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Abstract

Mobile IP, a IETF standard to handle mobility of Internet hosts has some existing problems like high handover latency, packet loss, inefficient routing etc. To overcome these problems, we designed alternative novel approach called Seamless IP diversity based Generalized Mobility Architecture (SIGMA), which utilizes multihoming and uses a transport layer protocol, Stream Control Transmission Protocol (SCTP). In our previous work, we have achieved a low latency handoff when MN moves between adjacent wireless network. Our analysis of our system showed that Mobile Node (MN) in SIGMA suffers some instability during handoff (i.e.,) MN makes use of multiple interface cards while in the overlapping region of the wireless network, which is due to the in-efficient handoff scheme of SIGMA. This instability can be eliminated by using a efficient handoff scheme, thus enhancing the stability of the SIGMA. So the objective of this paper is to design an efficient handoff scheme for SIGMA to overcome instability. We implemented a handoff scheme (SINHYR-handoff scheme) based on Signal to Noise Ratio (SNR), hysteresis and route cache flushing. We obtained results experimentally, which shows that the instability of SIGMA is avoided, thus enhanced the stability of during SIGMA handoff.

I. Introduction

Mobile IP [1] is the standard proposed by IETF to handle mobility of Internet hosts for mobile data communication. But Mobile IP has some existing problems, like high handover latency [2], high packet loss [3] [4], inefficient routing [2]. To eliminate these problems of Mobile IP [1], we already presented an alternative scheme for handoff, Seamless IP diversity based Generalized Mobility Architecture (SIGMA) [5], a novel approach to handoff. SIGMA utilizes multi-homing, which allows end points to utilize one or more IP addresses for communication, and thus achieves a low latency handoff between adjacent wireless network. We have used the Stream Control Transmission Protocol (SCTP) [6], a transport layer protocol being standardized by IETF and has multihoming capability, to validate and test the concepts and performance of SIGMA.

Thus, in our previous work [5] we have shown that we have achieved a low latency handoff, when a MN moves from one coverage area to another coverage area using SIGMA. Our analysis of our system showed that Mobile Node (MN) in SIGMA suffers some instability during handoff (i.e.,) MN makes use of multiple interface cards while in the overlapping region of the wireless network. We call this instable because, packet loss might occur if any one of APs goes down or if MN goes out of range from any of the APs, during that period. This instability is a result of excessive number of handoffs which is due to the in-efficient handoff scheme of SIGMA.

There are various previous works which are focussed on producing efficient handoff schemes. For example, some of the previous works like [7] [8] [9] are designed for cellular IP which makes use of average receiving power, receiving window, bit error ratio and signal strengths. In other works like [10] [11], they try to reduce layer2 handoff latency by using signal strength and using buffering techniques. In [12] [13], they make use of fuzzy logic and neural network techniques and others such as [14] [15], make use of Signal-to-Noise Ratio and designed for Mobile IP. All above stated schemes only deal with link layer or for specific architectures like cellular IP and Mobile IP. None of this work deal with transport layer. So *objective* of this paper is to develop a handoff scheme for SIGMA where the handoff is done at transport layer level.

To make an efficient handoff scheme, we need to know what are all the parameters used to initiate handoff process, the initiation of handoff is also known as handoff trigger. The different parameters generally used for the link layer handoff trigger referred by [16] are, Signal Strength which can be used for handover where there is less or no interference. Signal-to-Noise Ratio which can be used as a parameter when there is more noise. Signal-to-Interference Ratio which can be used as a parameter when there is more interference, noise. Bit-Error-Rate which can be used as a parameter in erroneous and more interference channel, but error control system is needed to detect and correct errors. Frame Error Rate (FER), which is also used in erroneous channel but not recommended due to its computing complexity. So in our policy, we plan to use Signal-to-Noise Ratio (SNR), since our experimental environment has only noise and less or no interferences.

To show the effectiveness of our handoff scheme, we want to find what are all the metrics used to compare the current results with our previous results of SIGMA. From some of the other previous works [17] [18] [19] [20] [21] [22], we infer that Packet Trace, RTT, Signaling load, Packet loss, handoff latency, handoff frequency and throughput are used as metrics.

But from our experimental setup, we can only get Throughput, Handoff frequency and Handoff latency, which we will be using to make the comparison with our initial implementation of SIGMA [5].

