Experimental Comparison of Handoff Performance of SIGMA and Mobile IP

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Abstract

Mobile IP and `SIGMA` are handoff schemes at the network layer and the transport layer respectively. `SIGMA` is based on IP diversity and aims to improve the handoff performance over Mobile IP by reducing the handoff latency. We compared the performance of the handoff schemes in an experimental test bed. Results show that `SIGMA` has a lower handoff latency when compared to Mobile IP. Moreover, `SIGMA` can achieve a seamless handoff between two subnets.

I. INTRODUCTION

The last two decades have seen considerable growth in wireless networks which allow users to access the Internet access without being tied down to one location. The current Internet infrastructure, however, was not initially designed for mobility. The Mobile IP (MIP) [1] standard from the Internet Engineering Task Force addresses the issue of mobility at the network layer, and extends the existing Internet protocol to support host mobility, including handoff, by introducing two network infrastructure entities: Home Agent (HA) and Foreign Agent (FA). A Correspondent Node (CN) communicates with the mobile node (MN) via its HA in the home network, even though the MN may have moved out of its home network. For CN to have seamless communication with the MN, the MN should be able to handoff quickly between networks.

Base Mobile IP suffers from handoff latency and packet loss which are two of the most important indicators of handoff performance. Large handoff latency degrades performance of realtime application during handoff. For instance, a large handoff latency will introduce interruption in a video conference session due to breaks in both audio and video data transmission. Mobile IP also requires change in the Internet infrastructure due to the addition of the HA and FA. To address the limitations of Mobile IP, we have developed a handoff scheme at the transport layer called Seamless IP diversity based Generalized Mobility Architecture (`SIGMA`) [2], which utilizes multi-homing and IP diversity to achieve seamless handoff between networks. The *objective* of this paper is to report on the comparative performance of Mobile IP and `SIGMA` using the experimental testbed we have developed at the University of Oklahoma. To put our work in context, we will next describe recent work which has been done to improve the performance of Mobile IP.

A. Contributions and Paper Structure

Simulation comparison between Mobile IP and `SIGMA` [2], in terms of handoff latency and throughput, shows a better performance of `SIGMA`, as compared to Mobile IP. In this paper, we present *experimental* results on performance evaluation of `SIGMA` and Mobile IP. The *contribution* of this paper is to demonstrate, based on experimental results from a prototype testbed, that `SIGMA` has a negligible handoff latency and can achieve seamless handoff, while Mobile IP suffers discontinuity in transmission during handoff. The handoff latency of Mobile IP was found to be eight seconds which is significantly higher than the six milliseconds handoff latency of `SIGMA`.

The rest of the paper is organized as follows: We provide a brief introduction to `SIGMA` in Sec. II. Sec. III describes the details of the experimental setup of `SIGMA` and Mobile IP. Comparison of handoff performance between Mobile IP and `SIGMA`, based on experimental results, are given in Sec. IV. Sec. V presents future work and concluding remarks.

II. INTRODUCTION TO `SIGMA`

To aid the reader in getting better understanding of `SIGMA`, we describe the various steps involved in `SIGMA` handoff in this section. A detailed description can be found in [2]. We will use the Stream Control Transmission Protocol [3], a new emerging transport layer protocol from IETF, to illustrate `SIGMA`.

Multi-homing (see Fig. 1) allows an association between two end points to span across multiple IP addresses or network interface cards. One of the addresses is designated as the primary while the other can be used as a backup in the case of

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failure of the primary address, or when the upper layer application explicitly requests the use of the backup. Retransmission of lost packets can also be done over the secondary address. A multi-homed SCTP association can speedup recovery from link failure situations without interrupting ongoing data transfers. Fig. 1 presents an example of SCTP multi-homing, where two nodes, CN and MN are connected through two wireless networks, with MN being multi-homed. One of MN's IP addresses is assigned as the primary address for CN to be used when transmitting data packets, while the other IP address is used as a backup address in case of primary address failure.

