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PERFORMANCE EVALUATION OF INTEGRATED MACRO AND MICRO MOBILITY PROTOCOLS FOR WIDE AREA WIRELESS NETWORKS

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Abstract
The success of next generation wireless networks will rely much on advanced mechanisms for seamless mobility support among emerging heterogeneous technologies. Currently, Mobile IP is the most promising solution for mobility management in the Internet. Several IP micro mobility approaches have been proposed to enhance the performance of Mobile IP which supports quality of service, minimum packet loss, limited handoff delay and scalability and power conservation but they are not scalable for macro mobility. A practical solution would therefore require integration of Mobile IP and Micro mobility protocols where Mobile IP handles macro mobility and micro mobility protocols handles micro mobility. In this paper an integrated mobility management protocol for IP based wireless networks is proposed and analyzed. Simulation results presented in this paper are based on ns 2.

Keywords:
Mobile IP, Micro mobility protocols, Seamless handoff, Integration, Protocol performance

1. INTRODUCTION

Increased research and development in the field of ubiquitous computing and particularly environments with embedded computers, information appliances and multimodal sensors allowing people to perform tasks efficiently by offering unprecedented levels of access to information and assistance from computers, has heightened the need for a comprehensive mobility solution. Existing mobility protocols are often categorized as either macro or micro mobility but a few, if any, bridge the divide between the two. Mobile IP is at present the IETF proposed standard for delivery of IP packets to mobile devices [1] [2]. However, as a macro mobility protocol, it does not adequately support data delivery to mobile devices that regularly roam within local networks. Hierarchical Mobile IP (HMIP), Cellular IP (CIP) and Handoff Aware Wireless Access Internet Infrastructure (HAWAII) protocols fall under the banner of micro mobility and as such deliver a number of benefits that macro mobility protocols alone could not. It is essential in smart environments to allow mobile hosts to roam seamlessly between areas to facilitate the continuous accessibility to services. Hierarchical Mobile IP, Cellular IP and HAWAII allow for roaming within a local area and do so with a nominal number of control signals, keeping network traffic to a minimum. However, Hierarchical Mobile IP, Cellular IP and HAWAII are not apt for global roaming so they must be used in conjunction with a macro management protocol such as Mobile IP.

In this paper, new integrated network architecture is proposed and it is based on the concept that most of the mobility can be managed locally within one domain without loading the core network [2] [3], as illustrated in Fig.1. This network architecture uses the standard Internet for the core network.

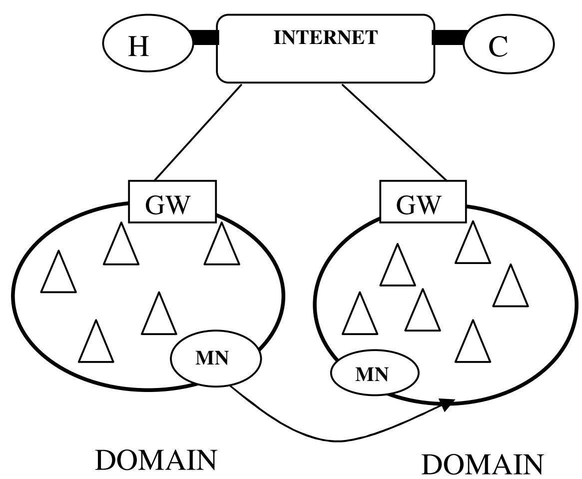

Fig.1 Macro and Micro mobility Protocols Integrated Architecture

The Mobile IP is used as an interdomain mobility protocol for macro mobility management, while Hierarchical Mobile IP, Cellular IP and HAWAII are employed for intra subnet mobility as support to the micro mobility and paging management [4][5][6][7][9]. Performance comparisons between the integration of Mobile IP/ Hierarchical Mobile IP protocols, the integration of Mobile IP/Cellular IP and the integration of Mobile IP / HAWAII protocols based on the number of packets lost during handoff and the throughput is also presented in this paper. For this comparison, the UDP and TCP probing traffic between the corresponding host and mobile hosts are used. The paper is structured as follows: Section 2 gives a brief description of Mobile IP and HAWAII protocol and in Section 3 integration of MIP and HAWAII protocol is presented. In Section 4, the implementation procedure and performance results are presented in Section 5. Conclusions are made in Section 6.

