Chapter II

Multimedia over Wireless Mobile Data Networks

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ABSTRACT

With the proliferation of wireless data networks, there is an increasing interest in carrying multimedia over wireless networks using portable devices such as laptops and personal digital assistants. Mobility gives rise to the need for handoff schemes between wireless access points. In this chapter, we demonstrate the effectiveness of transport layer handoff schemes for multimedia transmission, and compare with Mobile IP, the network layer-based industry standard handoff scheme.

I. INTRODUCTION

Mobile computers such as personal digital assistants (PDA) and laptop computers with multiple network interfaces are becoming very common. Many of the applications that run on a mobile computer involve multimedia, such as video conferencing, audio conferencing, watching live movies, sports, and so forth. This chapter deals with multimedia communication in mobile wireless devices, and, in particular, concentrates on the effect of mobility on streaming multimedia in wireless networks.

Streaming multimedia over wireless networks is a challenging task. Extensive research has been carried out to ensure a smooth and uninterrupted multimedia transmission to a mobile host (MH) over wireless media. The current research thrust is to ensure an uninterrupted multimedia transmission when the MH moves between networks or subnets. Ensuring uninterrupted multimedia transmission during handoff is challenging because the MH is already receiving multimedia from the network to which it is connected; when it moves into another network, it needs to break the connection with the old network and establish a connection with the new network. Figure 1 shows an MH connected to Wireless Network 1; when it moves, it has to make a connection with the new network, say Wireless Network 2. The re-establishment of a new connection takes a considerable amount of time, resulting in the possibility of interruption and resulting loss of multimedia.

The current TCP/IP network infrastructure was not designed for mobility. It does not support handoff between IP networks. For example, a device running a real-time application, such as video conference, cannot play smoothly when the user hands off from one wireless IP network to another, resulting in unsatisfactory performance to the user.

Mobile IP (MIP) (Perkins, 1996), from the Internet Engineering Task Force (IETF), addresses the mobility problem. MIP extends the existing IP protocol to support host mobility, including handoff, by introducing two network entities: home agent (HA) and foreign agent (FA). The HA and FA work together to achieve host mobility. The correspondent node (CN) always communicates with the mobile node (MN) via its home network address, even though MH may not dwell in the home network. For CN to have seamless access to MN, the MH has to be able to handoff in a timely manner between networks.

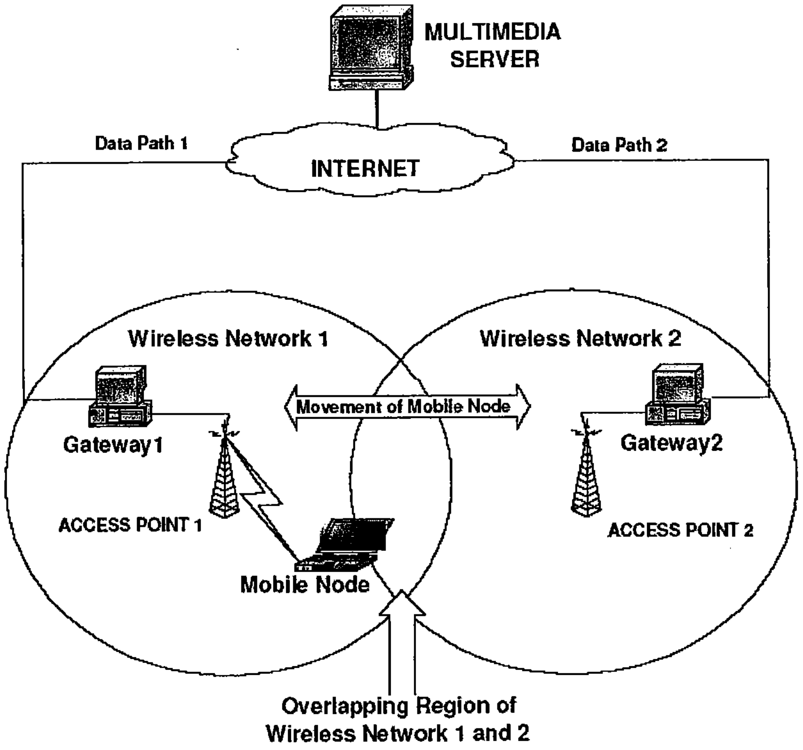
Handoff latency is one of the most important indicators of handoff performance. Large handoff latency degrades performance of real-time applications. For example, large handoff latency will introduce interruption in a video conference due to breaks in both audio and video data transmission. In addition to high handoff latency, MIP suffers from a number of other problems including triangle routing, high signaling traffic with the HA, and so forth. A number of approaches to reduce the MIP handoff latency are given next.

Mobile IP uses only one IP; a certain amount of latency in data transmission appears to be unavoidable when the MH performs a handoff. This is because of MN's inability to communicate with the CN through either the old path (because it has changed its wireless link to a new wireless network) or the new path (because HA has not yet granted its registration request). Thus, MH cannot send or receive data to or from the CN while the MH is performing registration, resulting in interruption of data communication during this time interval. This interruption is unacceptable in a real-world scenario, and may hinder the widespread deployment of real-time multimedia applications on wireless mobile networks. Seamless IP-diversity based generalized mobility architecture (SIGMA) overcomes the issue of discontinuity by exploiting multi-homing (Stewart, 2005) to keep the old data path alive until the new data path is ready to take over the data transfer, thus achieving lower latency and lower loss during handoff between adjacent subnets than Mobile IP.