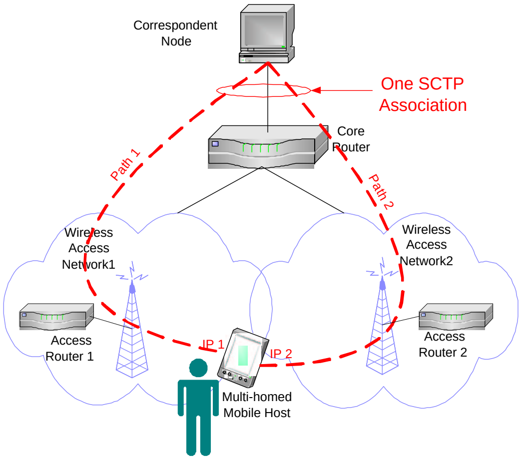


Fig. 1. A SCTP association featuring multi-homing.

A. STEP 1: Obtain new IP address

Referring to Fig. 1, the handoff preparation procedure begins when the MN moves into the overlapping radio coverage area of two adjacent subnets. Once the MN receives the router advertisement from the new access router (AR2), it should initiate the procedure of obtaining a new IP address (IP2 in Fig. 1). This can be accomplished through several methods: DHCP, DHCPv6, or IPv6 Stateless Address Autoconfiguration (SAA) [4]. The main difference between these methods lies in whether the IP address is generated by a server (DHCP/DHCPv6) or by the MN itself (IPv6 SAA). For cases where the MN is not concerned about the its IP address, but only requires the address to be unique and routable, IPv6 SAA is the preferred method for `SIGMA` to obtain a new address since it significantly reduces the required signalling time.

B. STEP 2: Add IP addresses to association

When the SCTP association is initially setup, only the CN's IP address and the MN's first IP address (IP1) are exchanged between CN and MN. After the MN obtains another IP address (IP2 in STEP 1), MN should bind IP2 into the association (in addition to IP1) and notify CN about the availability of the new IP address.

In `SIGMA`, MN notifies CN that IP2 is available for data transmission by sending an ASCONF chunk to CN with parameter type set to 0xC001 (Add IP Address). On receipt of this chunk, CN will add IP2 to its local control block for the association and reply to MN with an ASCONF-ACK chunk indicating the success of the IP addition. At this time, IP1 and IP2 are both ready for receiving data transmitted from CN to MN.

C. STEP 3: Redirect data packets to new IP address

When MN moves further into the coverage area of wireless access network2, data path2 becomes increasingly more reliable than data path1. CN can then redirect data traffic to the new IP address (IP2) to increase the possibility of data being delivered successfully to the MN. This task can be accomplished by the MN sending an ASCONF chunk with the Set-Primary-Address parameter, which results in CN setting its primary destination address to MN as IP2.

D. STEP 4: Updating the location manager

`SIGMA` supports location management by employing a location manager that maintains a database which records the correspondence between MN's identity and current primary IP address. MN can use any unique information as its identity, such as the home address (as in MIP), domain name, or a public key defined in the Public Key Infrastructure (PKI).

Following our example, once the Set-Primary-Address action is completed successfully, MN should update the location manager's relevant entry with the new IP address (IP2). The purpose of this procedure is to ensure that after MN moves from the wireless access network1 into network2, further association setup requests can be routed to MN's new IP address IP2. This update has no impact on existing active associations.

We can observe an important difference between `SIGMA` and MIP: the location management and data traffic forwarding functions are coupled together in MIP, whereas they are *decoupled in* `SIGMA` *to speedup handover and make the deployment more flexible*.

E. STEP 5: Delete or deactivate obsolete IP address

When MN moves out of the coverage of wireless access network1, no *new* or *retransmitted* data packets should be directed to address IP1. In `SIGMA`, MN can notifies CN that IP1 is out of service for data transmission by sending an ASCONF chunk to CN with parameter type set to 0xC002 (Delete IP Address). Once received, CN will delete IP1 from its local association control block and reply to MN with an ASCONF-ACK chunk indicating the success of the IP deletion.

A less aggressive way to prevent CN from sending data to IP1 is for the MN to advertise zero receiver window (corresponding to IP1) to CN [5]. This will give CN an impression that the interface (on which IP1 is bound) buffer is full and can not receive any more data. By deactivating, instead of deleting the IP address, `SIGMA` can adapt more gracefully to MN's zigzag (often referred to as ping pong) movement patterns, and reuse the previously obtained IP address (IP1) as long as the lifetime of IP1 has not expired. This will reduce the latency and signalling traffic that would have otherwise been caused by obtaining a new IP address.

F. Timing diagram of `SIGMA`

Fig. 2 summarizes the signalling sequences involved in `SIGMA`. Here we assume IPv6 SAA and MN initiated Set-Primary-Address. Timing diagrams for other scenarios can be drawn similarly, but are not shown here because of space limitations. In this figure, the numbers before the events correspond to the step numbers in Sec. II-A to II-E, respectively.