2. PROTOCOL OVERVIEW

2.1 MOBILE IP

The starting point for the design of an IP-based mobility management protocol is with Mobile IP, an IETF proposed standard [1][2][3][4]. Mobile IP provides a network layer solution to node mobility across IP networks. In Mobile IP, Mobility agents make themselves known by sending agent advertisement messages. An impatient MN may optionally solicit an agent advertisement message. After receiving an agent advertisement, a MN determines whether it is on its home network or a foreign network. While roaming, a Mobile Node (MN) maintains two IP addresses, a permanent home address used in all transport layer connections, and a topologically correct care-of address that reflects the current point of attachment. The care-of address is obtained through either a foreign agent or an auto-configuration process. While at home the MN uses its permanent home address. A location register on the home subnet, referred to as a Home Agent (HA), maintains a mobility binding that maps the MN home address to a care-of address. The HA acts as proxy on the home subnet, attracting packets addressed to the MN and employing tunneling to redirect packets to the MN care-of address. Mobile nodes send registration requests to inform the HA of any change in care-of address or to renew a mobility binding. Mobile IP provides an elegant solution for node mobility when the MN moves infrequently, precisely addressing the problem space for which it was developed. When applying Mobile IP to wireless or cellular environments, it has been shown to introduce significant latency simply because handoffs occur frequently and registration messages may travel large distances before packet redirection occurs. Thus, there is a need for a specific micro mobility protocol that interworks with Mobile IP for a complete IP-based mobility management mechanism.

2.2 HIERARCHICAL MOBILE IP

The Hierarchical Mobile IP protocol [5] [6] from Ericsson and Nokia employs a hierarchy of foreign agents to locally handle Mobile IP registration. In this protocol mobile hosts send Mobile IP registration messages (with appropriate extensions) to update their respective location information. Registration messages establish tunnels between neighboring foreign agents along the path from the mobile host to a gateway foreign agent. Packets addressed to 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. 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.

2.3 CELLULAR IP

The Cellular IP protocol [7] [8] from Columbia University and Ericsson Research supports paging and a number of handoff techniques. Location management and handoff support are integrated with routing in Cellular IP access networks. To minimize control messaging, regular data packets transmitted by mobile hosts are used to refresh host location information. Cellular IP uses mobile originated data packets to maintain reverse path routes. Nodes in a Cellular IP access network monitor (i.e., “snoop") mobile originated packets and maintain a distributed, hop-by-hop location data base that is used to route packets to mobile hosts. Cellular IP uses IP addresses to identify mobile hosts. The loss of downlink packets when a mobile host moves between access points is reduced by a set of customized handoff procedures. Cellular IP supports two types of handoff scheme. Cellular IP hard handoffs based on a simple approach that trades of some packet loss in exchange for minimizing handoff signaling rather than trying to guarantee zero packet loss. Cellular IP semisoft handoff prepares handoff by proactively notifying the new access point before actual handoff. Semisoft handoff minimizes packet loss providing improved TCP and UDP performance over hard handoff. Cellular IP also supports IP paging and is capable of distinguishing active and idle mobile hosts.

Paging systems help minimize signaling in support of better scalability and reduce the power consumption of mobile hosts. Cellular IP tracks the location of idle hosts in an approximate and efficient manner. Therefore, mobile hosts do not have to update their location after each handoff. This extends battery life and reduces air interface traffic. When packets need to be sent to an idle mobile host, the host is paged using a limited scope broadcast and in-band signaling. A mobile host becomes active upon reception of a paging packet and starts updating its location until it move to an idle state again.

Cellular IP also supports a fast security model that is suitable for micro-mobility environments based on fast session key management. Rather than defining new signaling, Cellular IP access networks use special session keys where base stations independently calculate keys. This eliminates the need for signaling in support of session key management, which would inevitably add additional delay to the handoff process.

2.4 HAWAII

Unlike Cellular IP, HAWAII [9] does not replace IP but works above IP. Each station inside the network must not only act as a classical IP router but also support specific mobility functions. The basic working of HAWAII is similar to the principles of Cellular IP: each station maintains a routing cache to manage the mobility and the hop-by-hop transmission of special packets in the network triggers the stations to update their cache. As in Cellular IP, the network is supposed to be organized as a hierarchical tree and a single gateway is located at the root of this tree. HAWAII defines two different handover mechanisms adapted to different radio access technologies (depending on whether the MN can communicate with more than one *base station* or not). These mechanisms present different properties and can be chosen to optimize the network with respect to packet losses, handoff latency or packet reordering. The paging requests, that must reach all the stations of an area, are transmitted to the multicast group corresponding to this area.

