Effect of Layer 2 Connection Setup on Performance of SIGMA

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Abstract— **In our earlier study, we proposed SIGMA, a Seamless IP diversity based Generalized Mobility Architecture. SIGMA utilizes IP diversity to achieve a seamless handover of a mobile host, and is designed to solve many of the drawbacks of Mobile IP. In this paper, we evaluate the impact of Layer 2 connection setup on the performance of SIGMA. Various aspects of Layer 2 connection setup, such as Layer 2 setup latency, Layer 2 beacon period, and mobile host moving speed, are considered. Criteria for performance evaluation include handover latency, packet loss, throughput. Our results show that SIGMA handover latency is insensitive to Layer 2 setup latency and beacon periods. Moreover, SIGMA can achieve a seamless handover if MH's moving speed is in reasonable limits.**

***K*eywords**: mobile handover, SIGMA, mobile IP, wireless networks

I. Introduction

Mobile IP (MIP) [1] has been designed to handle mobility of Internet hosts. MIP is known to suffer from high handover latency and high packet losses. Even the various recent proposed enhancements [2], [3] can not completely remove the handover latency, still resulting in a high packet loss rate [4]. A number of transport layer mobility protocols have also been proposed in the context of TCP: MSOCKS [5] and connection migration solution [6]. These protocols implement mobility as an end-to-end service without the requirement on the network layer infrastructures; they are not aimed at reducing the high latency and packet loss resulting from handovers. The handover latency for these schemes is in the scale of seconds.

To achieve seamless handoff, we designed a new mobility management scheme called Seamless IP diversity based Generalized Mobility Architecture (SIGMA) [7] to reduce handover latency and packet loss. The basic idea of SIGMA is to exploit IP diversity offered by multiple paths between a Mobile Host (MH) and its Correspondent Node (CN) to achieve concurrent communication. To achieve a seamless handover, the old path is kept alive during the process of setting up a new path. However, the impact of Layer 2 connection setup latency on SIGMA due to physical and/or link layer limitations of wireless systems, such as IEEE 802.11, GPRS, UMTS, etc., needs to be investigated to realize SIGMA. The Layer 2 connection setup time consists of the time between MH's entry into the coverage of an Access Point and the establishment of the Layer 2 connection, which could take up to 400-700ms [8]. The signaling messages of SIGMA cannot flow through the new access point until the completion of the Layer 2 setup. The question to be answered in this paper is: Does Layer 2 connection setup have any effect on the concurrency we expect to achieve through IP diversity? The *objective* of this paper is to investigate the effect of Layer 2 connection setup on the performance of SIGMA. The *contributions* of our paper can be outlined as follows:

- Illustrate the interaction between Layer 2 connection setup and transport layer handover procedure in SIGMA.
- Evaluate the performance of SIGMA for various Layer 2 parameters. The authors are not aware of any *previous studies on the impact of Layer 2 setup latency on transport layer mobility solutions*.

The rest of this paper is structured as follows. The impact of Layer 2 connection setup latency on SIGMA is discussed in Sec. II. We evaluate the effect of Layer 2 connection setup on the performance of SIGMA by *ns*-2 simulation; simulation topology and parameters are described in Sec. III. The impact of Layer 2 connection setup latency on SIGMA handover performance are illustrated through packet trace and congestion window trace in Sec. IV. Results demonstrating the performance of SIGMA under various parameters are shown in Sec. V. Finally, concluding remarks are presented in Sec. VI.

II. Impact of Layer 2 connection setup on SIGMA

A. SIGMA handover process

A typical mobile handover in SIGMA, using SCTP as an illustration, is shown in Fig. 1, where the Mobile Host (MH) is a multi-homed node connected through two wireless access networks. Correspondent node (CN) is a single-homed node sending traffic to MH, corresponding to the services like file download or web browsing by mobile users.