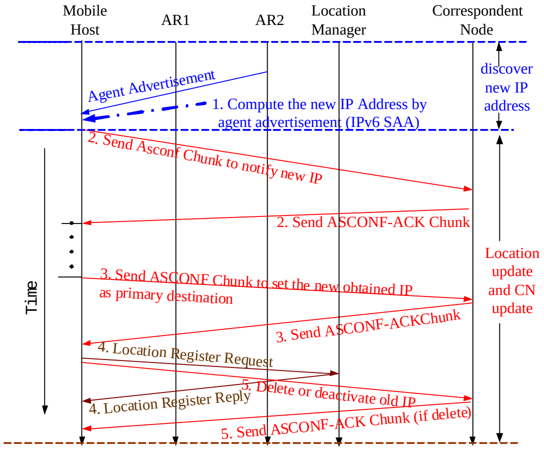


Fig. 2. Timeline of `SIGMA`.

III. EXPERIMENTAL SETUP

In this section, we describe the experimental testbed that has been used to implement the prototype of `SIGMA`. To make a fair comparison between the handoff performance of `SIGMA` and Mobile IP, we have used the same hardware infrastructure for both Mobile IP and `SIGMA`. Fig. 3 (to be described later) shows the topology of our test bed which has been used by a number of researchers [6], [7].

A number of Mobile IP implementations, such as HUT Dynamics [8], Stanford Mosquito [9] and NUS Mobile IP [10] are publicly available. We chose HUT Dynamics for testing Mobile IP in our testbed due to the following reasons:

1) Unlike Stanford Mosquito which integrates the FA and MN, HUT-Dynamics implements HA, FA and MN daemons separately. This architecture is similar to `SIGMA` where the two access points and MN are separate entities.
2) HUT-Dynamics implements hierarchical FAs which will allow future comparison between `SIGMA` and hierarchical Mobile IP.

Our Mobile IP testbed consists four nodes: Corespondent Node (CN), Foreign Agent (FA), Home Agent (HA) and Mobile Node (MN). All the nodes run corresponding agents developed by HUT-Dynamics. The CN and the machines running the HA and FA are connected to the Computer Science network of University of Oklahoma, while the MN and Access Points are connected to two separate private networks. IEEE 802.11b is used to connect the MN to the access points.

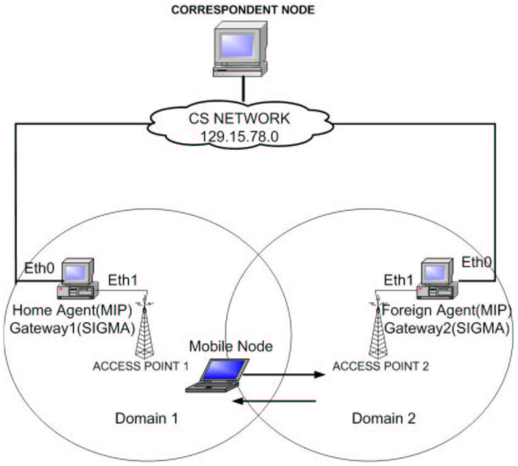


Fig. 3. SIGMA and Mobile IP testbed.

Node	Network Configuration
Home Agent (MIP) Gateway1 (SIGMA)	eth0: 129.15.78.171, gateway 129.15.78.172; eth1:10.1.8.1
Foreign Agent (MIP) Gateway2 (SIGMA)	eth0: 129.15.78.172 gateway 129.15.78.171; eth1: 10.1.6.1
Mobile Node	Mobile IP's Home Address: 10.1.8.5 SIGMA's IP1: 10.1.8.100 SIGMA's IP2 : 10.1.6.100
Correspondent Node	129.15.78.150

