

Handoff Mechanisms in Cellular IP: Enhancement into the Indirect Handoff Mechanism

Suraj Jaiswal¹, Joao Orvalho², Fernando Boavida²

¹Indian Institute of Technology, Guwahati, India

²University of Coimbra, Portugal

e-mail : suraj@iitg.ernet.in, {orvalho, boavida}@dei.uc.pt

Abstract: Mobile IP is now the standard for supporting mobility in IP networks. It provides seamless mobility by hiding the change of IP address when a mobile host moves between IP subnets. Nevertheless, Mobile IP is not designed to support fast handoff and seamless mobility in handoff-intensive environments. Several micro-mobility protocols have been proposed to support host mobility with frequent handoffs within a domain without interaction with the Mobile IP enabled internet. Cellular IP, HAWAII and HFA are some of the popular IP micro-mobility protocols. Cellular IP complements Mobile IP with support for fast, seamless and local handoff control, and IP paging. In this paper a modification to the existing indirect handoff mechanism in Cellular IP is proposed and subsequently assessed by simulation. The approach proposed in this paper, called Enhanced Indirect Handoff, constitutes a new way to handoff to the new base station where the handoff is initiated along the old base station, resulting in reduced handoff delay and hence reduced packet loss.

1. Introduction

Today wireless mobile communication is becoming very popular. Handheld computing devices like laptops and personal digital assistants are becoming popular choice for personal applications. As these devices become more powerful the demand for wireless access to the internet will grow exponentially. The wireless access network infrastructure will have to support a large number of mobile users with different access speed requirements and these users would expect same service quality as users in the fixed network. In the wireless access network, the wireless area is composed of number of small cells as in cellular networks. However, the smaller the cells are the more frequent the handoffs performed by the mobile users.

Mobile IP [1] is the current standard that supports host mobility. Whenever a mobile host leaves its home network and enters a foreign domain it acquires a care-of-address in the foreign network domain and informs its home agent about the care-of-address. This results in high latency and may result in packet loss if the mobile host performs local (within a domain) handoff frequently, since the care-of-address must be

communicated to the distant home agent after each handoff. To solve the issue of frequent handoffs within a single domain, IP micro-mobility protocols (e.g. Cellular IP [2][3], HAWAII [6], and HFA [7]) have been developed. Most of these protocols adopt a hierarchical approach by dividing the network into domains. These micro-mobility protocols support local movement of the mobile host in a single IP domain without bothering the home agent about the frequent handoffs. This has the benefit of reducing latency and packet loss during handoff and eliminating registration messages between mobile hosts and distant home agents when mobile hosts remain within their local coverage areas. Elimination of registration messages reduces the signalling load on the backbone network in support of mobility. Reduced signalling is necessary for the wireless access network to scale to very large number of mobile subscribers. When a mobile host changes domain, Mobile IP is used to support macro-mobility i.e. inter domain mobility.

1.1 Problems and Motivation

The fact that wireless cells have a limited coverage area due to limited transmission range of base stations means that a mobile host will be crossing through several wireless cells when it moves. This results in base station handoff or wireless cell switching. This handoff is necessary to maintain connectivity to and the location tracking of the mobile host. Handover is the process of passing the responsibility of communication connectivity from one base station to another. The wireless cell switching phenomenon tends to cause connectivity interruptions if the handover is not handled properly and quickly. Video and audio data are intolerant to delay and jitter and hence traffic interruptions as a result of the handover can be damaging to such multimedia applications. Therefore, other than an efficient way of providing handover, there is still a need to provide a continuous handover mechanism.

The decreasing wireless cells size also results in the decrease of the wireless cells overlapping width. With the mobile host migrating at a certain speed and direction, there will come a time when the handover mechanism cannot be completed within the time constraint imposed by the mobile host migration speed

and the decreasing wireless cells overlapping width. Hence, a fast handover mechanism is required.

