Support of Micro-Mobility in MPLS-based Wireless Access Networks

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Abstract- Multi-Protocol Label Switching (MPLS) has begun to deploy in the Internet backbone to support service differentiation and traffic engineering. In recent years, there has also been an interest to extend the MPLS capability to the wireless access networks. In this paper, we provide an overview of the MPLS-based micro-mobility management including label switched path setup, packet forwarding, handoff processing, and paging. In order to prevent packet loss during handoff, we propose a medium access control (MAC) layer assisted packet recovery scheme. A MAC buffer in the old base station caches the packets dropped by MAC layer and forwards these packets to the new base station. Simulation results show that our proposed scheme can eliminate the packet loss due to handoff and improve the TCP throughput dramatically when compared with IP micro-mobility protocols including Cellular IP, HAWAII, and Hierarchical Mobile IP.

I. INTRODUCTION

Mobile IP [1] is the current standard for supporting mobility in IP network. It provides seamless mobility by hiding the change of IP address when a mobile host moves between IP subnets, thus providing a good framework that allows users to roam outside their home network. However, Mobile IP is not designed to support fast handoff and seamless mobility in handoff-intensive environments. In recent years, various IP micro-mobility protocols (e.g., Cellular IP [2], HAWAII [3], HFA [4]) have been proposed aiming to support mobility within a domain. Most of these protocols adopt a hierarchical approach by dividing the network into domains. Mobile IP is used to support mobility between two domains while intra-domain mobility can be handled by micro-mobility scheme. Performance comparisons between these protocols can be found in [5].

In the high-speed wired networks, Multi-Protocol Label Switching (MPLS) has begun to deploy in the Internet backbone to support service differentiation and traffic engineering [6]. In MPLS, each packet is prepended with a label. The label is the only information used to determine the packet's next hop. MPLS simplifies the forwarding process by means of label swapping. Other advantages of MPLS include the ease of creating virtual private networks, the support of traffic engineering via constraint-based routes, and path protection via fast reroute.

Recently, there has been increasing interest in applying MPLS in IP-based wireless access networks [7]. An architecture integrating MPLS and Mobile IP which obviates the need for IP tunneling is proposed in [8]. Label Switched Path (LSP) setup and handoff processing mechanisms for MPLS-based micro-mobility management are proposed in [9]. In [10], a enhanced label edge router called the label edge mobility agent (LEMA) is proposed to create a hierarchical overlay network above the access network. The localized mobility of a mobile host is handled by an appropriately chosen LEMA. Paging and routing optimization mechanisms for MPLS-based micro-mobility management are proposed in [11].

Comparing with Cellular IP, HAWAII and HFA, MPLS-based micro-mobility has three advantages. First, it provides the capability to incorporate constraint-based routing and the support of traffic engineering in the wireless access networks. Second, it is the ease of deployment. Within the wireless access network, only the label switching router (LSR) which serves as the gateway, the paging server and the base stations need to be aware of the mobility of the mobile hosts. Third, it improves the network reliability through the use of path protection and restoration schemes (e.g., fast reroute [6]).

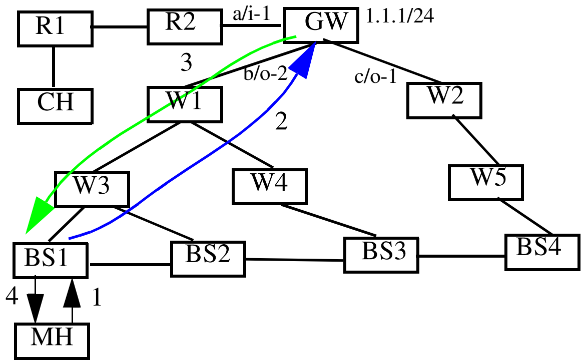
In this paper, we provide the quantitative results via ns-2 simulations of the TCP and UDP performance in the MPLS-based wireless access networks. In order to prevent packet loss during handoff, we propose a medium access control (MAC) layer assisted packet recovery scheme. A buffer in the old base station caches the packets dropped by the MAC layer due to handoff and forwards those packets to the new base station. We also compare the performance between our proposed protocol and other IP micro-mobility schemes including Cellular IP, HAWAII, and HFA.