3. INTEGRATION OF MOBILE IP WITH HMIP, CELLULAR IP AND HAWAII

With the advent of smart environments, computing devices will be embedded into everyday arbitrary objects and as a result the number of computing devices will escalate significantly. These devices should communicate in a non-intrusive manner to assist a user and they will have to maintain their usefulness as they roam from area to area. This means that effective roaming mechanisms must be applied. Mobile IP can control mobile devices roaming in a wide area and it enables the devices to operate adequately as they roam between administrative domains [10]. While Mobile IP is an established macro mobility protocol that is at present an IETF proposed standard, it does have limitations in its ability to manage sizeable numbers of frequently roaming mobile nodes. These limitations restrict Mobile IP from becoming the unique holistic solution to mobility. Mobile IP does not support fast and seamless handoffs, which is crucial within a local network where large numbers of devices migrate frequently. The overhead of the signaling traffic generated when using mobile and the QoS issues that arise from acquiring a new COA each time a node migrates, hamper Mobile IP from providing a complete mobility solution. However, using Mobile IP for micro mobility management is inefficient [10] [11] [12].

In contrast, Hierarchical Mobile IP, Cellular IP and HAWAII are micro mobility management protocols that effectively manage mobile nodes as they roam within a local network domain. Hierarchical Mobile IP, Cellular IP and HAWAII protocols support numerous frequently roaming nodes, with low latency handoffs, decreased network congestion and effective routing algorithms. However, these protocols are not apt for wide area mobility since the mapping entries and route lookup procedures increases rapidly with increase in mobile population. Micro mobility protocols and Mobile IP (Hierarchical Mobile IP and Mobile IP, Cellular IP and Mobile IP, HAWAII and Mobile IP) may be inter-connect to accomplish local and wide area mobility, while maintaining a distinct separation between areas governed by the different mobility protocols [13]. This separation allows for global roaming while eliminating the need to update the home agent each time the mobile node roams within a local network [14] [15].

3.1 INTERDOMAIN HANDOFF

The handoff between two domains, as defined here, means migration of an active MN between two cells managed either by HMIP or CIP or by HMIP by a different micro mobility management networks. Figure 2 and the steps outlined below describe how Mobile IP and micro mobility protocols inter-connect to accomplish local and wide area mobility. For hierarchical Mobile. IP the R_0 and R_1 act as gateway foreign agents for domain I and domain II, respectively, R_2 and R_3 correspond to foreign agents for domain I and domain II, respectively. For Cellular IP, R_0 and R_1 act as a gateway for domain I and domain II, respectively R_2 and R_3 correspond to Cellular IP enabled nodes for domain I and domain II, respectively. For HAWAII R_0 and R_1 act as Domain Root Routers for domain I and domain II, respectively, R_2 and R_3 correspond to HAWAII routers for domain I and domain II, respectively. The most apt way to outline the integration of Mobile IP with Hierarchical Mobile IP, Cellular IP and HAWAII is through the example network.

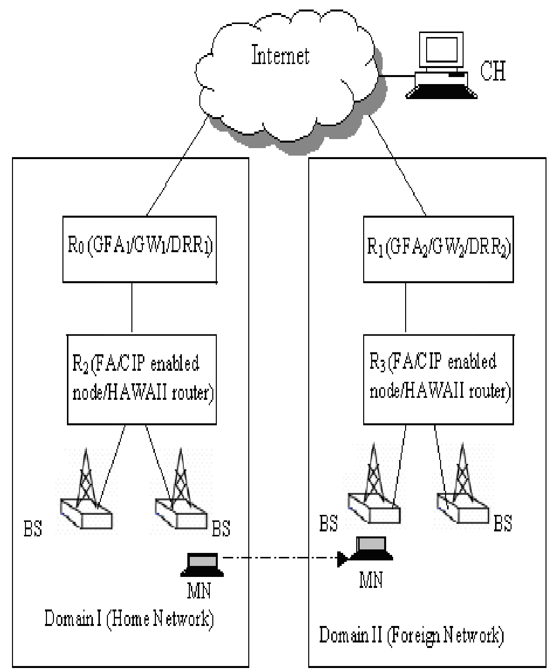

Fig.2 Integration of Mobile IP with HMIP, Cellular IP and HAWAII Example

The following sequence of events occurs when a correspondent node wants to send a packet to a mobile node that is currently residing in a foreign network. The signaling flow diagram is illustrated in Figure.3.

