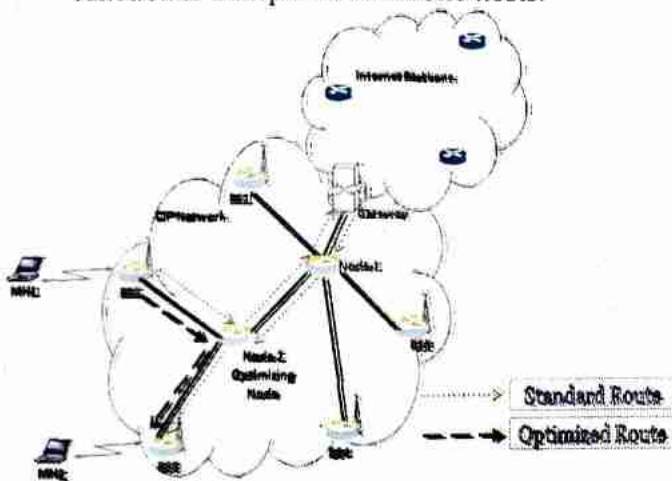


Figure 4: Cellular IP Route Optimisation.

However, some protocol extensions are made in order to maintain soft-state routing and to assure that route optimisation is efficiently terminated upon handoff. These extensions are:

1. The proxy Route Update (RU) packet that is sent by an optimising node uplink, on behalf of a mobile host. This is based on the original CIP route-update format.
2. The route optimisation teardown packet that is sent upon handoff, either by a mobile host or a crossover node. This is based on the original route-update format.
3. Two additional fields in routing-cache mappings:
 - The teardown optimisation (TO) flag (unset by default), that is set by route optimisation teardown packets to indicate that route optimisation can no longer be performed for the corresponding mobile host.
 - The route optimisation timestamp, that holds the time of the last route optimisation.

When route optimisation is enabled, each crossover node performs additional checks upon receiving uplink traffic. For each packet the routing-cache is checked for a mapping that corresponds to the uplink packet's destination. If a mapping is found with the TO-flag unset, the packet is relayed to the corresponding downlink interface (instead of being forwarded uplink to the gateway). At the same time, a proxy route-update packet is sent uplink towards the gateway. This packet carries in the control field the address of the mobile host that route optimisation is being performed for. Proxy route-update packets are sent uplink on behalf of the mobile host at route-timeout intervals for as long as route optimisation for this mobile host is being performed. Uplink nodes then use the control field of these packets to update their routing caches. The transmission of proxy route-update packets on behalf of a mobile host ceases when traffic from this mobile host is forwarded uplink, or if the route optimisation timestamp indicates that no route optimisation for this mobile host has been performed for one route-timeout period [12]. This protocol sequence is shown in Figure 5.

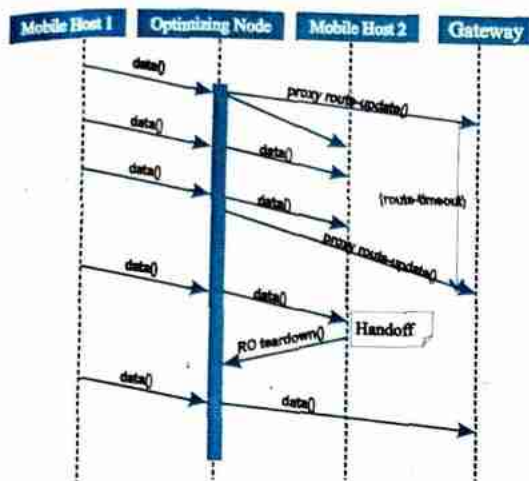


Figure 5: Route optimisation sequence resembling Figure 4.

(Data is optimised from MH1 to MH2 through the optimising crossover node. During that time proxy route-updates are sent to the gateway periodically. When MH2 makes a handoff, it sends a RO teardown message uplink, which ends the optimisation.)