The *objective* of this chapter is to demonstrate the effectiveness of SIGMA in reducing handoff latency, packet loss, and so forth, for multimedia transmission, and compare with that achieved by Mobile IP. The *contribution* of this chapter is to describe the implementation of a real-time streaming server and client in SIGMA to achieve seamless multimedia streaming during handoff. SIGMA *differs* from previous work in the sense that all previous attempts modified the hardware, infrastructure of the network, server, or client to achieve seamless multimedia transmission during handoff.

The rest of this chapter is organized as follows. Previous work on multimedia over wireless networks is described in the next section. The architecture of SIGMA is described in the third section, followed by the testbed on which video transmission has been tested for both MIP and SIGMA in the fourth section. Results of video over MIP and SIGMA and presented and compared

Figure 1. Illustration of handoff with mobile node connected to Wireless Network 1



in the fifth section, followed by conclusions in the last section.

BACKGROUND

A large amount of work has been carried out to improve the quality of multimedia over wireless networks. They can be categorized into two types:

- Studies related to improving multimedia (e.g., video or audio) over wireless networks. They do not consider the mobility of the MN, but attempt to provide a high quality multimedia transmission within the same wireless network for stationary servers and clients.
- Studies related to achieving seamless multimedia transmission during handoffs. They consider mobility of the MH and try to provide a seamless and high quality multimedia transmission when the MH (client) moves from one network to another.

Although our interest in this chapter is seamless multimedia transmission during handoffs, we describe previous work on both categories in the following sections.

Multimedia over Wireless Networks

Ahmed, Mehaoua, and Buridant (2001) worked on improving the quality of MPEG-4 transmission on wireless using differentiated services (Diffserv). They investigated QoS provisioning between MPEG-4 video application and Diffserv networks. To achieve the best possible QoS, all the components involved in the transmission process must collaborate. For example, the server must use stream properties to describe the QoS requirement for each stream to the network. They propose a solution by distinguishing the video data into important video data and less important video data (such as complementary raw data). Packets which are marked as less important are dropped in the first case if there is any congestion, so that the receiver can regenerate the video with the received important information.

Budagavi and Gibson (2001) improved the performance of video over wireless channels by multiframe video coding. The multiframe coder uses the redundancy that exists across multiple frames in a typical video conferencing sequence so that additional compression can be achieved using their multiframe-block motion compensation (MF-BMC) approach. They modeled the error propagation using the Markov chain, and concluded that use of multiple frames in motion increases the robustness. Their proposed MF-BMC scheme has been shown to be more robust on wireless networks when compared to the base-level H.263 codec which uses single frame-block motion compensation (SF-BMC).

There are a number of studies, such as Stedman, Gharavi, Hanzo, and Steele (1993), Illgner and Lappe (1995), Khansari, Jalai, Dubois, and Mermelstein (1996), and Hanzo and Streit (1995), which concentrate on improving quality of multimedia over wireless networks. Since we are only interested in studies that focus on achieving seamless multimedia transmission during handoff, we do not go into details of studies related to multimedia over wireless networks. Interested readers can use the references given earlier in this paragraph.

Seamless Multimedia over Mobile Networks

Lee, Lee, and Kim (2004) achieved seamless MPEG-4 streaming over a wireless LAN using Mobile IP. They achieved this by implementing packet forwarding with buffering mechanisms in the foreign agent (FA) and performed pre-buffering adjustment in a streaming client. Insufficient pre-buffered data, which is not enough to overcome the discontinuity of data transmission during the handoff period, will result in disruption in playback. Moreover, too much of pre-buffered data wastes memory and delays the starting time of playback. Find the optimal pre-buffering time is, therefore, an important issue in this approach.

Patanapongpibul and Mapp (2003) enable the MH to select the best point of attachment by having all the reachable router advertisements (RA) in a RA cache. RA cache will have the entire router's link whose advertisements are heard by the mobile node. These RAs are arranged in the cache according to a certain priority. The priority is based on two criteria: (1) the link signal strength, that is, signal quality and SNR level, and (2) the time since the RA entry was last updated. So the RAs with highest router priority are forwarded to the IP packet handler for processing. The disadvantage of this method includes extra memory for the RA cache.

Pan, Lee, Kim, and Suda (2004) insert four components in the transport layer of the video server and the client. These four components are: (1) a path management module, (2) a multipath distributor module at the sender, (3) a pair of rate control modules, and (4) a multipath collector module at the receiver. They achieve a seamless video by transferring the video over multiple paths to the destination during handoffs. The overhead of the proposed scheme is two-fold: reduction in transmission efficiency due to transmission of duplicated video packets and transmission of control packets associated with the proposed scheme, and processing of the proposed scheme at the sender and receiver.