1. When the correspondent node wishes to send an IP packet to the MN, so the packet is sent over the Internet using regular IP networking. The packet that is transmitted will use the home address of the MN as the destination address and address of the CN as the source address.
2. When the packet arrives at the home network, the home agent intercepts the packet and at this point Mobile IP takes control of routing.
3. The HA encapsulates the packet into another IP packet, using the care-of address of MN as the destination address and the HA external interface address as the source address. To encapsulate an IP datagram using IP-in-IP encapsulation, an outer IP header is inserted before the datagram's existing IP header, as follows:

Outer IP Header
IP Header
IP Payload

The outer IP header has a protocol number, its source address and destination address which identify the "endpoints" of the tunnel. The source address and destination addresses of the inner IP header identify the original sender and recipient of the datagram, respectively. The encapsulator, except to decrement the TTL, does not change the inner IP header and it remains unchanged during its delivery to the tunnel exit point. No change to IP options in the inner header occurs during delivery of the encapsulated datagram through the tunnel. To decapsulate an IP-in-IP encapsulated datagram is just to the reverse the operation, i.e. to strip off the outer IP header.

4. When the packet reaches the foreign network on which the MN is located, the border router of the foreign network forwards the packet to the GFA/ Gateway/DRR of the appropriate network.
5. Now, Hierarchical Mobile IP /Cellular IP/ HAWAII routing mechanisms take over. The reversed chain of cached mappings is utilized to forward the packet to the MN in Cellular IP and HAWAII protocols. In Hierarchical Mobile IP, the GFA maintains a visitor list entry which is also updated for the regional registrations performed by the mobile node. The list entry contains the current care-of address of the MN (i.e. FA address or co-located address) in the hierarchical foreign agent extension which is utilized to forward the packet to the MN for Hierarchical Mobile IP protocol.
6. In Cellular IP/HAWAII protocol, the gateway/DRR searches its route cache to discover the next hop downlink base station. In Hierarchical Mobile IP, the GFA searches its routing table to discover the next hop downlink FA.
7. In Cellular IP and HAWAII protocol when the base station that has a wireless interface to the MN is reached, the BS forwards the packet to the MN across the wireless interface. In Hierarchical Mobile IP protocols when the FA that has a wireless interface to the MN is reached, the BS encapsulates and tunnels the packet to the MN across the wireless interface.
8. The MN, then, decapsulates the packet and extracts the original packet sent by the CN.
9. The MN realizes that the packet is the first it has received from the CN since it roamed into the foreign network, as it is an IP-in-IP encapsulated packet. Therefore, the MN generates and sends a binding update to the CN. The binding update updates the CN binding cache i.e. a mapping between the MNs CoA and the MNs home address is created in the CNs binding cache.
10. If the MN wishes to send a reply to the CN, the packet will have the CoA of the MN as the source address and the address of the CN as the destination address.
11. The reply packet will then be sent across the wireless interface to the base station and then directly to the GFA /Cellular IP gateway/ HAWAII DRR via the shortest path. The GFA /Cellular IP gateway/ HAWAII DRR subsequently make the decision to forward the packet outside the domain.

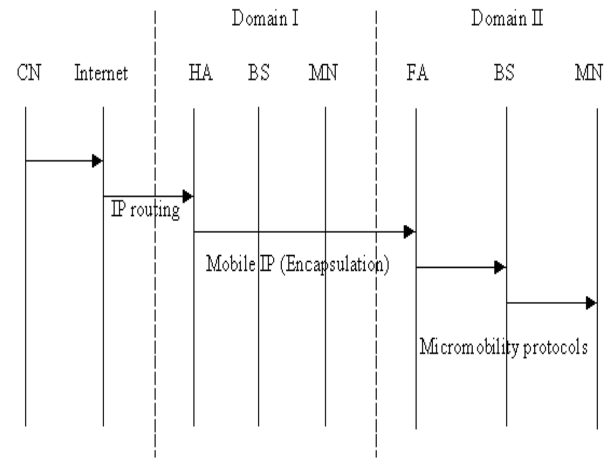

Fig.3 Signaling Flows during Interdomain Handoff

12. The packet is then forwarded to the CN using regular IP routing.
13. The CN can now use the CoA that is stored in its binding cache to address the packet directly to the CoA of the MN. This is accomplished using routing headers instead of encapsulating the packet, which diminishes the number of additional bits required.