When an active mobile host performs a handoff to a new base station, it first transmits a route optimisation teardown packet to the old one. This packet sets the TO-flag of routing-cache mappings, thus making the mobile host "unavailable" to receive any route-optimised data. This preserves the correctness of soft-state caches. As a result, data is no longer optimised for this mobile host, but will be normally forwarded uplink. If this route optimisation teardown packet is lost on the wireless channel, a black out time of one route-timeout would occur. To avoid this, a new route optimisation teardown packet is also sent by the uplink crossover node of the old and new base stations. Specifically, upon handoff, an active mobile host sends a route-update packet to the new base station. On a node, which is a crossover point between the old and new base stations, there will already exist an older cache mapping for this mobile host on another interface. If this mapping's TO-flag is not set (probably the route optimisation teardown packet sent through the old base station was lost or delayed), then another route optimisation teardown packet is sent downlink on that interface. This packet will be routed downlink following the

mobile host's old cache mappings that have not yet expired and will set the corresponding TO-flag at each crossover node. This assures that route optimisation is efficiently terminated upon handoff.

Although this route optimisation algorithm has been implemented and included with the CIPv6 release, it is difficult to get a reliable performance evaluation on a test bed. In order to see how RO performs in a larger network with many nodes, preliminary simulations have been performed in this work. The simulations have shown that a reduction in the average number of hops and end-to-end delay can be made with route optimisation in a CIP network with intra-domain traffic. The advantages of course increase as the percentage of intra-domain traffic increases. As proxy RU messages are used to keep uplink route-caches current during optimisation, the amount of signalling to the gateway increases slightly. This is however offset by the huge amount of data traffic that would otherwise be routed through the gateway. The simulation setup and results for route optimisation are presented below.

5.0 Simulation

Simulations were carried out using OPNET to better model an environment where many mobile hosts are involved. The goal of the simulations is to gain insight into the performance benefits of the route optimisation feature and to check the correctness of the protocol in different situations.

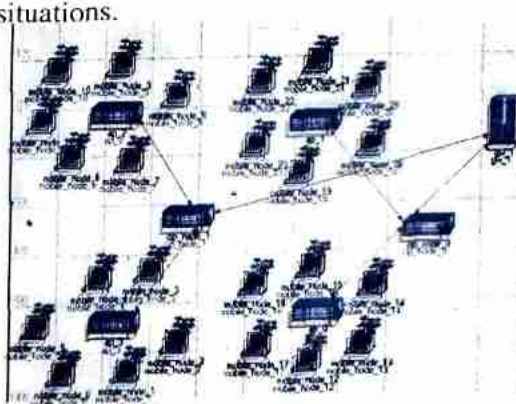


Figure 6: The simulated network model

The simulated network model is a Cellular IP network as shown in Figure 6. A gateway is used to route packets outside the local network to virtual Internet hosts. Two intermediate CIP switching nodes, each connected to two Access Points serve the purpose of forwarding packets to and from Mobile Hosts.

There are a total of 24 mobile hosts used in the simulations, with approximately 6 using each access point at any one time. The CIP gateway, intermediate nodes, and access points are modeled as switches. Within these switches there is a CIP processing entity that implements the protocol. The CIP host, node, and gateway models have the capability for normal CIP operation or Route Optimisation.

Access points are nodes with two interfaces, one wireless and the other wired. Mobile hosts are provided with a wireless interface. Links in the simulation are modeled as point-to-point wired links. Wired links have a 10 Mbps data rate, while AP to mobile host wireless links have a 1 Mbps data rate. Half of the mobile hosts are stationary, while the others have an assigned trajectory and move during the course of the simulation for handoffs between neighboring access points. Mobile nodes send traffic to other hosts either on the same network or on an outside

network. Mobile node traffic sources have an average transmission rate of 160 kbps with an idle time randomly spread over a 90% average value.

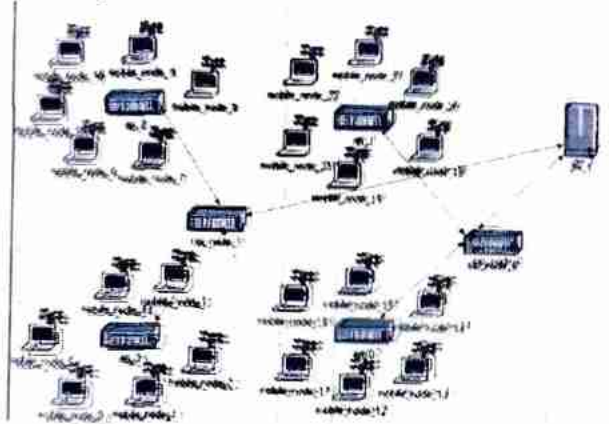


Figure 7: The intra-domain network scenario

Figure 7 and Figure 8 show the two network scenarios that have been used in the simulations. The first one is a network with 24 mobile hosts, 2 CIP nodes, 4 access points and a gateway with no external connections so that all traffic is internal, as seen in Figure 7. This is called the intra-domain scenario. The other scenario - the mixed scenario - (shown in Figure 8) is composed of two connected networks with the same topology as above to model a network with both intra- and inter-domain traffic.