Boukerche, Hong, and Jacob (2003) propose a two-phase handoff scheme to support synchronization of multimedia units (MMU) for wireless clients and distributed multimedia systems. This scheme is proposed for managing MMUs to deliver them to mobile hosts on time. The two-phase scheme consists of: setup handoff and end handoff. In the first phase, setup handoff procedure has two major tasks: updating new arrival BSs and maintaining the synchronization for newly arrived mobile hosts (MHs). If an MH can reach another BS, then MH reports "new BS arrived" to its primary BS. End handoff procedure deals with the ordering of MMUs and with the flow of MMUs for a new MH. Any base station can be a new primary base station. The algorithm notifies MHs, BSs, and servers, and then chooses the closest common node from the current primary base station and new base stations. This method suffers from the disadvantage of additional overhead of updating the base station (BS) with newly arrived BSs and ordering of MMUs.

SIGMA FOR SEAMLESS MULTIMEDIA IN MOBILE NETWORKS

Limitations of previously proposed schemes in achieving seamless multimedia transmission during handoff in a wireless environment have been discussed in the previous section. In this section, we will discuss our proposed handoff scheme, called SIGMA, which has been designed for seamless multimedia transmission during handoffs, followed by its advantages over previous schemes.

Introduction to SIGMA

To aid the reader in getting a better understanding of SIGMA, in this section, we describe the various steps involved in a SIGMA handoff. A detailed description of SIGMA can be found in Fu, Ma, Atiquzzaman, and Lee (2005). We will use the stream control transmission protocol (Stewart, 2005), a new emerging transport layer protocol from IETF, to illustrate SIGMA.

Stream control transmission protocol's (SCTP) multi-homing (see Figure 2) allows an association between two endpoints 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 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. The built-in support for multi-homed endpoints by SCTP is especially useful in environments that require high-availability of the applications, such as Signaling System 7 (SS7) transport. A multi-homed SCTP association can speedup recovery from link failure situations without interrupting any ongoing data transfer. Figure 2 presents an example of SCTP multi-homing where two nodes,

CN and MH, are connected through two wireless networks, with MH being multi-homed. One of MN's IP addresses is assigned as the primary address for use by CN for transmitting data packets; the other IP address can be used as a backup in case of primary address failure.

STEP 1: Obtain New IP Address

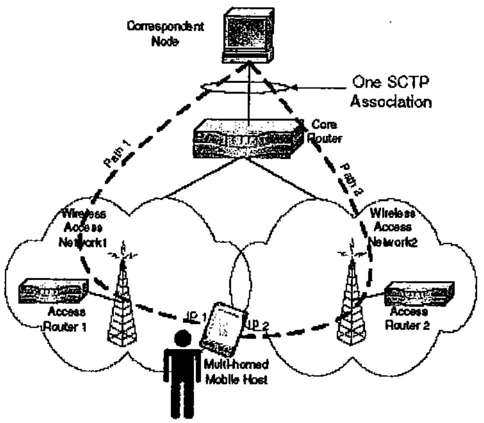
Referring to Figure 2, the handoff preparation procedure begins when the MH moves into the overlapping radio coverage area of two adjacent subnets. Once the MH receives the router advertisement from the new access router (AR2), it should initiate the procedure of obtaining a new IP address (IP2 in Figure 2). This can be accomplished through several methods: DHCP, DHCPv6, or IPv6 Stateless Address Autoconfiguration (SAA) (Thomson & Narten, 1998). The main difference between these methods lies in whether the IP address is generated by a server (DHCP/DHCPv6) or by the MH itself (IPv6 SAA). For cases where the MH is not concerned about its IP address but only requires the address to be unique and routable, IPv6 SAA is a preferred method for SIGMA to obtain a new address since it significantly reduces the required signaling time.

STEP 2: Add IP Addresses to Association

When the SCTP association is initially setup, only the CN's IP address and the MH's first IP address (IP1) are exchanged between CN and MH. After the MH obtains another IP address (IP2 in STEP 1), MH should bind IP2 into the association (in addition to IP1) and notify CN about the availability of the new IP address (Fu, Ma, Atiquzzaman, & Lee, 2005).

SCTP provides a graceful method to modify an existing association when the MH wishes to notify the CN that a new IP address will be added

Figure 2. An SCTP association featuring multi-homing



to the association and the old IP addresses will probably be taken out of the association. The IETF Transport Area Working Group (TSVWG) is working on the "SCTP Address Dynamic Reconfiguration" Internet draft (Stewart, 2005), which defines two new chunk types (ASCONF and ASCONF-ACK) and several parameter types (Add IP Address, Delete IP address, Set Primary Address, etc.). This option will be very useful in mobile environments for supporting service reconfiguration without interrupting on-going data transfers.

In SIGMA, MH notifies CN that IP2 is available for data transmission by sending an ASCONF chunk to CN. On receipt of this chunk, CN will add IP2 to its local control block for the association and reply to MH 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 MH.

STEP 3: Redirect Data Packets to New IP Address

When MH 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 MH. This task can be accomplished by the MH sending an ASCONF chunk with the Set-Primary-Address parameter, which results in CN setting its primary destination address to MH as IP2.