This paper is organized as follows: Section II gives an overview of MPLS-based IP mobility management in terms of label switched path setup, packet forwarding, handoff processing and paging. Section III proposes the MAC layer assisted packet recovery scheme. Section IV presents the UDP and TCP performance in terms of UDP packet loss and TCP throughput. In addition, the TCP throughput comparisons among Cellular IP, HAWAII, and HFA are also given. Section V concludes our work and outlines the on-going and future work.

II. OVERVIEW OF MPLS-BASED IP MOBILITY MANAGEMENT

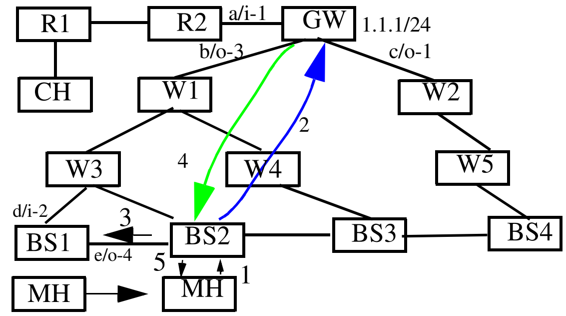
A. Label Switched Path (LSP) Setup

In our proposed framework, the Mobile IP registration protocol can be used to setup LSP for the mobile host (MH). The base station (BS) periodically broadcasts the Mobile IP *adver-*



Node	I/F	I/L	FEC	O/F	O/L	S	Timer	Note
GW	a	i-1	1.1.1/24	-	-	1	-	R1->GW
GW	-	-	BS1	b	o-2	0	-	GW->BS1
GW	-	-	1.1.1.1	b	o-2	0	T_a	GW->MH

Figure 1. Registration process.



Node	I/F	I/L	FEC	O/F	O/L	S	Timer	Note
GW	a	i-1	1.1.1/24	-	-	1	-	R1->GW
GW	-	-	BS2	b	o-3	0	-	GW->BS2
GW	-	-	1.1.1.1	b	o-3	0	T_a	GW->MH
BS1	d	i-2	BS1	-	-	1	-	GW->BS1
BS1	-	-	BS2	e	o-4	0	-	BS1->BS2
BS1	-	-	MH	e	o-4	0	T_a	BS1->MH

Figure 2. Handoff process.

tisement message to all mobile hosts. Upon receiving the *advertisement* message, the mobile host sends a Mobile IP *registration request* as reply (step 1 in Fig. 1). From this *registration request* message, the base station can decide whether the mobile host is powered on and whether the mobile host is in its home domain or not. If the mobile host is in its home domain, the base station sends a Mobile IP *registration request* message to the gateway (GW) (step 2 in Fig. 1). The gateway creates an LSP entry for the mobile host in its Label Forwarding Information Base (LFIB). It places the mobile host's address on the Forwarding Equivalence Class (FEC) field of the LSP entry for mobile host's serving base station. The gateway sends a Mobile IP *registration reply* message to the base station which relays it to the mobile host (steps 3 and 4 in Fig. 1). In this case, in the downlink direction, there are two LSP segments for the mobile host, one is from the correspondent host (CH)'s LSR to gateway, and the other segment is from the gateway to the mobile host's serving base station (i.e., BS1).

In the uplink direction, all packets from mobile host will travel to the gateway first and then be forwarded to the destination. The Label Distribution Protocol (LDP) [12] can be used to establish the LSPs. We assume that the LSP between correspondent host and Home Agent (HA)/gateway as well as the LSP between gateway and base station are pre-configured via LDP. In Fig. 1, all the intermediate nodes (e.g., R1, W1, GW, BS1) are assumed to be MPLS capable routers. The gateway is the domain root router with MPLS micro-mobility support. The gateway also serves as the home agent for the mobile host. The LFIB for the gateway is shown in the inner table in Fig. 1. The notations used in Fig. 1 are as follows: I/F: Incoming interFace; I/L: Incoming Label; O/F: Outgoing interFace; O/L: Outgoing Label; S: *Segmented* flag. The *segmented* flag (with a value of 1 or 0) is used to indicate the need for further LFIB look-up for packet forwarding.

B. Packet Forwarding

If a correspondent host wants to communicate with the mobile host, the packets are first transmitted via the pre-configured LSP between the correspondent host's LSR and the mobile host's home agent. The home agent knows whether there is another LSP segment for the mobile host via checking the *segmented* flag in the LFIB. If the value of the *segmented* flag is 1, the home agent selects an LSP by using the IP destination address as an index. All packets destined for mobile host will use this LSP to reach the mobile host's serving base station via the normal label forwarding scheme. If the mobile host has roamed to another domain, the foreign gateway also performs the procedures described above. Finally, the packets arrive the mobile host's serving base station. The base station relays the packets to mobile host via wireless channel.