Currently there are two major radio technologies in use for wireless access to the fixed network infrastructure. These radio technologies have major influence on the handoff performance in mobile networks. The first radio technology is TDMA (Time Division Multiple Access) where multiple users are accommodated by dividing a given time into time slots with slots being allocated to different users or more precisely, users take turn to transmit their data. In TDMA, due to spectrum reuse, a given slot on a given frequency channel can't be used by neighboring cells. So when a mobile host which is in a cell moves from one cell to another, at a certain point it has to switch between cells. In TDMA it will be commanded by the system to change frequencies, all at once. This is called a *hard handoff*, so called because it is all or nothing: the transition is a hard one. TDMA is the access technique used in the European digital standard, GSM (Global System for Mobiles), and the Japanese digital standard, personal digital cellular (PDC). The reason for choosing TDMA for all these standards was that it enables some vital features for system operation in an advanced cellular or PCS environment. Today, TDMA is an available, well-proven technique in commercial operation in many systems.

In CDMA, all the cells operate on the same frequency. The mobile host still has a single RF receiver which converts radio frequency down to base band, but behind that it has a *rake receiver* with multiple *fingers*. Since all the cells operate on the same frequency, the single RF receiver picks up all of those which are within range. The mobile host then assigns fingers from the rake receiver to various signals, and these are added together to create the full signal the phone utilizes. When the mobile host is about halfway between two cells, while in a call, the mobile host is not only handling its transport of data back and forth to the cell, but it's also actively looking for other cells. When it finds one whose signal strength is good (on the same frequency, remember) it will inform the cell system of this. The cell system might decide at that point to route the call through *both* cells simultaneously. The specification actually permits a mobile host to talk to six cells at once, though no radio receiver currently in existence has this capability. So when a CDMA mobile host in a call moves from one cell to another, the handoff process happens in multiple steps. First the mobile host notices the second cell, and the cell begins to carry the call on both cells. As the mobile host continues to move, eventually the signal strength from the one the mobile host is moving away from will drop to the point where it isn't useful any longer. Again, the mobile will inform the cell system of this fact, and the system will drop the original cell. Thus it is not an all-or-nothing transition, which is why it is called *soft*. The 3G networks enabling wireless access to the Internet, UMTS (Universal Mobile Telecommunications System), will be using CDMA as a multiple access technique.

Amongst the micro-mobility protocols, Cellular IP and HAWAII provide two different handoff mechanisms optimised for different networks. Cellular IP semi-soft handoff (section 2.2) exploits the notion that some mobile hosts can simultaneously receive packets from the new and old base stations during handoff as in CDMA. Not all wireless technologies have simultaneous connection capability, e.g. TDMA. They cannot listen to the current BS while sending a route-update packet to the new BS. For this situation an alternative indirect technique (section 2.3) is used to reduce packet loss and improve performance. Nevertheless, the indirect handoff mechanism proposed for Cellular IP in [3] introduces considerable latency during the handoff phase, thus leading to performance degradation for multimedia applications in handoff intensive environments.

The above therefore summarizes the need for a fast, efficient and continuous indirect handover mechanism in Cellular IP.

This paper focuses on the indirect handoff mechanism in Cellular IP, and proposes some enhancements to this mechanism. The paper is organized as follows. In section 2, a brief introduction to Cellular IP and related protocols is given. This is followed by a presentation of the enhanced indirect handoff proposal, in section 3. The proposal was assessed by simulation and section 4 presents and interprets the respective results. Section 5 highlights and summarises the benefits of the proposed scheme.

2. Background and Related Work

2.1 Related Work

Recently, many micro-mobility solutions have been discussed in the literature. In [7] Mobile IP is extended using an arrangement of foreign agents in a hierarchy. The top of the hierarchy called Gateway Foreign Agent resides at the edge of the access network and is defined by a care-of address registered with home agents. When a packet is received, the gateway foreign agent interacts with a local database to determine which lower level regional foreign agent (RFA located in the access network) to forward the packet to. This procedure may be repeated, depending on the depth of the routing hierarchy. The domain foreign agents [8] and local registration schemes [9] use similar ideas.