TABLE I

MOBILE IP AND SIGMA NETWORK CONFIGURATIONS

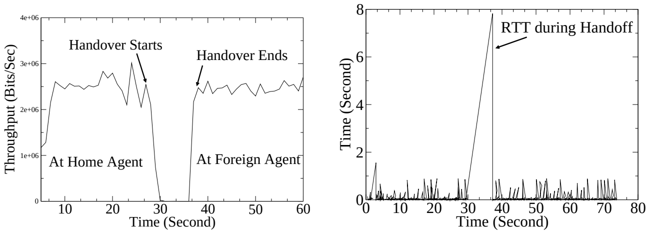
The network topology of SIGMA is similar to that of Mobile IP with the exception that there is no HA or FA in SIGMA. As shown in Fig. 3, the machines which run the HA and FA in the case of Mobile IP act as gateways in the case of SIGMA. The various IP addresses are shown in Table I. For both Mobile IP and SIGMA data were sent from the CN to the MN using file transfer programs we wrote to carry out the experiments. The difference between the file transfer programs lies in the lower layer sockets: the file sender for Mobile IP is based on the regular TCP sockets, while that for SIGMA is based on SCTP sockets. We did not use the traditional *ftp* program for file transfer because it was not available for the SCTP protocol. To obtain access to the SCTP socket, we used Linux 2.6.2 kernel with Linux Kernel SCTP (lksctp) [11] version 2.6.2-0.9.0 on both CN and MN. The SIGMA handoff program which runs in the MN has two functions: (i) monitoring the link layer signal strength to determine the time to handoff, and (ii) carrying out all the signalling shown in Fig. 2. Ethereal [12] was used on both CN and MN to capture packets during handoff. The captured packets were analyzed and the results are given in the next section.

IV. RESULTS

In this section, we present and compare the results of handoffs for Mobile IP and SIGMA. For comparison, we use throughput, RTT and handoff latency as the performance measures. *Throughput* is measured by the rate at which payload data are received at the MN. *RTT* is the time required for a data packet to travel from the source to the destination and back. We define *handoff latency* as the time interval between the MN receiving the last packet from Domain 1 (previous network) and the first packet from Domain 2 (the new network). The experimental results are described below.

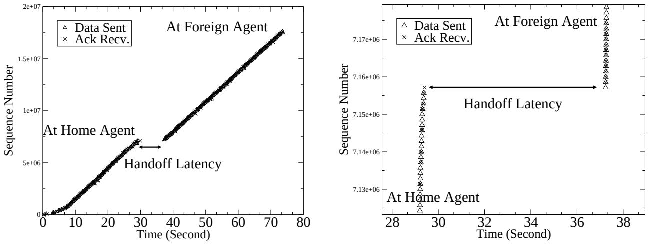
A. Results for Mobile IP Handoff

Fig. 4(a) shows the throughput during Mobile IP handoff between Domain 1 and Domain 2. The variations in throughput within Home and within Foreign Agents are due to network congestion arising from cross traffic in the production CS network. The average throughput before handoff is about 2.436 Mbps, and it is 2.390 Mbps after handoff due to triangular routing. The average throughput during handoff is zero, which lasts for about eight seconds (from time $t = 30$ second to $t = 38$ second in Fig. 4(a)).



(a) Throughput (b) RTT

Fig. 4. Throughput and RTT of Mobile IP handoff.



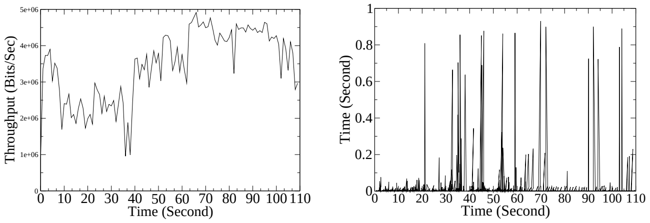
(a) Full range packet trace (b) Zoomed in view of the packet trace

Fig. 5. Packet trace of Mobile IP handoff.

Fig. 4(b) shows the RTT for the Mobile IP handoff. As we can see, the RTT goes as high as eight seconds (the handoff latency time) during the handoff. Fig. 5(a), shows the packet trace of the Mobile IP handover. The actual handoff latency for Mobile IP can be clearly calculated by having a zoomed-in view of the packet trace graph. Fig. 5(b) shows a zoomed-in view of the packet trace, where the calculated handoff latency is eight seconds for Mobile IP.