From the above description, there are three LSP segments between the correspondent host and mobile host: correspondent host's LSR to home agent, home agent to foreign gateway, and foreign gateway to mobile host's serving base station. For outgoing direction, data packets follow the path to the gateway and then be forwarded to the destination via normal label swapping scheme.

C. Handoff

As in Mobile IP, the base station periodically sends the Mobile IP *advertisement* message to mobile host. The mobile host replies with a Mobile IP *registration request* (step 1 in Fig. 2). When a mobile host handoffs from one base station to another within the same domain, the new base station informs the gateway via the Mobile IP *registration request* message (step 2 in Fig. 2). The new base station also sends a *handoff notification* to the old base station so that the old base station can forward packets for the mobile host to the new base station (step 3 in Fig. 2). Upon receiving the *registration request* message, the gateway updates the entry for the mobile host in its LFIB. It places the mobile host's address on the FEC column of the entry for the new base station, and sends a *registration reply* (step 4 in Fig. 2). The new base station then sends a Mobile IP *registration reply* message to mobile host (step 5 in Fig. 2). Upon receiving the *handoff notification* message from the mobile host, the old base station adds an LSP entry in LFIB for the mobile host by including the mobile host's address to the FEC column of the LSP entry for the new base station and starts the active timer T_a. At the same time, the old base station sets the *segmented* flag to 1 in the entry for the LSP from the gateway to itself. From this point on, the old base station will divert packets destined for the mobile host to the new base station on the appropriate LSP until the timer T_a expires. The handoff process is illustrated in Fig. 2. The LFIBs for the gateway and base station BS1 are shown in the inner table in Fig. 2.

In our proposed framework, we use the active timer T_a to decide whether or not the mobile host is active (i.e., transmitting or receiving data packets). Each incoming or outgoing data packet refreshes the timer T_a. When the timer expires, the network assumes the mobile host to be in "idle" state and removes the LSP entry for this user in the LFIB.

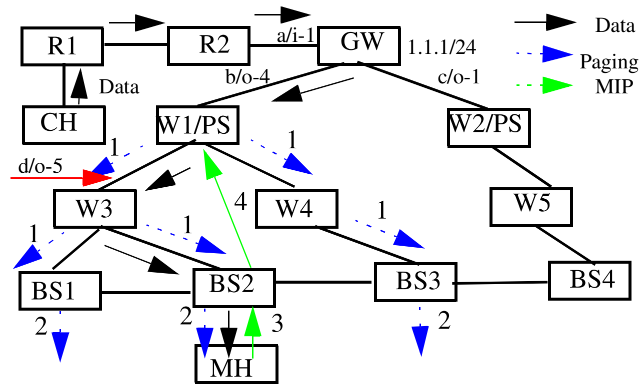
D. Paging

In order to reduce the power consumption of mobile hosts and signalling load in the access network caused by frequent registration due to handoffs, we propose to employ paging in MPLS-based micro-mobility management architecture. The wireless access network domain is divided into different paging areas. When an idle mobile host crosses a cell boundary but stays within the same paging area, it needs not send a *registration request* message to the gateway to report its location. We assume that there is a paging server in each paging area.

Whether the mobile host is in its idle or active state, the gateway maintains the location information of that mobile host in the granularity of a paging area. When a mobile host crosses a paging area boundary, it sends a *registration request* message to the gateway to report its current paging area. On the other hand, when the mobile host is in its active state, it sends a *registration request* message to the paging server upon every cell boundary crossing. In this way, we introduce an extra level of hierarchy after adopting the paging server.

In the forward path (from gateway to mobile host), incoming packets destined for the mobile host are intercepted by the gateway. The gateway then forwards those packets to the corresponding paging server. The paging server forwards those packets to the corresponding base station. In the reverse path (from mobile host to gateway), outgoing packets are sent to the paging server first. The paging server then forwards those packets to the gateway. The gateway forwards those packets to the appropriate destinations.