The handover process of SIGMA can be described by the following five steps [7]:

STEP 1: Obtain new IP address

Refer to Fig. 1 as an example, the handover preparation procedure begins when MH moves into the overlapping radio coverage area of two adjacent subnets. MH first needs to finish a Layer 2 connection setup (as will be discussed in

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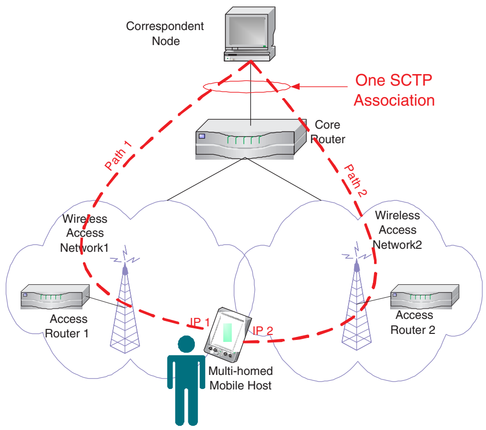

Fig. 1. An SCTP association with multi-homed mobile host.

Sec. II-B). Once the MH finishes Layer 2 connection setup and receives router advertisement from the new access router (AR2), it obtains a new IP address (IP2 in Fig. 1). This can be accomplished through several methods: DHCP, DHCPv6, or IPv6 stateless address autoconfiguration (SAA). We call the time required for MH to acquire the new IP address as address resolution time.

STEP 2: Add IP addresses into the association

After the MH obtains the IP address IP2 by STEP 1, MH notifies CN about the availability of the new IP address through SCTP Address Dynamic Reconfiguration option [9].

STEP 3: Redirect data packets to new IP address

When MH moves further into the coverage area of wireless access network2, CN redirects data traffic to the new IP address (IP2) to increase the possibility of data being delivered successfully to the MH.

STEP 4: Update location manager (LM)

SIGMA supports location management by employing a location manager which maintains a database recording the correspondence between MH's identity and MH's current primary IP address. Once MH decides to handover, it updates the LM's relevant entry with the new IP address (IP2).

STEP 5: Delete or deactivate obsolete IP address

When MH moves out of the coverage of wireless access network1, no *new* or *retransmitted* data should be directed to address IP1. In SIGMA, MH notifies CN that IP1 is out of service for data transmission by sending an ASCONF chunk [9] to CN to delete IP1 from CN's available destination IP list.

B. Layer 2 connection setup

In the state-of-the-art mobile systems, when a mobile host changes its point of attachment to the network, it needs to perform a Layer 2 (data link layer) handover to cutoff the association with the old access point and re-associate with a new one. As an example, in IEEE802.11 WLAN infrastructure mode, this Layer 2 handover will require several steps: detection, probe, and authentication and reassociation with the new AP. These procedures can take up to 400-700ms [8] to set up the new Layer 2 connection, after which higher layer protocols can proceed with their signaling procedure, such as Layer 3 router advertisements.

In SIGMA, each MH is equipped with multiple interface cards. Therefore, instead of Layer 2 handover, SIGMA performs Layer 2 connection setup on the second interface card while using the first card for communicating with the old AP. The difference between Layer 2 handover and setup is that in setup case the last step is association instead of reassociation in the case of handover. Mishra et al. [8] also show that the majority of the Layer 2 handover time is for detection and channel probing. Therefore, we assume the time required for Layer 2 handover and setup are similar.