STEP 4: Updating the Location Manager

SIGMA supports location management by employing a location manager that maintains a database which records the correspondence between MH's identity and current primary IP address (Reaz, Atiquzzaman, & Fu, 2005). MH 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, MH should update the location manager's relevant entry with the new IP address (IP2). The purpose of this procedure is to ensure that after MH moves from the wireless access network1 into network2, further association setup requests can be routed to MH'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 handoff and make the deployment more flexible.*

STEP 5: Delete or Deactivate Obsolete IP Address

When MH moves out of the coverage of wireless access network1, no *new* or *retransmitted* data packets should be directed to address IP1. In SIGMA, MH can notify CN that IP1 is out of service for data transmission by sending an ASCONF chunk to CN (Delete IP Address). Once received, CN will delete IP1 from its local association control block and reply to MH 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 MH to advertise a zero receiver window (corresponding to IP1) to CN (Goff, Moronski, Phatak, & Gupta, 2000). This will give CN an impression that the interface (on which IP1 is bound) buffer is full and cannot receive any more data. By deactivating instead of deleting the IP address, SIGMA can adapt more gracefully to MH'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 signaling traffic that would have otherwise been caused by obtaining a new IP address.

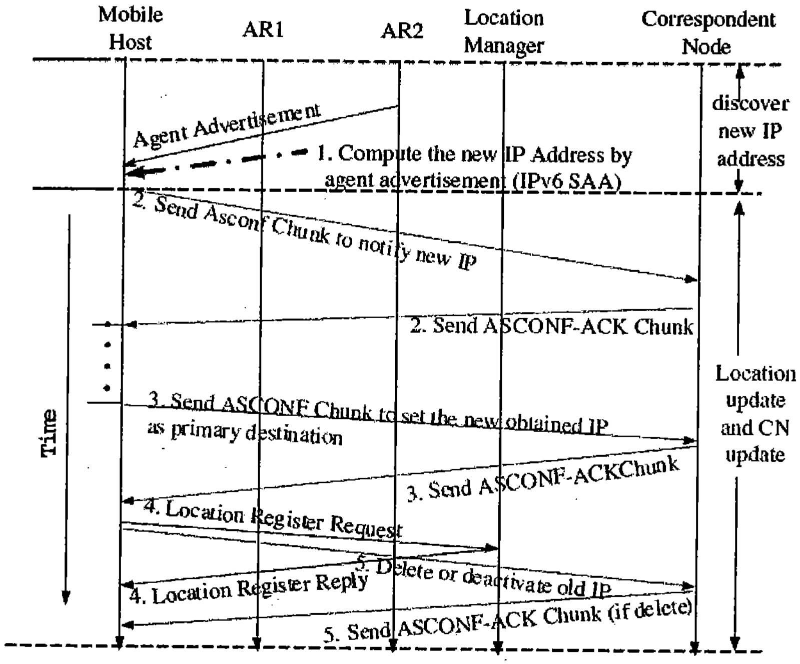
Timing Diagram of SIGMA

Figure 3 summarizes the signaling sequences involved in SIGMA. Here we assume IPv6 SAA and MH 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 the previous sub-sections, respectively.

Advantages of SIGMA over the Previous Works

A number of previous work have considered seamless multimedia transmission during handoff, as mentioned in the second section, which have their own disadvantages. Here, we discuss the

Figure 3. Timeline of signaling in SIGMA



advantages of SIGMA over previous work. Lee et al. (2004) performed pre-buffering adjustment in client. Playback disruption may occur if the pre-buffered data is not enough to overcome the discontinuity of data transmission that occurs during handoff. Moreover, excessive pre-buffered data wastes memory usage and delays the starting time of playback. Find the optimal pre-buffering time is an important issue in this approach. Since SIGMA does not pre-buffer any data in the client, such optimization issues are not present in SIGMA.

Patanapongpibul et al. (2003) use the router advertisement (RA) cache. The disadvantage of this method is that it needs extra memory for RA cache; SIGMA does not involve any caching and hence does not suffer from such memory problems. Pan et al. (2004) use multipath (as discussed earlier), which suffers from (1) reduction in bandwidth efficiency due to transmission of duplicated video packets and transmission of control packets associated with the proposed scheme, and (2) processing overhead at the sender and receiver. Absence of multipaths or duplicate video packets in SIGMA results in higher link bandwidth efficiency.

Boukerche et al. (2003) proposed a two-phase handoff scheme which has additional overhead of updating the base station (BS) with newly arrived BSs, and also ordering of multimedia units (MMUs). In SIGMA, there is no feedback from MH to any of the base stations, and hence does not require ordering of multimedia units or packets.