When mobile host is in its idle state, the paging server buffers all the incoming packets correspond to that mobile host and sends a *paging request* to all base stations within its paging area via multicast (step 1 in Fig. 3). Those base stations then send a layer-2 paging request via wireless channel (step 2 in Fig. 3). Upon receiving the paging request, the mobile host sends a Mobile IP *registration request* message to the base station (step 3 in Fig. 3). The base station sends a *registration request* message to the paging server (step 4 in Fig. 3). Finally, the paging server installs an LSP entry for the mobile host. The LFIBs for the gateway GW and paging server W1 are shown in the inner table in Fig. 3.



Node	I/F	I/L	FEC	O/F	O/L	S	Timer	Note
GW	a	i-1	1.1.1/24	-	-	1	-	R1->GW
W1	b	o-4	W1	-	-	1	-	GW->W1
W1	-	-	BS2	d	o-5	0	-	W1 ->BS2
W1	-	-	1.1.1.1	d	o-5	0	T_a	W1->MH

Figure 3. Paging process.

III. MAC LAYER ASSISTED PACKET RECOVERY

In wireless networks such as GPRS [13] or Wireless LANs [14], automatic retransmission is used to counteract the error-prone wireless channel and to improve the transmission reliability. The medium access control (MAC) layer in Wireless LAN uses the Request To Send (RTS), Clear To Send (CTS), DATA, and Acknowledgment (ACK) for data exchange. The MAC layer users the RTS control frame and a short CTS frame to reserve access to the channel. After data transmission, the ACK frame confirms the success of the transmission. In this way, the MAC layer maintains information about which frames have been successfully delivered.

Our proposed MAC layer assisted packet recovery scheme is designed to prevent the packet loss due to handoff. In general, the packet loss during handoff is caused by the broken or deteriorated wireless connection between the old base station and the mobile host. In our proposed scheme, a buffer in the MAC layer is used to cache the packets dropped by the MAC layer. These packets are then transmitted from the old base station to the new base station.

The MAC layer assisted packet recovery procedure is illustrated in Fig. 4 (a). IP packets are passed from the network layer down to the link layer (LL). Within the LL module, a MAC layer frame is constructed from an IP packet by adding the appropriate MAC layer header and trailer. The MAC layer frame is then placed in the interface queue IFq for transmission. The MAC module in Fig. 4(a) is responsible for channel access (i.e., RTS/CTS/DATA/ACK). If a particular frame transmission is not successful after a certain number of times, this frame is

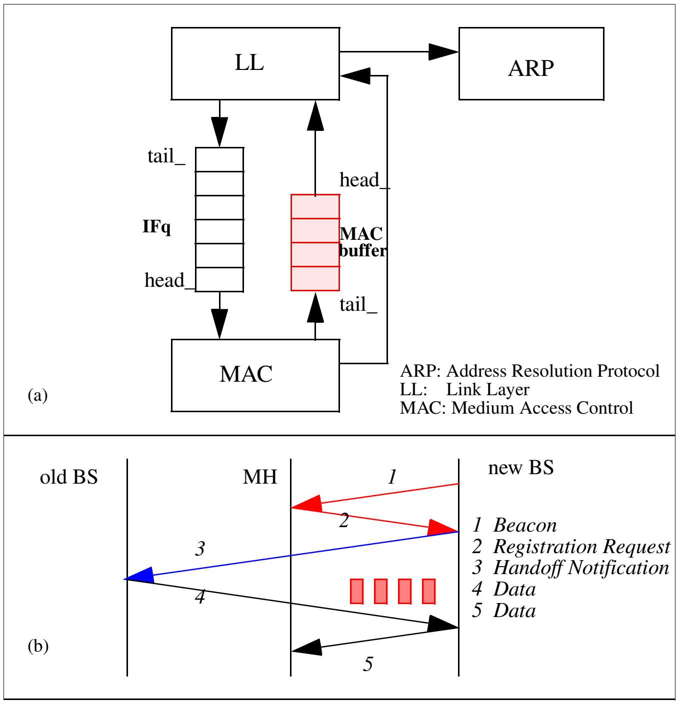


Figure 4. MAC layer assisted packet recovery.

then placed in the MAC buffer.

After receiving a *handoff notification* from the new base station, the old base station forwards those frames in the MAC buffer correspond to that mobile host to the new base station via the pre-configured LSP. After that, those frames in the IFq buffer correspond to that mobile host are also forwarded to the new base station. Note that all mobile hosts within the coverage of the same base station share the MAC buffer. The base station uses the mobile host's MAC address carried in the *handoff notification* to identify which packets belong to the corresponding mobile host. In this way, we can eliminate the packet loss due to handoff and thus improve the application performance. The MAC layer assisted packet recovery process is illustrated in Fig. 4(b).