C. Impact of Layer 2 connection setup on SIGMA

In SIGMA, the Layer 2 connection setup will postpone the time that MH can start STEP 1 (see Sec. II-A), since MH can receive the router advertisement from the new AR only after Layer 2 connection setup finishes. Therefore, STEP 2 is also postponed because this step is in synchronous with the STEP 1. However, the time of starting STEP 3 and STEP 4 may or may not be affected by the Layer 2 connection setup latency. Consider a linear movement from AR1 to AR2 as an example, ideally (without any Layer 2 connection setup latency) the STEP 3 and STEP 4 of SIGMA handover should start at (say time t) the point of the overlapping region that gives MH enough time to finish STEP 3 and STEP 4 before it moves out of the coverage of AR1. When Layer 2 connection setup latency come into play, depending on the MH's moving speed, overlapping region size, round trip time from MH to CN (for ADDIP chunks to come back), the time (say time t') that STEP 2 finishes could fall before or behind the time t. If $t' \leq t$, the Layer 2 connection setup has virtually no impact on SIGMA handover since the new data path through AR2 is available before MH moves into coverage of AR2, and there is no loss happened due to SIGMA handover. However, if $t' > t$, the Layer 2 connection setup push the latest starting point of STEP 3 and STEP 4 from t to t', which will cause these two steps cannot be finished before MH moves out of AR1 coverage, and some packet losses will happen.

III. Simulation Topology and Parameters

We have used *ns-2* simulator that supports SCTP as the transport protocol, and we have also implemented SIGMA on *ns-2*. Standard *ns-2* simulator does not have direct support for Layer 2 connection setup latency simulation; an MH can communicate with two APs simultaneously once the MH has entered into the overlapping region of the two APs. In order to simulate mobile handovers between real-world infrastructure mode WLANs, we also implemented Layer connection setup latency in *ns-2* IEEE 802.11 code by introducing Layer 2 beacons and a set of timers.

A. Simulation topology

The network topology shown in Fig. 2 has been used to study the effect of Layer 2 connection setup in SIGMA.

IEEE 802.11 is used as the MAC protocol. AR1 and AR2 are two access routers corresponding to the two subnets involved in the handoff. The Stream Control Transmission Protocol (SCTP) [10], with built-in multihoming capabilities, has been used in the simulation to support IP diversity. The link characteristics, namely the bandwidth (megabits/s) and propagation delay (milliseconds), are shown on the links. MH initially has an IP address of IP1 when it is associated with AR1. After moving into the overlapping region, MH acquires a new IP address (IP2) from AR2, while still retaining IP1. Once MH moves out of the coverage of AR1, IP1 is deleted and only IP2 is available.

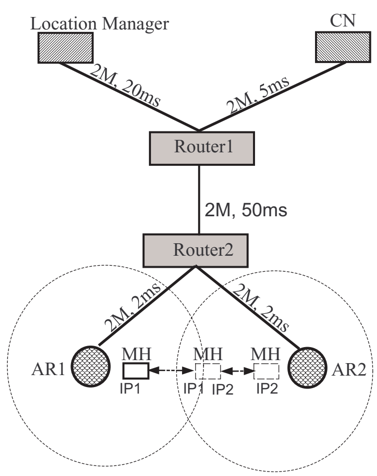

Fig. 2. Simulation topology.

B. Simulation parameters

We have used the following parameters in our simulations:

- A pair of FTP source and sink agents are attached to the CN and MH, respectively, to transfer bulk data from CN to MH. To remove transients from the result, each simulation run lasts for 500 seconds of MH's linear back and forth movement between AR1 and AR2.
- Each base station has a radio coverage area of 40 meters in radius. The overlapping region between two ARs is 10 meters. The advertisement period of the AR1/AR2 is one second, but the advertisements from them are not synchronized.

IV. Packet trace of SIGMA

In this section, we show simulation packet traces and congestion window traces of SIGMA to illustrate the impact of Layer 2 connection setup latency on SIGMA handover performance. These trace results can be classified into two categories: (1) no Layer 2 connection setup latency, (2) Layer 2 connection setup latency of 200ms. In all categories, the IP address resolution latency is set to 500ms.

Fig. 3 shows packet trace observed at the CN during a typical SIGMA handover with data being sent from CN to MH with no Layer 2 setup latency. The segment sequence numbers are shown as MOD 100. We can observe that data segments are sent to IP1 until time 8.140 sec (point t_1), and then to IP2 almost immediately (point t_2), with all these segments being successfully delivered to MH.