These hierarchical mobility solutions do not, however, support the notion of passive connectivity (e.g. as in cellular networks) with its separation of active and idle users, as is the case with Cellular IP and HAWAII. In these proposals, a foreign agent maintains cache entries for each mobile host in its region having to search a potentially large database in order to route each packet. In contrast, Cellular IP routing cache only contains entries for active mobile hosts that have recently transmitted packets. This reduces the search

time and increases protocol scalability. Other differences exist.

Some of the schemes are implemented as an overlay over standard IP routers running an intra-domain routing protocol (e.g. RIP, OSPF), as with HAWAII and HFA schemes, while in Cellular IP per mobile host routing is the only routing that the Cellular IP nodes are capable of. *Cellular IP is itself a layer three routing protocol; that is, Cellular IP replaces IP routing in the wireless access network but without modifying the IP packet format and forwarding mechanism.* The overlay approach allows more sophisticated seamless handoff techniques, as it allows nodes to communicate with one another to forward buffered packets, etc. It also may be able to rely on some of the reliability mechanisms of the underlying intra-domain routing protocol, and may be easier to implement using existing equipment. However, it is not as lightweight and scalable over a range of wireless access environments as the non-overlay approach, since full-fledged IP routers are used. Cellular IP with its non-overlay, simpler approach can be implemented with low-cost “layer two switches”.

2.2 Cellular IP

Cellular IP (CIP) is a micro-mobility protocol developed for wireless access network. A CIP access network ([2], [3]) connects to the Internet via a domain gateway router. A mobile node attached to the access network will use the IP address of the gateway as its Mobile IP care-of-address. The main component of CIP networks is the base station. Base stations are used as wireless access points by mobile hosts in order to send and receive data.

After a mobile host powers up, it informs the gateway router about its current point of attachment by means of a route update control packet. This packet received by the base station is forwarded towards the gateway on a hop-by-hop basis along the shortest path. The network interface link used by a node to forward the packet towards the gateway is called the *uplink* of the node and all other links attached to the node are called *downlinks*. Each CIP node maintains a routing cache in which it stores the mobile host specific routes. The per host location information stored in CIP nodes is not a network address. Rather, per host location state represents the next hop route to forward packets toward a given mobile host. The path taken by the packets from a mobile host towards the gateway is cached by all the intermediate nodes. To route packets destined for the mobile host, the nodes use the reverse of the path used by recently transmitted packets from the mobile node which are present in the routing cache. Note that CIP routing is based on the interface links rather than on the IP address of the next hop as in normal IP routing. The CIP routing table contains as entry the interface on which to forward a packet. CIP nodes forward packets either along the uplink interface or along one of the downlink interfaces.

In CIP, a mobile host initiates a handoff, based on signal strength measurements. Following, two handoff mechanisms of CIP which minimize packet losses are described.

2.3 Semi-Soft Handoff

Semi-soft handoff is optimised for CDMA kind of networks. CIP-enabled mobile nodes keep information about the received signal strength from the periodic base station CIP beacon broadcasts. When a mobile node decides to handoff to a new base station based on signal strength measurements, it informs the new base station about the impending handoff while listening to the old base station. The new base station initiates the establishment of a mobile-specific route from the CIP gateway to this new base station so that data packets destined for the mobile host can be sent to the new base station ahead of the actual handoff, while the mobile node keeps on getting data from the old base station during this time. This is called semi-soft handoff.

Semi-soft handoff is achieved by sending a semi-soft packet towards the gateway from the mobile node to the new base station. When the semi-soft handoff packet reaches a *cross over node* (so called because it is the common node on the shortest path from the old and new base station to the gateway) the cross over node starts sending the data also towards the new base station. As the semi-soft handoff packet is forwarded towards the gateway, a reverse mapping for the mobile node is created in the CIP-enabled nodes to route data packets towards the mobile node. Thus, the semi-soft packet needs to travel only to the cross over node, which can then start sending data packets to both the old and the new base stations. In the worst case this cross over node can be the gateway.