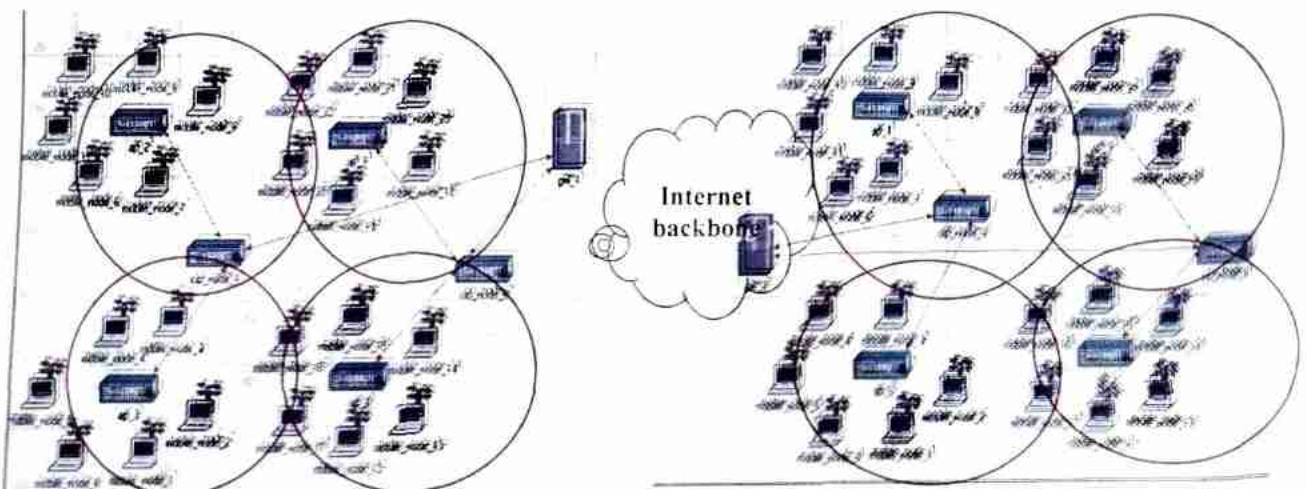


Figure 8: The mixed network scenario

The simulation time was 10 minutes for each scenario. Statistics were collected to measure the number of hops to a destination, application end-to-end delay, and signalling

load the protocols place on the network. For each scenario standard Cellular IP is compared to CIP with route optimisation.

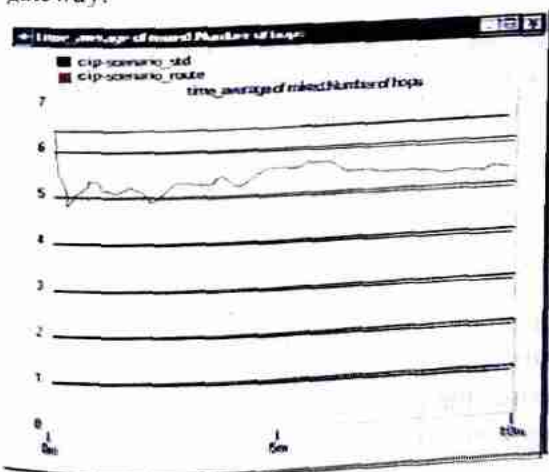
6.0 Simulation Results

In this section the simulation results is presented, taking into account three parameters that optimization a local routing protocol, in particular the number of hops in the network for a packet to reach its destination node, the end-to-end delay that gives a measure of the congestion in the network, and the ptimizat generated by the gateway in the network.