IV. UDP/TCP PERFORMANCE

A. Simulation Model

We use the ns-2 version 2.1b6 [15] as our simulation tool as well MPLS module and IP micro-mobility module CIMS contributed by Gaeil Ahn and Columbia University, respectively [16][17]. We extend the MPLS module to hierarchical address format which is necessary for Mobile IP based simulation. We use the similar network topology adopted in [5] to study the performance of MPLS-based micro-mobility management on UDP and TCP applications. The network topology is shown in Fig. 1.

We assume that the network in Fig. 1 is the mobile host's home network. In the network each wired connection is modeled as a 10 Mb/s duplex link with link delay of 10 ms. Since the base stations are assumed to be LSRs with mobility management capabilities, we assume that there is a direct connection between each pair of neighboring base station. The mobile host connects to the base station using ns-2 IEEE 802.11 wireless LAN model. The coordinates for four base stations are (0, 0), (140, 140), (280, 280), (420, 420), the unit is meter. The base station broadcasts beacon signals at an interval of 0.5s. In order to model the scenarios where neighboring base stations can overlap with each other, we adjust the transmitting power of base stations according to the overlapping distance, denoted by d(overlap). The Fig. 5 shows the concept of overlapping distance. When the mobile host crosses the cell boundary, upon receiving the first beacon signal from the new base station, the mobile host assumes that a handoff has occurred and notifies the base station [18]. In this simulation, we do not implement the active timer T_a and leave it for further study when we investigate the performance of different paging area sizes.

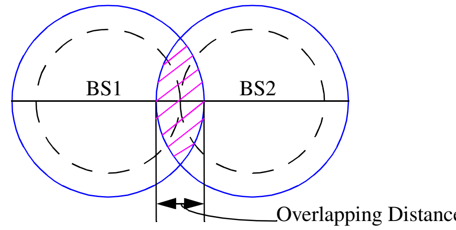


Figure 5. Illustration of overlapping distance.

B. UDP Performance

In this experiment, UDP probing traffic is directed from correspondent host to mobile host and consists of 210 bytes packets transmitted at 10 ms interval. The mobile host moves from BS1 to BS2 at a speed of 20 m/s. In Fig. 1, LSRs W1 and W2 are assumed to be the paging servers.

Fig. 6 shows the results of packet loss caused by handoff without packet recovery scheme under different overlapping distances. We use RTP sequence number to record the UDP packets. As shown in Fig. 6, the number of packet loss are 22, 9, 0 with overlapping distance of 0, 5 and 10 meter, respectively. Note that the time during which the packets are lost is equal to the sum of the second layer (i.e., data link layer) handoff time and the delay between the new base station and paging server. From Fig. 6, we can observe that neighboring base stations overlapping does reduce the packet loss during handoff.

Fig. 7 shows the UDP packet number during handoff with the use of MAC layer assisted packet recovery. The consecutive sequence of UDP packet numbers indicate that there is no packet loss during handoff. In addition, the larger the overlapping distance between neighboring base stations, the smaller the time gap between the two packet streams.

C. TCP Performance with MAC Layer Assisted Packet Recovery

We examine the impact of TCP Reno performance in MPLS-based micro-mobility scheme. In the first experiment, we study the TCP packet number observed at the mobile host when handoff occurs. In Fig. 1, the MH moves from BS1 to BS2 at a speed

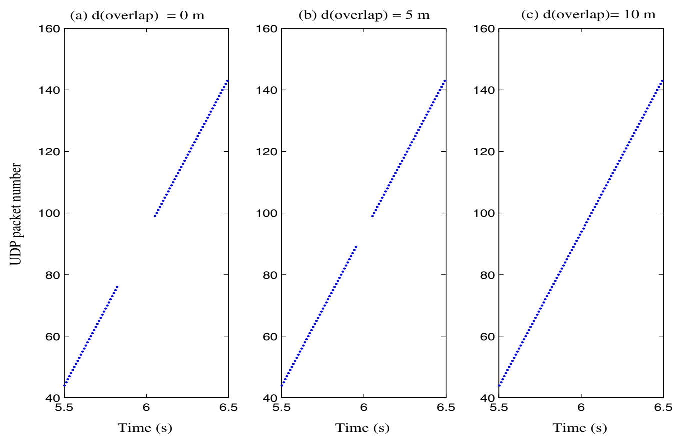


Figure 6. UDP packet number without packet recovery.

of 20 m/s, the overlapping distance is 0 meter.