This is all done before the handoff has actually taken place so when the mobile node handoffs it keeps on getting data packets without having to initiate any handover messages, hence preventing any packet loss. Otherwise it would have lost those packets which are forwarded along the old path by the cross over node during the time it takes for the handoff message to reach the cross over node.

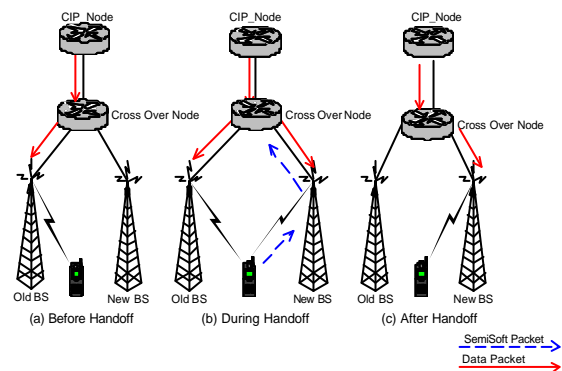


Figure 1 – Semi-soft Handoff

After handoff is complete the mobile host sends a route update packet towards the gateway which results in the cross over node removing the old entry in the routing table. See Figure 1 for illustration of the Semi-soft handoff mechanism.

2.4 Indirect Handoff

CIP indirect handoff is optimised for TDMA networks. In this case, CIP mobile nodes cannot directly inform the new base station about the impending handoff, as this would require a switching of frequency to communicate with the new base station and, as a result, sudden disconnection of communication with the current base station, which is equivalent to a hard handoff. Hence, a mobile node wishing to minimize packet loss sends an indirect handoff packet to the old base station with the IP address of the new base station as destination address. The IP address of the new base station is available from the beacon packet it broadcasts periodically. This handoff control packet is forwarded to the gateway uplink using the CIP routing table and then the gateway uses normal IP routing to deliver this packet to the new base station. When the new base station receives this indirect handoff packet it sends a *semi-soft* packet uplink towards the gateway to establish the mobile-specific routes in the CIP nodes. This now works as the semi-soft handoff process.

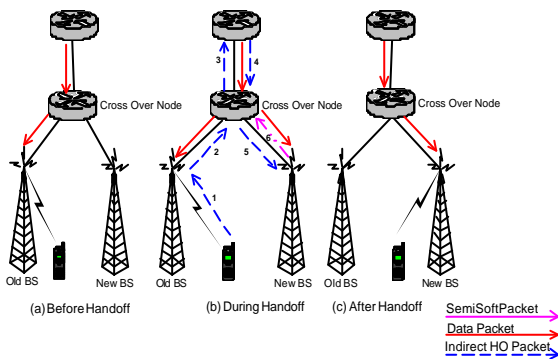


Figure 2 – Indirect Handoff

Though indirect handoff is initiated before the actual handoff, as in the semi-soft handoff case, there are, in general, packet losses because of the high latency in the path setup from new base station to the gateway. Also, note that the mobile host cannot communicate with two base stations simultaneously, as in the semi-soft mechanism. Figure 2 illustrates the indirect handoff mechanism. The messages numbered 1 to 5 shows the flow of the indirect handoff packet and the message numbered 6 shows the semi-soft packet sent by the new base station.

3. Enhanced Indirect Handoff

In CIP every packet being forwarded uplink must go through the gateway. This increases the message processing load on the gateway. Though this restriction has been done away with in revised Cellular IPv6

protocol [3] for intra domain traffic, the indirect handoff packet must still go through the gateway to the new base station. This results in a considerable latency for indirect handoff. Also for indirect handoff, CIP requires regular IP forwarding engine to be present along with the CIP routing table. The regular IP routing table will contain routing entries for every node in the Cellular IP access network. This may result in unnecessary signalling in the whole access network for maintaining IP routing table and if the number of nodes in the access network is large then the routing table will consume a significant amount of memory. Also, the original design of Cellular IP replaces IP routing by Cellular IP per-host based routing mechanism, but indirect handoff requires regular IP forwarding to be present.