EXPERIMENTAL TESTBED

Having reviewed the advantages of SIGMA over other schemes for multimedia transmission in the previous section, in this section, we present experimental results for SIGMA as obtained from an experimental setup we have developed at the University of Oklahoma. We compare the results of handoff performance during multimedia transmission over both SIGMA and Mobile IP. To make a fair comparison, we have used the same test bed for both MIP and SIGMA. Figure 4 (to be described later) shows the topology of our test bed, which has been used by a number of researchers—Seol, Kim, Yu, and Lee (2002), Wu, Banerjee, Basu, and Das (2003), Onoe, Atsumi, Sato, and Mizuno (2001)—for measurement of handoff performance. The difference in data communication between the CN and the MH for MIP and SIGMA lies in the lower layer sockets: the file sender for MIP is based on the regular TCP socket, while that for SIGMA is based on SCTP socket. 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) version 2.6.2-0.9.0 on both CN and MN. A number of MIP implementations, such as HUT Dynamics (HUT), Stanford Mosquito (MNET), and NUS Mobile IP (MIP), are publicly available. We chose HUT Dynamics for testing MIP in our test bed due to the following reasons: (1) Unlike Stanford Mosquito, which integrates the FA and MN, HUT Dynamics implements HA, FA, and MH daemons separately. This architecture is similar to SIGMA where the two access points and MH are separate entities. (2) HUT Dynamics implements hierarchical FAs, which will allow future comparison between SIGMA and hierarchical Mobile IP. Our MIP testbed consists four nodes: correspondent node (CN), foreign agent (FA), home agent (HA), and mobile node (MN). All the nodes run corresponding agents developed by HUT Dynamics. The hardware and software configuration of the nodes are given in Table 1.

The CN and the machines running the HA and FA are connected to the Computer Science (CS) network of the University of Oklahoma, while the MH and access points are connected to two separate private networks. The various IP addresses are shown in Table 2. IEEE 802.11b is used to connect the MH to the access points.

Table 1. Mobile IP and SIGMA testbed configurations

Node	Hardware	Software	Operating System
Home Agent(MIP) Gateway1 (SIGMA)	Desktop, two NICs	HUT Dynamics 0.8.1 Home Agent Daemon (MIP)	Redhat Linux 9 kernel 2.4.20
Foreign Agent (MIP) Gateway2 (SIGMA)	Desktop, two NICs	HUT Dynamics 0.8.1 Foreign Agent Daemon (MIP)	Redhat Linux 9 kernel 2.4.20
Mobile Node	Dell Inspiron- 1100 Laptop, one Avaya 802.11b wireless card	HUT Dynamics 0.8.1 Mobile Node Daemon (MIP), File receiver	Redhat Linux 9 kernel 2.4.20
Correspondent Node	Desktop, one NIC	File sender	Redhat Linux 9 2.6.20

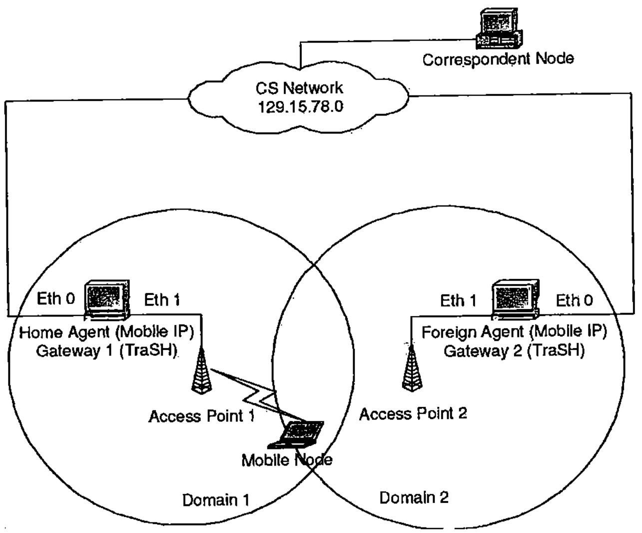
Table 2. Mobile IP and SIGMA network configurations

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

The network topology of SIGMA is similar to the one of Mobile IP except that there is no HA or FA in SIGMA. As shown in Figure 4, the machines which run the HA and FA in the case of MIP act as gateways in the case of SIGMA. Table 1 shows the hardware and software configuration for the SIGMA experiment. The various IP addresses are shown in Table 2. The experimental procedure of Mobile IP and SIGMA is given next:

1. Start with the MH in Domain 1.
2. **For Mobile IP:** Run HUT Dynamics daemons for HA, FA, and MN. **For SIGMA:** Run the SIGMA handoff program, which has two functions: (1) monitoring the link layer signal strength to determine the time to handoff, and (2) carrying out the signaling shown in Figure 4.
3. Run file sender/video server and file receiver/video client (using TCP sockets for Mobile

Figure 4. SIGMA and Mobile IP testbed



IP, using SCTP sockets for SIGMA) on CN and MN, respectively.

4. Run Ethereal (ETHEREAL) on the CN and MH to capture packets.
5. Move MH from Domain 1 to Domain 2 to perform handoff by Mobile IP and SIGMA. Capture all packets sent from CN and received at MN.

RESULTS

Various results were collected on the experimental setup and procedure described earlier. In this section, we present two kinds of results: file transfer and multimedia transmission. The reason for showing the results of file transfer is to prove that SIGMA achieves seamless handoff not only for multimedia but also for file transfers.