The Registration Latency is also a part of the handoff latency in Mobile IP. The Registration Latency, the time taken by the MN to register it with the Agents, is calculated as follows. Our Ethereal capture showed that the MN sent registration request to the HA at time $t = 14.5123$ second, and received reply from the HA at about $t = 14.5180$ second, resulting in a registration time with HA of 5.7 milliseconds. Similarly during Mobile IP handoff, Ethereal capture showed that the MN sent Registration request to FA at time $t = 7.1190$ second, and received reply from the FA at about $t = 7.2374$, resulting in a registration time with FA of 38.3 milliseconds. The reason being, when Mobile node registers with the Home Agent, it can directly register it with the Home Agent. In the other hand, if it registers with the Foreign Agent, the MN registers each new care-of-address with its home agent possibly by way the foreign agent. So the Registration Latency is greater when the MN is in the Foreign Agent, which is added to the handoff latency.

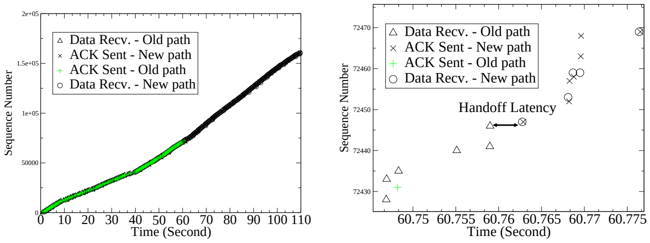
B. Results from SIGMA *Handoff*



(a) Throughput (b) RTT

Fig. 6. Throughput and RTT of SIGMA handoff.

Fig. 6(a) shows the throughput result of SIGMA where we can observe that the throughput during SIGMA handoff does not go to zero. The variations in the throughput are due to the network congestion arising from cross traffic in the production CS network. We could not actually see the gap caused by the handoff in the throughput graph, since the latency is in milliseconds and the graph is in seconds. It should be emphasized that our Ethereal capture showed the handoff starting at $t = 60.755$ second and ending at $t = 60.761$, lasting for a total of about six milliseconds. Fig. 6(b) shows the RTT for the SIGMA handover. As can be seen, there is no sudden increase of RTT during handoff, which shows a seamless handoff. The spikes result network congestion arising from cross traffic in the production CS network.



(a) Full range packet trace

(b) Zoomed in view of the packet trace

Fig. 7. Packet trace of SIGMA handoff.

Fig. 7(a) shows the packet trace during SIGMA handoff. It can be seen that packets arrive at the MN without any gap or disruption; this demonstrates SIGMA's smoother handoff as compared to Mobile IP. We have thus shown experimentally that *a seamless handoff can be realized with* SIGMA. Fig. 7(b) shows a zoomed-in view of the packet trace during SIGMA handoff, where we can see the handoff latency of six milliseconds between the packets arrived from old and new paths.

C. *Comparison of* SIGMA *and Mobile IP Handoffs*

We observed in Sec. IV-A that the registration time of Mobile IP was only 0.1 second, and the handoff latencies of Mobile IP and SIGMA were eight seconds and six millisecond, respectively. We describe below the reasons for Mobile IPś handoff latency being much longer than its registration time.

The handoff latency in Mobile IP comes from three factors: (i) remaining Home Registration Life Time after link layer handoff which can be from 0 to one Life Time, (ii) FA advertisement interval plus the time span of last time advertisement which was not listened by MN, and (iii) Registration Latency.

In the HUT Dynamics implementation of Mobile IP the MN obtains a registration life time after every successful registration. It originates another registration on expiry of this lifetime. So it is possible for the MN to postpone registration even after it has completed a link layer handoff and received FA advertisements. This may introduce some delay which can be up to the duration of a life time. As mentioned in the previous section, the registration of MN also costs some time, measured as 38.3 millisecond in our testbed.

During the above three latency factors, the CN can not communicate through either the previous path because it has completed link layer handoff to the new access point but the MN has not yet completed the registration. As a result, the throughput was found to be zero during this time. Obviously, this kind of shortcoming has been eliminated in SIGMA because of the use of IP diversity and the decoupling of registration and data transfer. As a result, data continues to flow between the CN and MN during the handoff process.

V. CONCLUSIONS

In this paper, we have compared the handoff performance of SIGMA, our proposed seamless handoff scheme, which is based on IP diversity, with Mobile IP on an experimental testbed. The throughput and packet trace of Mobile IP and SIGMA were analyzed which gives a handoff latency of eight seconds and six milliseconds respectively. The reason for lower handoff latency of SIGMA is due to its use of IP diversity, i.e., the MN prepares the new path (registration, etc.) while still communicating through the old path. This eliminates the communication disruption between CN and MN during handoff, resulting in a low latency and seamless handoff in the case of SIGMA.

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