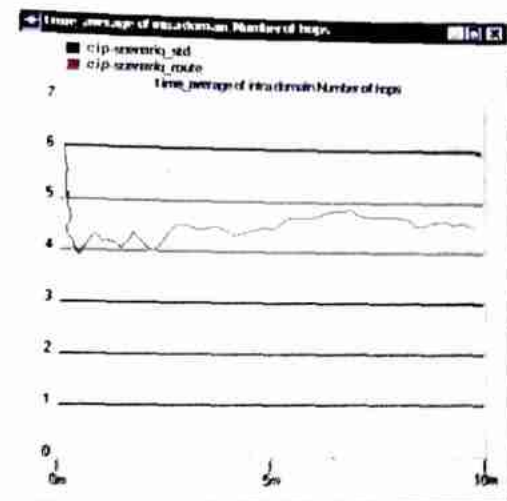
A point worth noticing is that in the simulated network only two levels of hierarchy were present. However, in a more complex network the advantage of optimization will increase, just as with only one level of routers (gateway and Aps) there is no performance gain. For the purpose of this work, that is, to give an idea of the protocol scalability, these results are reliable. Finally, to gain further insights measurement should be carried out in real test bed environment with a sufficient number of hosts.

i. Number of Hops

The result can be seen from Figure 9 (a) and (b) below. As can be expected Route Optimization will always decrease the number of hops with respect to standard Cellular IP where the number of hops is fixed since all packets must travel to the gateway.



(a) Number of hops, for mixed scenario compared



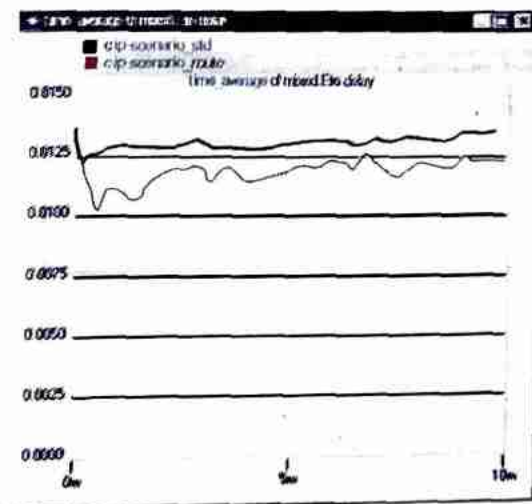
(b) Number of hops for intra-domain scenario compared

Figure 9: Number of hops

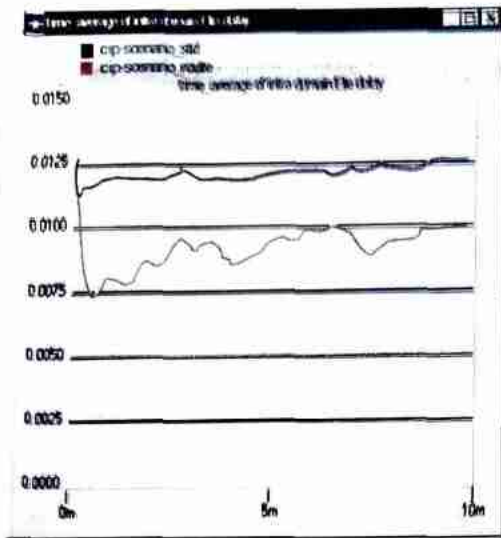
The result shows the number of hops for the mixed scenario which is further reduced for the intra-domain scenario.

ii. End-to-End Delay

Whenever a packet reaches its destination the total route time is computed to estimate the packet delivery time. It is worth noticing that the lower number of hops make it possible to have lower end-to-end delays in cases where optimisation is done.



(a) End-to-end delay for mixed scenario compare



(b) End-to-end delay for intra-domain scenario compared

Figure 10: ETE delay

Therefore, the end-to-end delay of traffic in a CIP network for the mixed scenario is seen with Figure 10(a), but with only intra-domain traffic the end-to-end delay improvement is better as seen in Figure 10(b).

iii. Gateway Signaling Load

The one disadvantage of this route optimisation technique is that the amount of signalling between crossover nodes and the gateway is higher as seen in Figure 11.

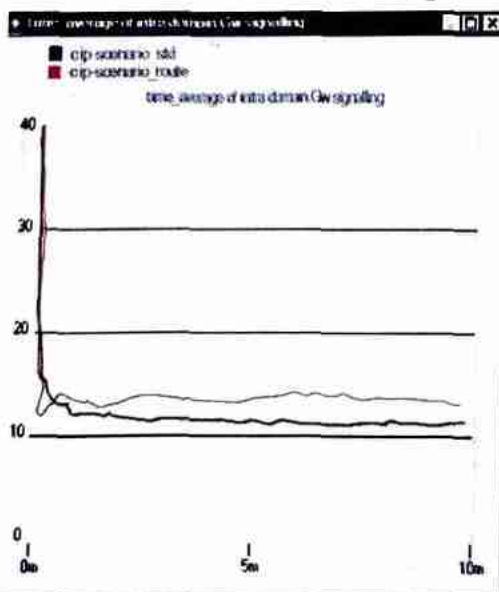


Figure 11: Gateway signalling load

However, this is offset by the actual traffic load of the gateway, which decreases with route optimization. Since all traffic in the CIP network must pass through the gateway it puts a high data packet load on the gateway. With CIP route optimisation none of the intra-domain data traffic passes through the gateway. However the signaling load is slightly higher because of proxy route-update packets. Route optimisation does not affect the amount of signalling between the AP and MH.