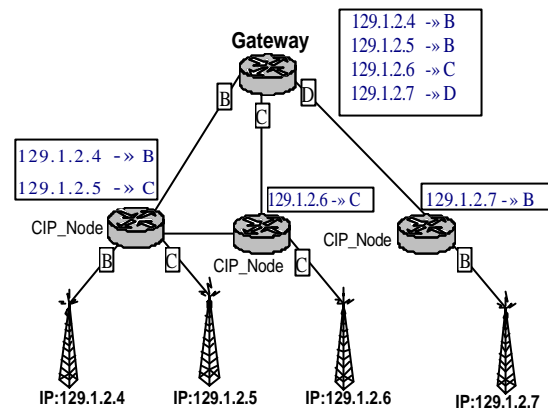


Figure 3 – Base Station specific routing entries in Cellular IP nodes

To overcome the above shortcomings in Cellular IP, we introduce the concept of base station specific routing table for indirect handoff, which does not require regular IP forwarding to be present for indirect handoff.

The base station specific routing table is similar to the mobile node specific routing table in the sense that the former contains per base station routing entries. The base stations send routing updates uplink, towards the gateway, on a hop-by-hop basis, just like mobile nodes send route update packets. Routing updates from base stations are used by traversed cellular IP nodes in order to update their routing entry for that particular base station. A CIP node contains the routing entry for only those base stations whose shortest path to the gateway contains this cellular IP node, hence this routing table for base stations will be very small (a large wireless access network will have somewhere around a hundred base stations). The timer associated with these routing entries makes the routing fault tolerant against base station failures. The base stations send route updates periodically. This period can be in the order of minutes so as not to overload the access network without compromising the freshness of the routing entries. Figure 3 makes the idea more clear. The box in the figure shows the entries in the base

station specific routing table and alphabet letters denote interfaces.

As can be seen from figure 3, for example, routing entry for base station 129.1.2.6 is only in those nodes which lie on its shortest path to the gateway. Other nodes in the access network need not have an entry for this base station.

When a mobile node decides to handoff to a new base station, it sends an Enhanced Indirect Handoff packet to the old base station. This packet contains as destination address the IP address of the new base station. The old base station forwards this packet uplink, towards the gateway. When a node receives this packet from its downlink neighbour, it checks in the base station specific routing table if it has an entry for the destination base station. If it does not have an entry it forwards this packet towards the gateway. If it has an entry then this node is a cross over node for the mobile node.