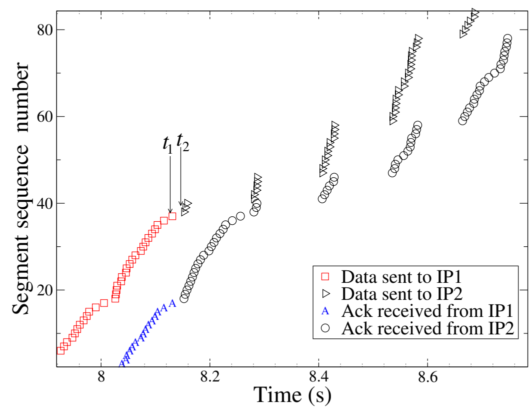

Fig. 3. Segment sequence of SIGMA during a handover with no Layer 2 setup latency.

Fig. 4 shows the packet trace observed at the CN during a typical SIGMA handover with Layer 2 setup latency of 200ms. We can see that data segments are sent to IP1 until time 8.16 sec (point t_1), and then to IP2 almost immediately (point t_2), with all the segments being successfully delivered to MH. Therefore, SIGMA experienced a seamless handover even with Layer 2 setup latency; this is because the new path is setup in parallel to data forwarding over the old path. *The only impact of Layer 2 setup is to push the time instant of* SIGMA *handover by 20ms* (8.14 sec vs. 8.16 sec). This explains the basics of how SIGMA achieves a low handover latency, low packet loss rate and high throughput (given in detail in [7]).

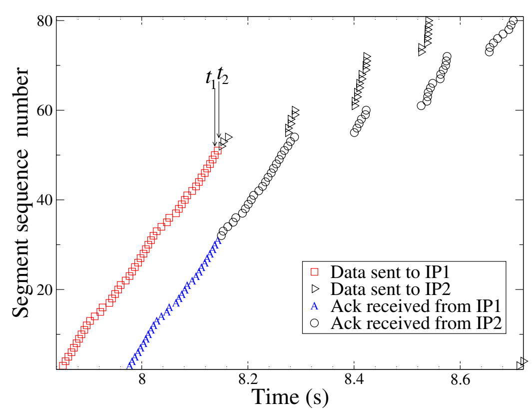

Fig. 4. Segment sequence of SIGMA during a handover with Layer 2 setup latency of 200ms.

V. Comparison results showing effect of various parameters

In this section, we present results showing the effect of various parameters on SIGMA in terms of handover latency, throughput, and packet loss rate.

A. SIGMA *handover latency*

We define *handover latency* of SIGMA as the time interval between the last data segment received through the old path and the first data segment received through the new path from CN to MH. In this section, we examine the impact of Layer 2 connection setup latency, IP address resolution latency, moving speed, and Layer 2 beacon period on the handover latency of SIGMA.

1) Impact of Layer 2 connection setup latency: First we look at the handover latency of SIGMA when the Layer 2 connection setup latency range from 100 to 600ms, and IP address resolution latency ranges from 300 to 600ms. The values of Layer 2 connection setup latency corresponds to the empirical values in IEEE 802.11 networks [8]. The moving speed is fixed at 5m/s. It can be seen from Fig. 5 that the handover latency of SIGMA is very low (in the range of 5-10ms) when the combined latency of Layer 2 connection setup and IP address resolution is less than 900ms. This is because when the MH is using the old path for communication with CN, it can perform the Layer 2 connection setup and address resolution on the other interface in parallel (as shown in packet trace in Sec. IV); thus the impact of these latencies can be noticeably reduced compared to MIP. When the combined latency is larger than 900ms, this parallelism is broken since the MH does not have enough time to finish all the signaling required in SIGMA before moving out of overlapping region. Some packets sent to the outdated AR are lost, and CN is forced to backoff by SCTP's congestion control algorithms.