Results for File Transfer

In this section, we present and compare the results of handoffs using MIP and SIGMA for file transfer. For comparison, we use throughput, RTT, and handoff latency as the performance measures. *Throughput* is measured by the rate at which packets 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 MH receiving the last packet from Domain

Figure 5. Throughput during MIP handoff

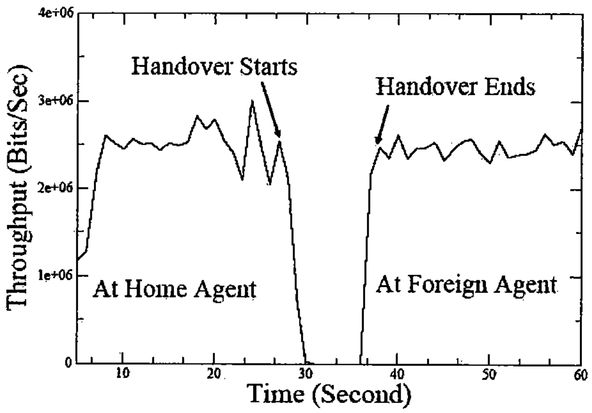


Figure 6. Packet trace during MIP handoff

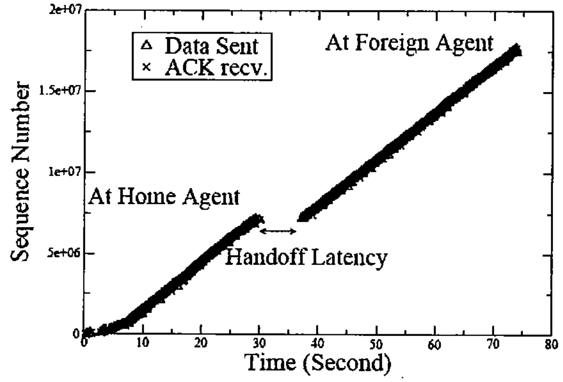


Figure 7. Zoomed in view during MIP handoff instant

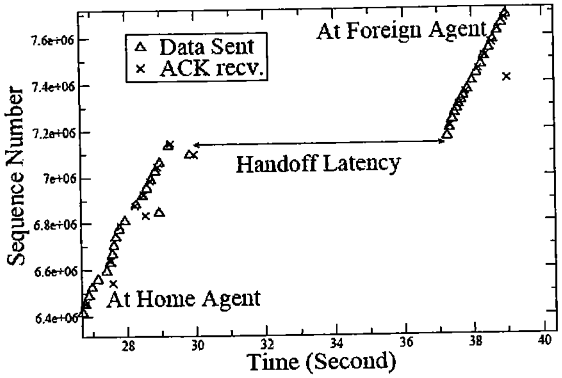
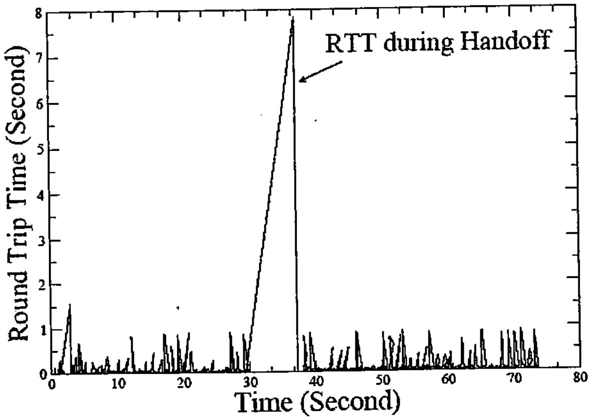


Figure 8. RTT during MIP handoff



1 (previous network) and the first packet from Domain 2 (the new network). The experimental results are described next.

Results from Mobile IP Handoff

Figure 5 shows the throughput during Mobile IP handoff between Domain 1 and Domain 2. The variations in throughput within HA (from 20 second to 30 second) and within FA (from 37 second to 60 second) are due to network congestion arising from cross traffic in the production CS network.

The average throughput before, during and after handoff are 2.436 Mbps, 0 Mbps and 2.390 Mbps, respectively. Figure 6 shows the packet trace during MIP handoff. The actual handoff latency for MIP can be clearly calculated by having a zoomed-in view of the packet trace graph. Figure 7 shows a zoomed-in view of the packet trace, where the calculated handoff latency is eight seconds for Mobile IP. Figure 8 shows the RTT for the MIP handoff. As we can see, the RTT is high for eight seconds (the handoff latency time), during the handoff.

The registration time (or registration latency) is also a part of the handoff latency. Registration latency, the time taken by the MH to register with the agent (HA or FA), is calculated as follows. Ethereal capture showed that the MH sent a registration request to the HA at time t = 14.5123 second and received a reply from the HA at t = 14.5180 second. Hence, the calculated registration time for registering with HA is 5.7 milliseconds. Similarly, during MIP handoff, Ethereal capture showed that the MH sent a registration request to FA at time t =7.1190 second and received a reply from the FA at t =7.2374, resulting in a registration time of 38.3 milliseconds. This is due to the fact that after the MH registers with the HA, it can directly register with the HA. On the other hand, if it registers with the FA, the MH registers each new care-of-address with its HA possibly through FA. The registration latency is, therefore, higher when the MH is in the FA.

Results from SIGMA Handoff

Figure 9 shows the throughput during SIGMA handoff where it can observed that the throughput does not go to zero. The variation in throughput is due to network congestion arising from cross traffic in the production CS network. Although we cannot see the handoff due to it being very small, it should be emphasized that the ethereal capture showed the handoff starting and ending at t = 60.755 and t = 60.761 seconds, respectively, that is, a handoff latency of six milliseconds.