Fig. 8(a) shows the TCP behavior during handoff without packet recovery. At time 6.006s, the mobile host receives the beacon signal from the new base station. We can observe that TCP slow start [19] is initiated due to timeout.

Fig. 8(b) shows the TCP packet number observed at the mobile host with the use of MAC layer assisted packet recovery. From this figure, we can observe that no TCP packet is either dropped or retransmitted, and no TCP slow start is initiated. The gap between the two packets streams (210 ms in Fig. 8(b)) is equal to the handoff time plus the link delay from new base station to old base station via which the *handoff notification* message traverses.

D. TCP Performance with Different Overlapping Distance

We compare the TCP Reno throughput with and without MAC layer assisted packet recovery under varying overlapping distance. In this experiment, the paging servers are assumed to be located in W1 and W2 in Fig. 1. The mobile host moves back and forth between BS1 and BS4 at different speeds. The simulation time is 400s.

The results are shown in Fig. 9. From this figure, we can make the following observations. First of all, a higher TCP throughput can always be achieved with the use of the MAC layer assisted packet recovery. The larger the overlapping distance between neighboring base stations, the higher the TCP throughput. The reason is that with a larger overlapping distance, the mobile host can receive the beacon signal from the new base station sooner and can also maintain the connection with the old base station longer. We can also observe that the TCP throughput decreases as the speed of the mobile host increases.

E. Comparisons with IP Micro-Mobility Protocols

We compare the TCP performance between our proposed MPLS-based micro-mobility management scheme and other existing proposals, including Cellular IP hard and semi-soft handoff, HAWAII UNF and MSF, and HFA. In these experiments, the mobile host moves between BS1 and BS4 back and forth at different speeds. The simulation time is 400s. In Fig. 1,

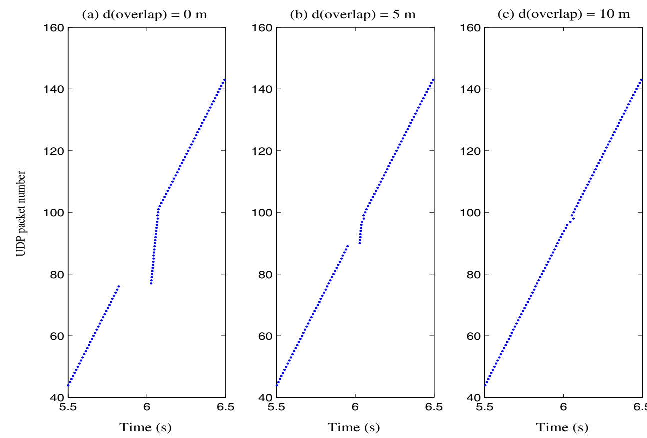


Figure 7. UDP packet number with MAC layer assisted packet recovery.

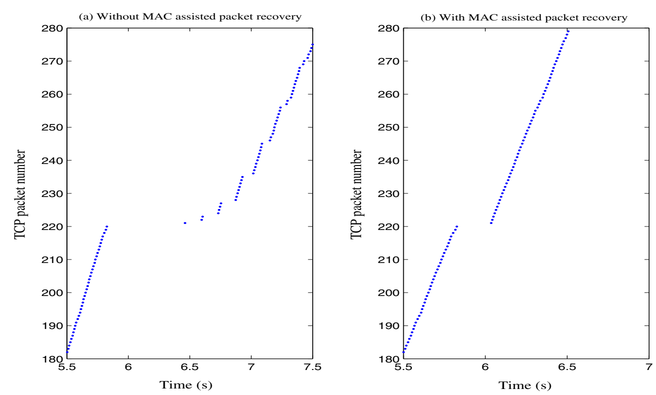


Figure 8. TCP packet number.

the paging servers are assumed to be located at W1 and W2. In order to provide a fair comparison, we made some modifications in HFA and HAWAII module from CIMS. In the original CIMS, upon receiving the first beacon signal from the new base station, the connection between the mobile host and the old base station is cut off to simulate the network where mobile host can only listen one base station's signal at any given time. We model this by adjusting the transmitting power of the base station. In Cellular IP: the route update interval value is 0.5s; the routing cache time out value is 1.5s; the paging cache time out value is 15s; the active time value is 2s; and the semi-soft delay is 50ms. In Fig. 1, all nodes except CH, R1 and R2 are assumed to be Cellular IP capable nodes and are configured with routing cache and paging cache. In HAWAII and HFA, beacon signal is transmitted at an interval of 0.5s.