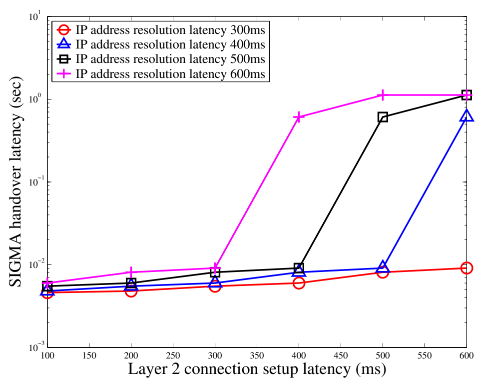

Fig. 5. Impact of Layer 2 connection setup latency and IP address resolution latency.

2) Impact of moving speed and Layer 2 beacon period: Next we vary the movement speed of MH from 2.5m/s up to 20m/s, vary the Layer 2 beacon period from 20ms to 80ms, and fix both the Layer 2 connection setup latency and IP address resolution latency to 100ms. As shown in Fig. 6, when MH's moving speed is less than 15m/s, the impact of moving speed is not obvious. When MH moves faster, SIGMA will experience a higher handover latency due to MH having insufficient time to prepare for the handover. Therefore, there is a higher possibility that the packets are forwarded to the outdated path and are lost. The time instant that MH can receive packets from new path will be postponed and the handover latency increases accordingly.

Comparing the curves of different Layer 2 beacon period in Fig. 6, we can see a Layer 2 beacon period of 20ms generates the highest handover latency at low moving speeds (under 15m/s). This is because too small a beacon period (e.g. 20ms) produces a high volume of beacons, which contend with payload data and SIGMA signaling traffic for the limited wireless bandwidth. The packet loss rate for the signaling packets thus increase and require additional retransmission time to deliver them successfully. The handover latency will therefore increase. However, at higher speeds (more than 15m/s), the small Layer 2 beacon period can help the MH to detect the new AP and begin Layer 2 connection setup earlier, thus reducing the possibility that packets are forwarded to the outdated path. resulting in a decrease of the handover latency.

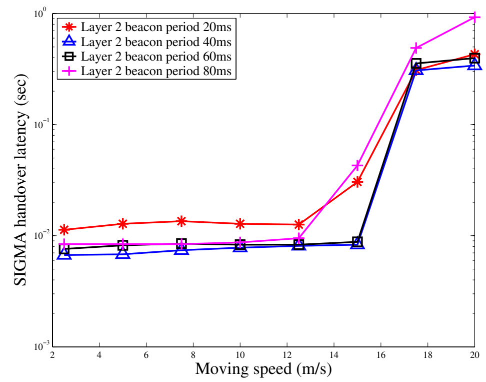

Fig. 6. Impact of moving speed and Layer 2 beacons.

B. *Throughput and packet loss rate*

We define *throughput* as the total number of useful bits that can be delivered to MH's upper layer application divided by the simulation time. This gives us an estimate of average transmission speed that can be achieved by the SCTP association. *Packet loss rate* is defined as the number of lost packets due to handover divided by the total number of packets sent by CN. In this section, we will examine the impact of different parameters (same ones as we have seen in Sec. V-A) on the throughput and packet loss rate of SIGMA.

1) Impact of Layer 2 connection setup latency and address resolution latency: It can be seen from Fig. 7 that the packet loss rate during SIGMA handover is zero when the combined latency of Layer 2 connection setup and IP address resolution is less than 900ms. Moreover, Fig. 8 shows that the throughput of SIGMA is much higher in these cases, because the packet losses trigger congestion control and force the sender to reduce the sending rate. High packet loss rate happens when the combined latency is larger than 900ms. This is because the time-consuming Layer 2 connection setup and new IP address resolution will disable the MH to finish SIGMA signaling in time before it moves out of the overlapping region, and some packets are sent to the outdated location and are lost.