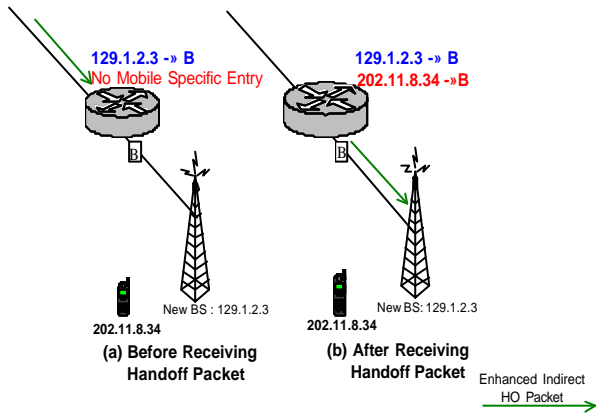


Figure 4 – Mobile host routing entry configuration during handoff

In semi-soft handoff, when a CIP node determines itself to be a cross over node for a mobile host during handoff it also starts forwarding data destined for the mobile host towards the new base station, as the routing entry for the mobile host along the new path is already configured by the semi-soft handoff packet. In the scheme proposed in this paper, when a node determines itself to be a cross over node, as explained above, the mobile node specific routing entry is not configured along the new path till then. But the data packets for the mobile host along the new path will take the same route as that taken by the Enhanced Indirect Handoff packet for the new base station. Only the last hop of the data packets is different, which is through the wireless interface of the new base station. The proposed scheme takes advantage of this commonality between the paths for mobile node and new base station. The cross over node sends the Enhanced Indirect Handoff packet towards the new base station. When a node receives this packet from its uplink interface (the interface used to forward packets towards the gateway) it creates an entry for the mobile node (IP address is in source IP address field of the handoff packet) in the CIP routing table with the same interface to forward the data packet as that for the new

base station in the Base Station specific routing table. Figure 4 shows how a node configures the routing entry of a mobile node in the CIP mobile host specific routing table using Base Station specific routing table when it receives an Enhanced Indirect Handoff packet from its uplink interface.

When the new base station receives this handoff packet it configures a routing entry for the mobile host through its wireless interface and it needs not send any semi-soft handoff packet towards the gateway. The cross over node can start forwarding data also towards the new base station after a little delay. This delay ensures that the downlink routing entries for the mobile node are configured along the new path. This delay allows the Enhanced Indirect Handoff packet to get ahead of the data packets for the mobile node.

Note that the proposed scheme starts bi-casting data at the cross over node as in semi-soft handoff; with the only difference that handoff is initiated along the old base station while semi-soft handoff is initiated along the new base station. Also, the enhanced indirect handoff always maintains the shortest path from the gateway to the mobile node as the mobile host performs handoff.

4. Simulation Results

To evaluate the performance of the proposed handoff mechanism CIMS [4] micro-mobility suite was used, which is implemented in ns-2. Code has been added to CIMS in order to support indirect handoff as well as the enhanced indirect handoff scheme. The implementation of indirect handoff was made according to the latest description in [3]. Below, a brief description of the used simulation model is given.

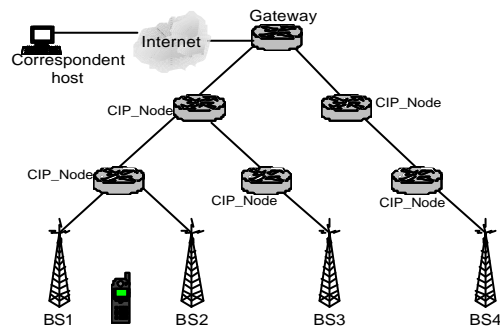


Figure 5 – Topology used in the simulation

Topology: Simulations were performed for an IP domain with a single gateway and having a tree topology as shown in Figure 5. This topology has also been used for Cellular IP handoff evaluation in [5].

Links: All wired links in the access network have a capacity of 10 Mbps and a delay of 2ms. The mobile host communicates with the base stations using IEEE 802.11 MAC enabled wireless link.

Base Stations: The distance between two adjacent base stations is 200m with a cell overlap of 30m. All base stations are in a straight line.

Scenario: During one simulation period of 60 seconds the mobile host travels from the leftmost base station towards the rightmost base station with a speed of 20m/s and back. During this period it makes six handovers. The mobile moves in a straight line such that it passes through the region of maximum overlap between the cells.

4.1 UDP performance

Many real-time Internet applications like audio use UDP. These applications usually carry constant bit rate traffic. Therefore, CBR traffic over UDP was used to model such applications in the simulations. The CBR packet size used was 210 bytes. For Hawaii's MSF scheme [6] a buffer size of five packets was used.

In CIP indirect handoff and enhanced indirect handoff, after initiating handoff the mobile can do the actual handoff after a time period which is proportional to the mobile-to-gateway round trip time. In the experiments for UDP performance this round trip time was estimated to be around 13ms and therefore the handoff delay was set to be 15ms to accommodate the delay that packets experience due to queuing at the bottleneck wireless interface.