The TCP throughput with overlapping distance of 0 meter is shown in Fig. 10. From this figure, we can make the following observations. First of all, our proposed MPLS-based micro-mobility management with MAC layer assisted packet recovery outperforms all other IP micro-mobility schemes. Second, the performance between MPLS-based micro-mobility management without MAC layer assisted packet recovery and HFA is very close since HFA does not use any packet recovery scheme. Third, HAWAII MSF gains a small edge over HFA, MPLS without packet recovery as well as Cellular IP semi-soft hand-

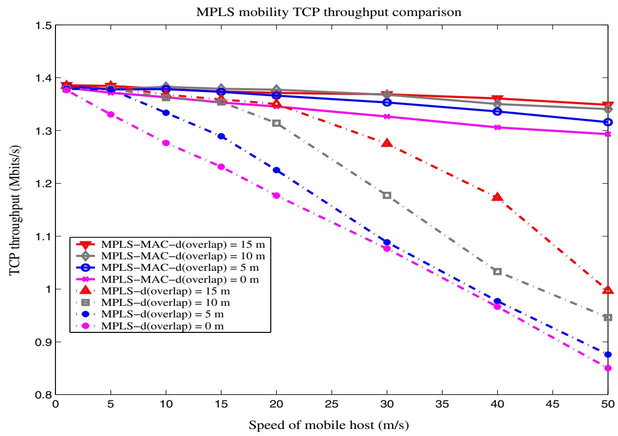


Figure 9. MPLS-based micro-mobility TCP throughput.

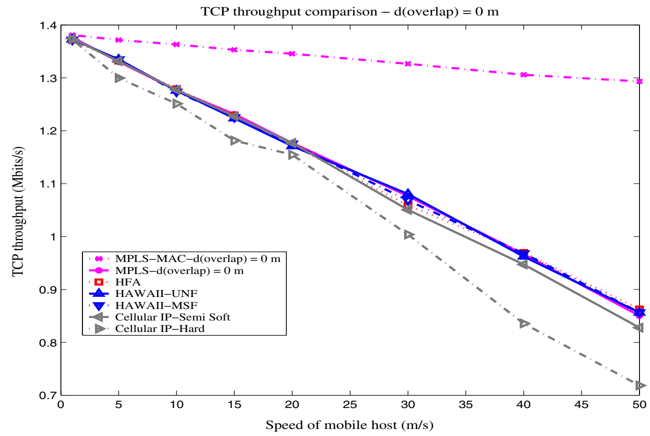


Figure 10. TCP throughput comparison.

off. When no packet recovery scheme is used, the performance of MSF and UNF in HAWAII is very close. The advantage of MSF over UNF is that packet recovery scheme can be applied in the old base station. Note that in MSF, packets are first forwarded from the old base station to the new base station before they are diverted at the crossover router. In addition, we observe that in Cellular IP, periodical route-update and paging-update messages are sent that would compete the shared wireless channel with the data packets. Cellular IP gives a lower TCP throughput when compared with other schemes.

We also perform simulations with overlapping distance of 5, 10 and 15 meters. The comparsion results are the same as that with overlapping distance of 0 meter.

IV. Conclusions

In this paper, we provided an overview of MPLS-based micro-mobility management for wireless access networks. We presented the procedures for LSP setup, packets forwarding, handoff, and paging. In order to reduce packet loss due to handoff, we proposed a MAC layer assisted packet recovery scheme. Packets are forwarded from the old base station to the new base station during handoff. Simulation results indicated that our proposed MAC layer assisted packet recovery can prevent packet loss for either UDP or TCP traffic during handoff. On TCP throughput, the MPLS-based micro-mobility with MAC layer assisted packet recovery outperforms other IP micro-mobility schemes. Our current work includes the performance analysis with the use of our proposed active timer. Further work includes the study of location update and paging cost associated with our proposed framework.

Acknowledgements

This work was supported by a grant from Motorola Canada Ltd. and by the Natural Sciences and Engineering Research Council of Canada under grant CRDPJ 223095-98.

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