Figure 10 shows the packet trace during SIGMA handoff. It can be seen that packets arrive at the MH without any gap or disruption; this is also a powerful proof of SIGMA's smoother handoff as compared to handoff in Mobile IP. This experimentally demonstrates that *a seamless handoff can be realized with SIGMA*. Figure 11 shows a zoomed-in view of the packet trace during the SIGMA handoff period; a handoff latency of six milliseconds can be seen between the packets arriving at the old and new paths.

Figure 12 shows the RTT during SIGMA handoff. A seamless handoff is evident from the absence of any sudden RTT increase during handoff.

Result of Multimedia Data Transfer

To test the handoff performance for multimedia over SIGMA, we used a streaming video client and a streaming server at the MH and CN, respectively (details in the fourth section). Apple's Darwin Streaming Server (DARWIN) and CISCO's MPEG4IP player (MPEG) were modified to stream data over SCTP. A seamless handoff, with no interruption in the video stream, was achieved with SIGMA.

Figure 9. Throughput during SIGMA handoff

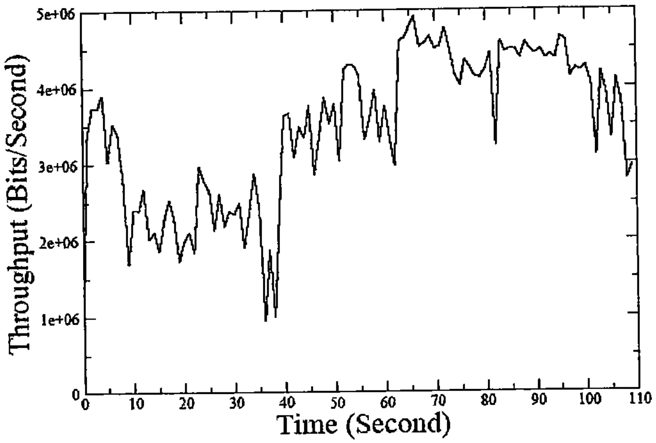


Figure 10. Packet trace during SIGMA handoff

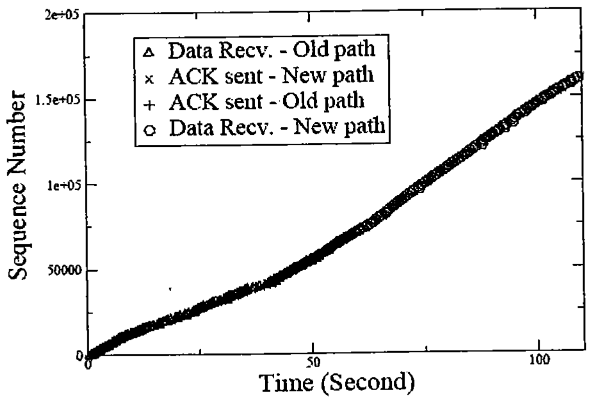


Figure 11. Zoomed in view during SIGMA handoff

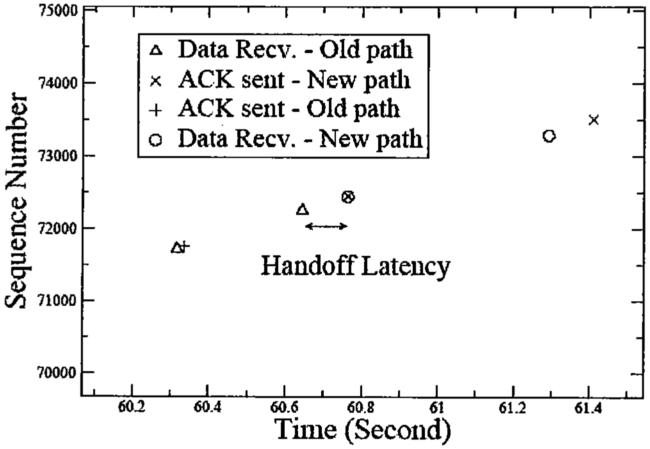


Figure 12. RTT during SIGMA handoff

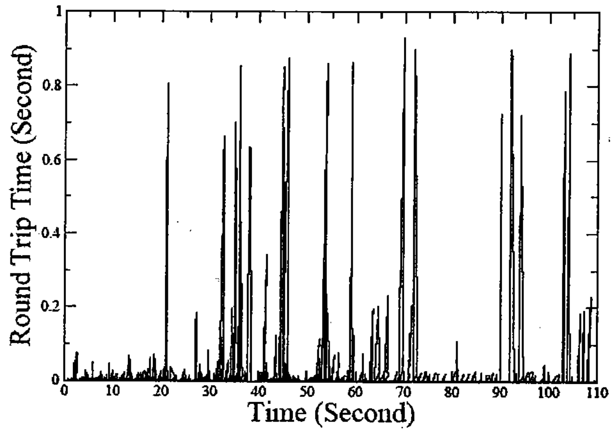


Figure 13. Throughput of video during SIGMA handoff

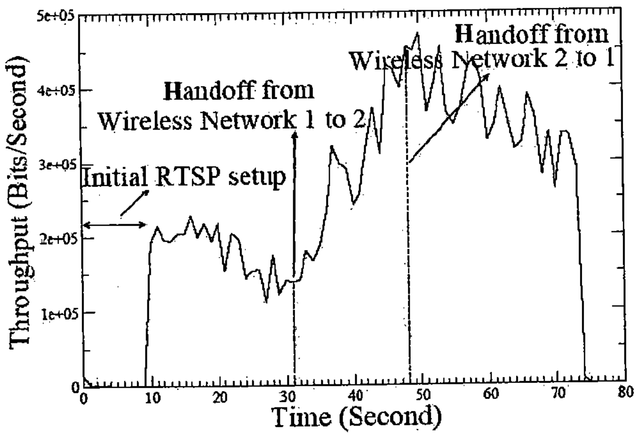


Figure 14. Screen shot of MPEG4-IP player

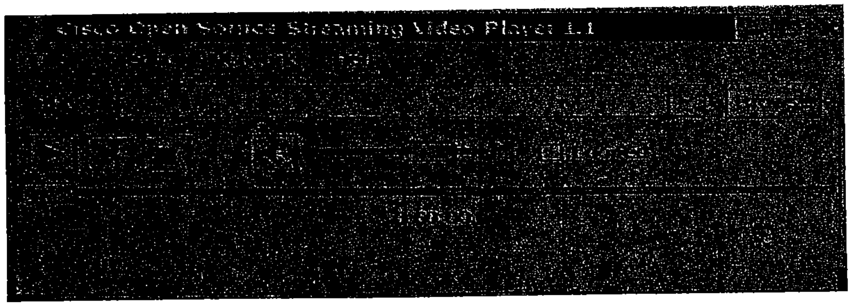


Figure 15. Screen-shot of MPEG4-IP player playing streaming video

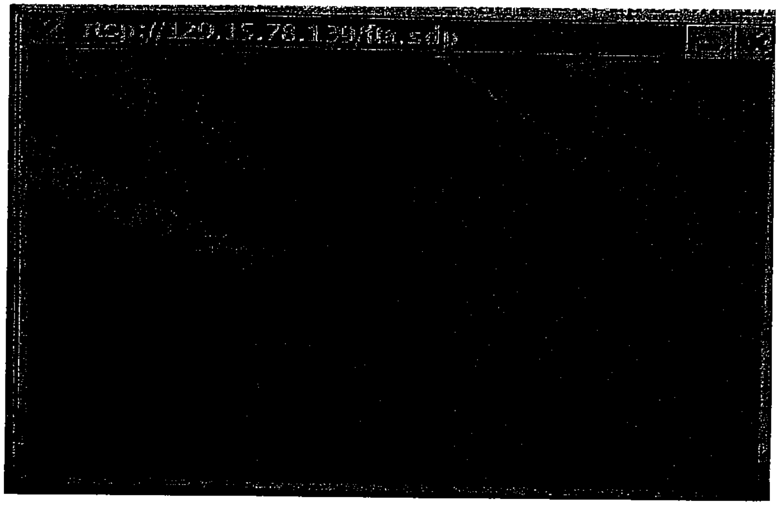


Figure 13 shows the throughput of multimedia (video) data, when the MH moves between subnets. The connection request and setup between the client and server is carried out during the first 10 seconds. It can be seen that the throughput does not drop during handoff at time = 31 second when MH moves from wireless network 1 to 2. A second handoff takes place when the MH moves from network 2 to network 1 at time = 48. It is seen that seamless handoff is achieved by SIGMA for both the handoffs.