4. SIMULATION MODEL

The simulation network topology and simulation environment of integration of Mobile IP and HMIP protocols, integration of Mobile IP and Cellular IP and integration of Mobile IP and HAWAII protocols are shown in Figure 4 and in Table 1. The network simulator (ns2.1b6) is used to evaluate the performance of the proposed architecture [16] [17]. In integration of Mobile IP and Hierarchical Mobile IP topologies, the node 0 acts as a router and nodes 1 and 2 act as gateway foreign agents, nodes 3 and 4 act as foreign agents FA1 and FA2, respectively, and BS1 to BS4 act as a base stations.

In integration of Mobile IP and Cellular IP topology, the node 0 acts a router, the nodes 1 and 2 act as gateway to Cellular IP network and nodes 3 and 4 act as CIP enabled nodes, whereas all the base stations (BS1-BS4) act as mobility unaware routers. In integration of Mobile IP and HAWAII topology, the node 0 acts a router, the nodes 1 and 2 act as Domain root routers in HAWAII network and nodes 3 and 4 act as HAWAII routers, whereas all the base stations (BS1-BS4) act as mobility unaware routers. Here, each wired communication is modeled as 10Mbps duplex link with 2ms delay.

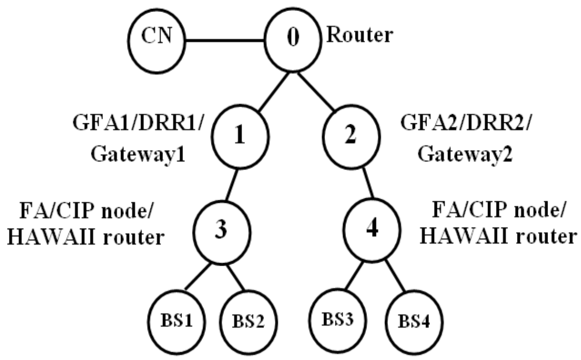

Fig.4 Simulation Model for Integration of Mobile IP and Cellular IP

Mobile host connects to the base station using ns-2 carrier sense multiple access with collision avoidance wireless link model with 2ms delay whereas each base station operates on a different frequency band. Simulation results are obtained using a single mobile host, continuously moving between base stations at a speed that could be varied. Such a movement pattern ensures that the mobile host always goes through the maximum overlapping region between the two radio cells. In the simulation scenario the overlap was set to 30m. The nodes are modeled without constraints on switching capacity or message processing speed. During such a simulation, MN has to perform three handovers to move from BS1 to BS4.

Table 1 Simulation Environment

Topography	670 m x 670 m
Wired Link Bandwidth	10Mbps
Wired Link Delay	2ms
Wireless Protocol	802.11
Overlap of coverage area	30m
CBR Traffic: packet Size	210 bytes
Application	CBR
CN to BS total delay	8ms

5. PERFORMANCE ANALYSIS

Simulation is the primary method that has been used to evaluate the performance of integration of macro and micro mobility protocols. This section presents the UDP and TCP performance of integrations of Mobile IP with Cellular IP and Hierarchical Mobile IP.

5.1 UDP SIMULATION RESULTS

The simulation network accommodates UDP traffic. UDP probing traffic is directed from correspondent node to mobile node, with a packet interarrival time of 10ms and a packet size of 210 bytes. During simulation, an MN travels periodically from BS1 to BS4 with a constant speed of 20m/s. A single simulation run is 60 seconds in duration.