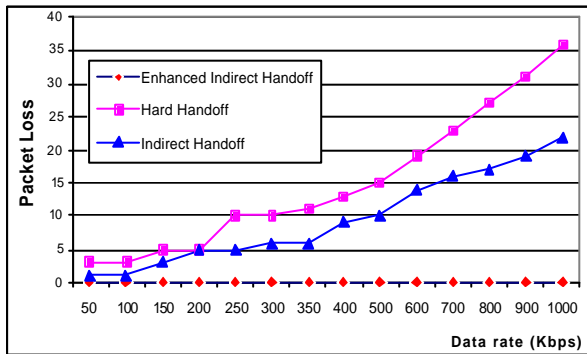


Figure 6 – Number of packets lost when data rate is increasing for Cellular IP handoff schemes

As can be seen in Figure 6 (with a handoff delay of 15ms), the proposed scheme shows improved performance compared to indirect handoff and hard handoff. In addition, the enhanced indirect handoff scheme results in low handoff delay as compared to indirect handoff, as can be derived from the analysis of figures 6 and 7. Figure 7 shows that indirect handoff requires at least two times the round trip time ($2 \times 15\text{ms}$) from mobile node to gateway in order to achieve zero packet loss. In presence of background competing traffic and varying access network load, the mobile to gateway round trip time would be much higher and, as such, twice this round trip time as indirect handoff delay is not advisable, as some real-time and multimedia applications cannot tolerate such long delays and packet losses.

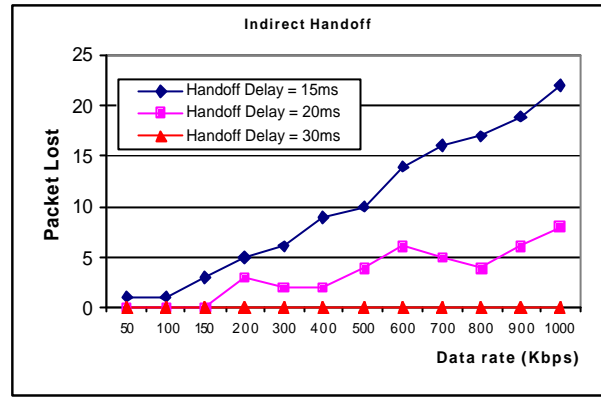


Figure 7 – Number of packets lost for indirect handoff scheme for different values of handoff delay.

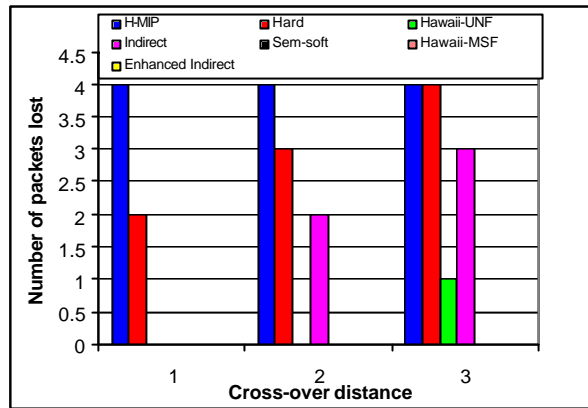


Figure 8 – UDP performance for different handoff schemes when cross-over distance is different

In a subsequent simulation (Figure 8) the effect of the cross over distance on the handoff schemes was evaluated. In this experiment the CBR packet size used is 210 bytes with a data rate of 500 Kbps. When the mobile node moves between BS1 to BS2 the delay is small. As the cross-over distance increases handoff delay increases with each additional hop. Simulations showed that semi-soft, Hawaii's multiple stream forwarding scheme and enhanced indirect handoff do not suffer any packet losses. This is because both enhanced indirect and semi-soft are capable of starting bi-casting of the data at the cross-over node early during the handoff while Hawaii-MSF buffers the packet at the old base station and forwards towards the new base station after the mobile host handoffs. But indirect handoff takes more than one round trip time (mobile node to gateway) to start the bi-casting and, as such, its performance degrades as the cross-over distance increases. Hard handoff performs even worse because it initiates handoff after it loses contact with the old base station and, thus, it loses those packets which are sent towards the old base station just before the handoff packet configures the new route towards the new base station. In contrast to CIP and Hawaii, Hierarchical Mobile IP performs updates of routing entries only when registration messages reach the gateway foreign agent. As a result Hierarchical Mobile IP cannot take advantage of the topological closeness of the cross-over nodes to the base stations and hence shows the same number of packet loss independent of the cross-over distance.