Figure 14 shows a screen capture of the MPEG4IP player used in our experiment. Figure 15 shows the video playing in the player during handoff, where "rtsp://129.15.78.139/fta.sdp" represents the server's IP address and the streaming format (SDP).

Comparison of SIGMA and MIP Handoffs

We observed previously that the registration time of MIP was only 0.1 second, and the handoff latencies of MIP and SIGMA were eight seconds and six milliseconds, respectively. We describe the reasons for the MIP handoff latency being much longer than its registration time in the following:

1. In HUT Dynamics, the MIP implementation used in this study, the MH obtains a registration lifetime after every successful registration. It originates another registration on expiry of this lifetime. So it is possible for the MH 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.
2. As mentioned in the previous section, the registration of MH also costs some time, measured as 38.3 milliseconds in our testbed.

The handoff latency in MIP comes from three factors: (1) remaining home registration lifetime after link layer handoff which can be from zero to a lifetime, (2) FA advertisement interval plus the time span of last time advertisement which is not listened by MN, and (3) registration latency. During these three times, the CN cannot communicate through either the previous path because it has completed link layer handoff, or the new path because MH has not yet completed the registration. As a result, the throughput was zero during this time. Obviously, such shortcoming has been eliminated in SIGMA through multi-homing and decoupling of registration and data transfer. Consequently, data continue to flow between the CN and MH during the handoff process.

CONCLUSION AND FUTURE TRENDS

We have shown that SIGMA achieves seamless multimedia transmission during handoff between wireless networks. As future work, video streaming can be tested over SIGMA during vertical handoffs, that is, between wireless LANs, cellular, and satellite networks.

ACKNOWLEDGMENT

The work reported in this chapter was funded by National Aeronautics and Space Administration (NASA) grant no. NAG3-2922.

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