5.1.1 Handoff Performance:

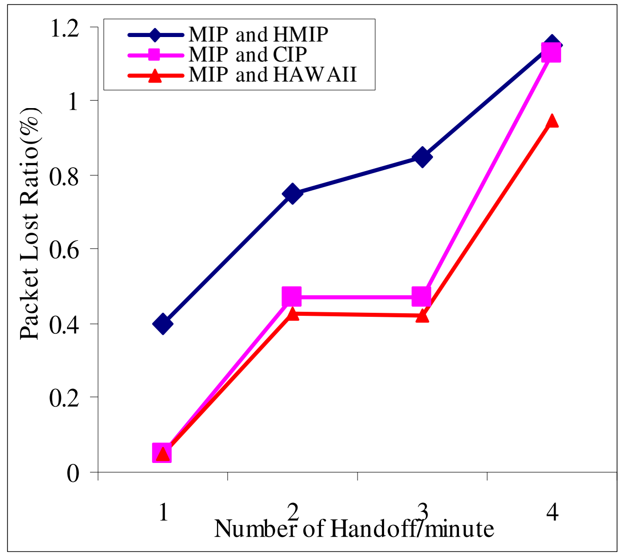

Fig. 5 UDP Packet Loss Ratio in Case of Periodic Handoff

The simulation result for UDP download during handoff is plotted in Figure 5. It shows the comparison of the UDP packet loss ratio in integration of Mobile IP and HMIP with integration of Mobile IP and Cellular IP. It is clear from Figure 5 that the packet loss ratio increases with increasing handoff frequency for all integrations of Mobile IP with HMIP, Mobile IP with Cellular IP and Mobile IP with HAWAII protocols. The packet loss ratio is low in integration of Mobile IP and Cellular IP protocols and integration of Mobile IP and Cellular IP protocols architectures when compared to that of the integration of Mobile IP and HMIP protocols. This is because of the low handoff latency in Cellular IP and HAWAII micro mobility protocols.

5.1.2 Packet Loss with Variable Mobile Speed:

In this case, the simulation results are obtained using a single mobile node, continuously travels from BS1 to BS4 with variable speed. The UDP packet loss with variable speed of the MN is plotted in Figure 6 for integration of Mobile IP with HMIP, integration of Mobile IP with Cellular IP and Mobile IP with HAWAII protocols. When the speed of MN increases, the frequency of handoff gets increased and as a result the packet loss also gets increased. This phenomenon is observed from Figure 6 for integration of the micro mobility protocols with Mobile IP. It is further observed that the UDP packet loss ratio is low in integration of Mobile IP and Cellular IP and integration of Mobile IP and HAWAII when compared to integration of Mobile IP and HMIP protocols because of the low handoff latency in Cellular IP and HAWAII.

5.2 TCP SIMULATION RESULTS

Investigating TCP performance is important because its flow control has been shown to operate sub-optimally in wireless environments. TCP is a reliable connection oriented transport protocol that performs well in traditional networks. However, in networks with wireless and other lossy links, the protocol suffers

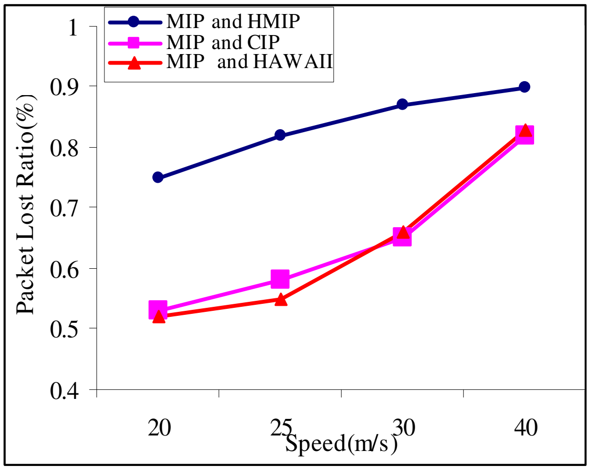

Fig.6 UDP Packet Loss Ratio Vs Variable Speed

from losses and delays due to frequent handoffs in wireless networks running Mobile IP. Several IP micro mobility management protocols have been proposed to reduce handoff latency and the load on the network when a mobile node moves among small wireless cells. In this simulation, a TCP source agent is attached to the CN and a TCP sink is attached at the MN. The MN is initially positioned near the BS1. The MN is allowed to move towards BS4, 4 seconds after the simulation starts. The TCP Tahoe implementation is used with a packet size of 1460 bytes. An FTP session between the MN and the CN is started 1 second after the simulation has started. The bulk FTP data traffic flow is from the CN to the MN.