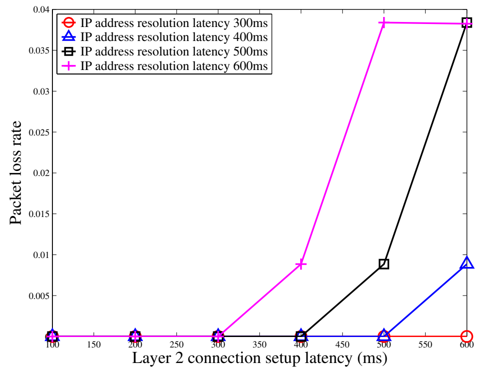

Fig. 7. Impact of Layer 2 connection setup latency and address resolution latency on packet loss rate.

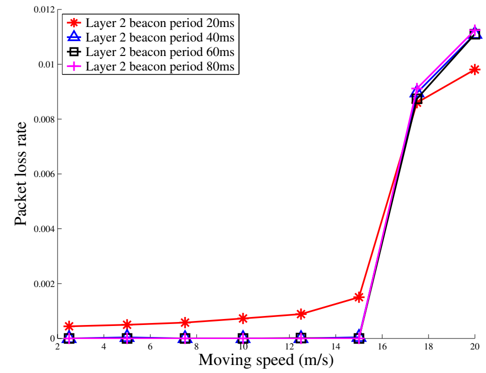

Fig. 9. Impact of moving speed and beacon period on packet loss rate.

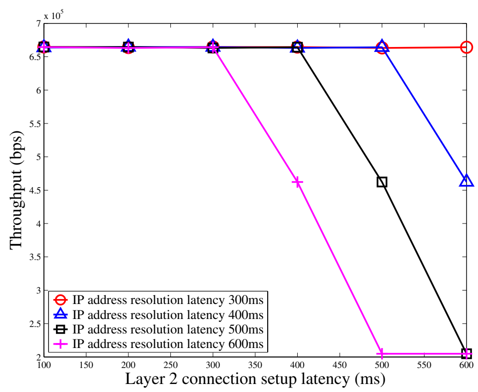

Fig. 8. Impact of Layer 2 connection setup latency and address resolution latency on throughput.

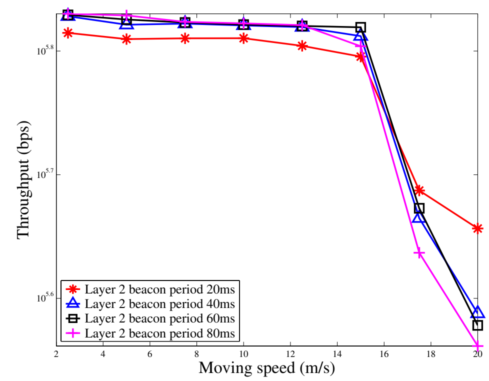

Fig. 10. Impact of moving speed and beacon period on throughput.

2) Impact of moving speed: When MH moves faster than 15m/s, SIGMA experiences a higher packet loss rate (Fig. 9) and decreased throughput (Fig. 10) when compared with low moving speed. This is because of the possibility of packets being forwarded to outdated path increasing with an increase in the speed. Those packets are dropped by AR1/AR2, either because they are not aware of MH's current location or the buffer space is full.

As shown in Sec. V-A.2, too small a beacon period (20ms) produces a high volume of beacons, which contend with payload data and SIGMA signaling traffic for the limited wireless bandwidth, thus increasing the packet loss rate. We can also notice that reducing the Layer 2 beacon period somewhat offsets the impact of high speed by detecting the new AP and beginning the Layer 2 connection setup earlier. Therefore, there will be a smaller probability that the packets are sent to an outdated location and get dropped by the AR.

VI. Conclusions

This paper evaluated the impact of Layer 2 setup on different performance measures of SIGMA, including handover latency, packet loss and throughput (although partial results have been shown in this abstract). Our results show that SIGMA handover latency is insensitive to Layer 2 setup latency and beacon periods. Moreover, SIGMA can achieve a seamless handover if MH's moving speed is not too high, but is within reasonable limits.

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