7.0 Conclusions

The theme of this paper has been on improving micromobility routing, which is the key to enabling wireless Internet. The original introduction of Cellular IP as a solution for the intra-domain routing problem was quite unique. Cellular IPv6 is an attempt to modernize this original protocol by taking advantage of the new features of IPv6 and Mobile IPv6. This improved protocol has a better standard authentication mechanism, built-in IPv6 headers, and offers a new handoff method.

This paper has compared the performance of two different Cellular IP networks – Standard Cellular IP and Cellular IP with Route Optimisation (RO). A two-level Cellular IP network was simulated with a mixed traffic scenario (both inter- and intra-domain traffic) and a purely intra-domain traffic scenario. Section 6 provides the result for this experiment. The experiment shows that in RO intra-domain traffic takes the shortest route through the network. To accomplish this, possible cross-over nodes perform the additional task of forwarding the actual data along the shortest path. However, in order to maintain the soft-state routing-caches of CIP, this cross-over node then sends proxy route-update packets uplink towards the gateway.

This method optimizes intra-domain traffic, while minimizing the amount of data handled by the gateway. CIP route optimisation involves modification only to CIP nodes that could be cross-over points. The gateway and MHs are unaffected.

For future work, micromobility research also has other open issues which need to be solved. These include authentication and billing issues, such as the integration of Authentication, Authorization and Accounting (AAA) with currently proposed protocols. The integration of quality of service with micromobility is another area which is starting to receive attention. Finally, many of these wireless access network scenarios have assumed only a single wireless hop. However, there are many situations where multi-hop wireless networks will be used. This is a difficult problem to solve, involving both routing mechanisms and performance problems.

References

- [1] Finishing the job: Mobile-phone access will soon be universal. The next task is to do the same for the internet. (2008) URL: <http://www.sacids.org/index.php?l=42&n=97>
- [2] Charles E. Perkins. (May 1997) Mobile IP. IEEE Communications Magazine pp. 84 – 99.
- [3] Campbell A. et al. (June/July 2000) Design, Implementation and Evaluation of Cellular IP. IEEE Personal Communications pp. 42–49.
- [4] Chang W., Jie L. & Hisao K. (2003) A Dynamic and Distributed Domain-Based Mobility Management Method for Mobile IPv6. IEEE Wireless Communication, pp. 1964 – 1968.
- [5] Shelby Z. et al. (July 2001) Cellular IPv6. IETF Internet-Draft, draft-shelby-cellularip6-01.
- [6] Conference program INET 2001, 6-8 June. (2001) URL: <http://se.services.fujitsu.com/veteran/01q2/sid10-11.pdf>.
- [7] Valko A. (1999) Cellular IP: A New Approach to Internet Host Mobility. ACM Computer Communication Review pp. 50–56.
- [8] Campbell A. et al. (2001) Comparison of IP Micro-Mobility Protocols. NSF Wireless Technology Award ANI-9979439.
- [9] Shelby Z. et al. (June 2001) Cellular IP Route Optimisation. IETF Internet-Draft, draft-shelby-cip-route-optimisation-00.txt.
- [10] Eriko N., Ben L., Chansu Y., & Myungchul K. (2007) Adaptive Semi-Soft Handoff for Cellular IP Networks. International Journal of Wireless and Mobile Computing, pp. 109-119.
- [11] Ian F., Jiang X., & Shantidev M. (August 2004) A Survey of Mobility Management in Next-Generation All-IP-based Wireless Systems. IEEE Wireless Communications.
- [12] Gatzounas D., Shelby Z. et al. (2001) Route Optimisation for Cellular IP Networks. In: *IP Cellular Networks*.
- [13] Deering S. & Hinden R. (1998) Internet Protocol, Version 6 (IPv6). IETF Internet RFC246