5.2.1 Throughput due to Periodic Handoffs:

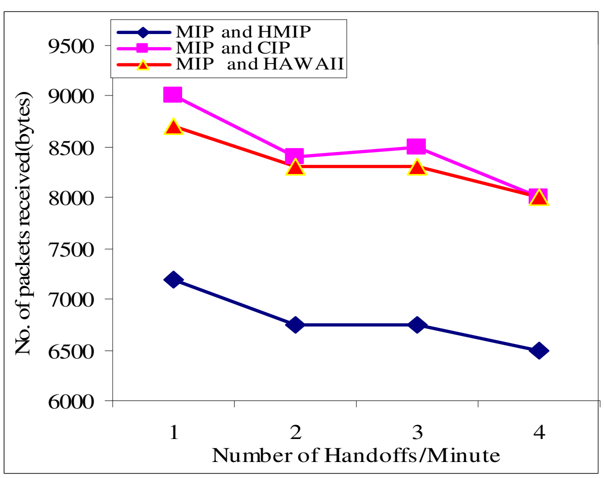

Fig.7 TCP Throughputs in Case of Periodic Handoffs

To obtain these results, the mobile node is allowed to move between base stations. During simulation, an MN travels periodically between BS1-BS4 with a constant speed of 20m/s and the TCP probing traffic is transmitted between the CN and the MN. Figure 7 shows the comparison of TCP throughput due to periodic handoffs for integration of Mobile IP with HMIP, Mobile IP with Cellular IP and Mobile IP with HAWAII protocols. The degradation caused by packet loss increases with the increasing handoff frequency. It is further observed from Figure 7 that the integration of Mobile IP and Cellular IP and the integration of Mobile IP and HAWAII provides better throughput when compared to the integration of Mobile IP and HMIP protocols. The low handoff latency has a great impact on the throughput.

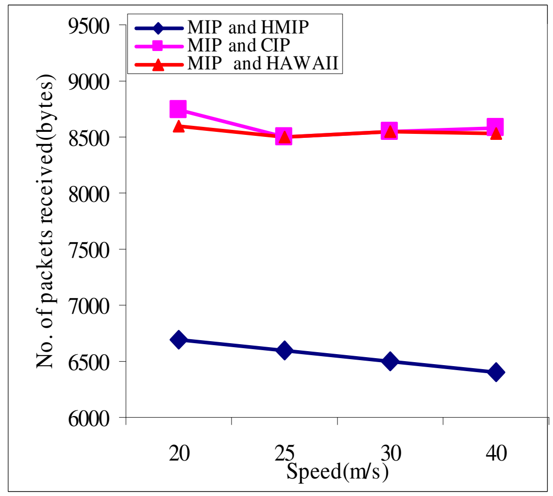

Fig. 8 TCP Throughput Vs Variable Speed

5.2.2 Throughput with Variable Mobile Speed:

In this case, the simulation results are obtained using a single mobile node, continuously moving between the BS1-BS4 with variable speed. The TCP throughput with variable speed of the MN is plotted in Figure 8 for integration of Mobile IP with HMIP protocol, Mobile IP with Cellular IP hard handoff and Mobile IP with HAWAII MSF protocols. When the speed of MN increases, the frequency of handoff gets increased and as a result the packet loss gets increased. This phenomenon is observed from Figure 8 for integration of the micro mobility protocols with Mobile IP. It is further observed that the integration of Mobile IP and Cellular IP and the integration of Mobile IP and HAWAII provide better throughput performance when compared to integration of Mobile IP and HMIP protocols. This is because of the presence of low handoff latency in Cellular IP and HAWAII protocols.

6. CONCLUSION

To provide a complete micro mobility solution, integration of micro and macro mobility protocols architecture is proposed in this paper. The UDP and TCP performance result of the integration of Mobile IP and HMIP protocol, integration of Mobile IP and Cellular IP protocol and the integration of Mobile IP and HAWAII protocols is presented and compared.

The results show that the integration of Cellular IP with Mobile IP protocols and the integration of HAWAII with Mobile IP protocols give better performance when compared to the integration of Mobile IP with Hierarchical Mobile IP protocols. Since Mobile IPv4 without route optimization is used in this simulation, the UDP packet loss and TCP throughput degradation is high. The performance can further be improved with Mobile IPv4 route optimization.

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