4.2 TCP performance

To study the impact of handoff on TCP, New-Reno TCP was used to download data from the correspondent host in the Internet to the mobile node in the access network. The New-Reno TCP implements a small change at the sender side that eliminates Reno's wait for a retransmit timer when multiple packets are lost from a window, in addition to fast retransmit/recovery as in Reno TCP. The TCP segment size used in simulations was 1000 bytes. FTP downloads from the correspondent host represent greedy downloads.

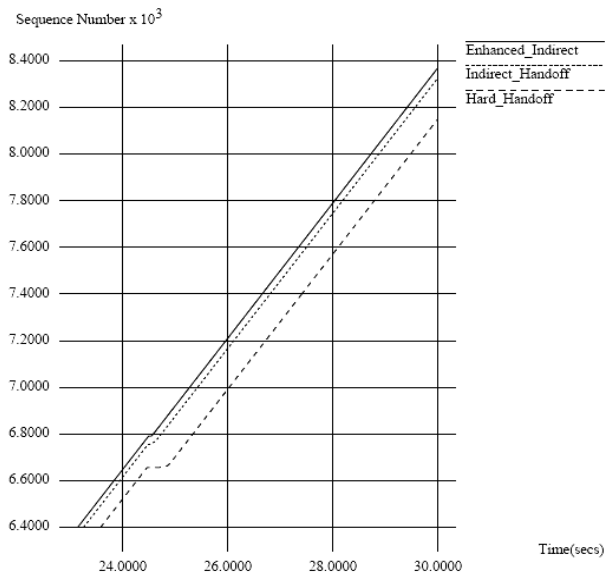


Figure 9 – Packet Sequence Numbers Sent by New Reno

During handoff, multiple packets are lost from a single window of New-Reno TCP source data. When New-Reno detects three consecutive duplicate acknowledgements for the same packet it does a fast retransmit of the TCP packet having sequence number next to that acknowledged by the duplicate acknowledgements, and thereafter enters into fast recovery state. It can recover without a retransmission timeout, retransmitting one lost packet per round-trip time until all of the lost packets from that window have been retransmitted. In figure 9 (mobile node performs three handoffs) the kink at 24.46sec for enhanced indirect handoff is smaller than that for indirect handoff, while for hard handoff it is much larger than both of the indirect handoff schemes. This indicates that in the case of enhanced indirect handoff, New-Reno recovers from losses more quickly, since it has to do fewer retransmissions per round-trip time as compared to indirect and hard handoff schemes. As a result, enhanced indirect handoff attains higher TCP sequence number compared to indirect and hard handoff.

5. Conclusion

In this paper, an enhancement to the existing indirect handoff mechanism in Cellular IP was presented and

analysed, with the aim of contributing to faster and seamless handoff control in mobile environments.

The approach proposed in this paper, called Enhanced Indirect Handoff, is based on the concept of base station specific routing entry. Analysis by simulation led to the conclusion that this concept results in reduced packet losses and reduced handoff delay. Additionally, Enhanced Indirect Handoff reduces the signalling load on the gateway since handoff packets are not forwarded uplink further than the cross over node while in the original indirect handoff case the corresponding packets must go to the gateway so as to be correctly sent to the new base station. As a final advantage, and compared to the indirect handoff scheme, the Enhanced Indirect Handoff does not require the access network to implement an IP routing table at each node along with the Cellular IP routing mechanism.

6. Acknowledgements

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