From our experimental setup, we collected the above stated parameters. These results show that our handoff scheme reduce the number of handoff and the instability of SIGMA. Rest of the paper is organized as follows, Sec II has the introduction to SIGMA. Sec III explains the instability of the SIGMA. Sec IV has all the related previous works on handoff schemes, their methods, advantages and disadvantages. Sec V explains the handoff scheme for SIGMA. Sec VI has the experimental setup used to measure the results. Sec VII has the results and analysis of the collected results using the handoff scheme in our test bed. Sec VIII is the conclusion and future work. Lets have a brief introduction about SIGMA before describing the handoff scheme for SIGMA.

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. We will use the Stream Control Transmission Protocol [6], new emerging transport layer protocol from IETF, to illustrate SIGMA.

SCTP's 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 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 SS7 signaling transport. A multi-homed SCTP association can speedup recovery from link failure situations without interrupting any ongoing data transfer. Fig. 1 presents an example of SCTP multi-homing, in which 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 use when transmitting data packets, while the other IP address can be used as a backup address in case of primary address failure.

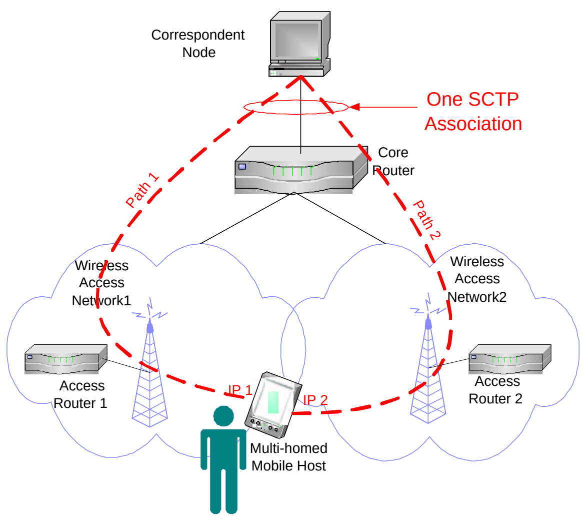

Fig. 1. A SCTP association featuring multi-homing.

1) STEP 1: Obtain new IP address: Referring to Fig. 1, 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 Fig. 1). This can be accomplished through several methods: DHCP, DHCPv6, or IPv6 Stateless Address Autoconfiguration (SAA) [23]. 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 the 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 signalling time.

2) 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.

SCTP provides a graceful method to modify an existing association when the MH wishes to notify the CN that a new IP address will will be added to the association and the old IP addresses will be probably be taken out of the association.

The IETF Transport Area Working Group (TSVWG) is working on the ”SCTP Address Dynamic Reconfiguration” Internet draft [24], 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 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 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.

3) 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.

4) 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. 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.

5) 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 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 MH with an ASCONF-ACK chunk indicating the success of the IP deletion.

In all of these five steps, step three is of more importance. The execution of step three in SIGMA is the place where the actual handoff of SIGMA is taking place. So, the handoff scheme for SIGMA has to consider, at what exact time the MH should send Set Primary (i.e.) to execute the step three, the objective being to reduce the number of handoffs and avoid the instability of SIGMA.

III. Instability of SIGMA

In this section, we demonstrate the instability of SIGMA due to the absence of efficient handoff scheme. We collected results from handoff experiments on the experimental setup given in Section VI. We collected and processed the data by using the same procedure as given by Section VI.

Fig. 2, is the throughput obtained by using the earlier implementation of SIGMA which uses handoff scheme with signal-strength information alone to make the handoff. We are presenting this graph here in order to explain the instability of SIGMA due to inefficient handoff policy.

When MN moves from one wireless network region to another wireless network region, we can say that MN goes through different states, depending on which position the MN is with respect to the access points. We categorize the MN to be in 2 states.

- Stable state is where the MN receives data and sends SACK through same IP.
- Unstable state where the MN receives data through one IP and sends SACK through another IP.

  As shown in the Fig. 6, the graph is divided into five regions where the MN will be in these two states alternatively.

  1) From time 0 to 23 seconds, the MN is in wireless network 1 during which the data is received and sends SACK through IP1 (10.1.8.100) (i.e.) MN is in stable state.
  2) From time 23 to 36 seconds, MN is said to be in unstable state, where the data is received from IP2 (10.1.6.100) and SACK is being sent from IP1 (10.1.8.100) due to the excessive number of handoff because of ping pong effect of the signal strengths.
  3) After this MN enters the wireless network-2 completely, during which the MN is in stable state again receiving data and sending through single IP (i.e) IP2 (10.1.6.100).
  4) When MN moves back from wireless network-2 to wireless network-1, it again goes to unstable state, so from time 38 to 52 the data is being received from IP1 (10.1.8.100) and SACK is being sent from IP2 (10.1.6.100), which is again due to the number of handoff due to the ping pong effect.

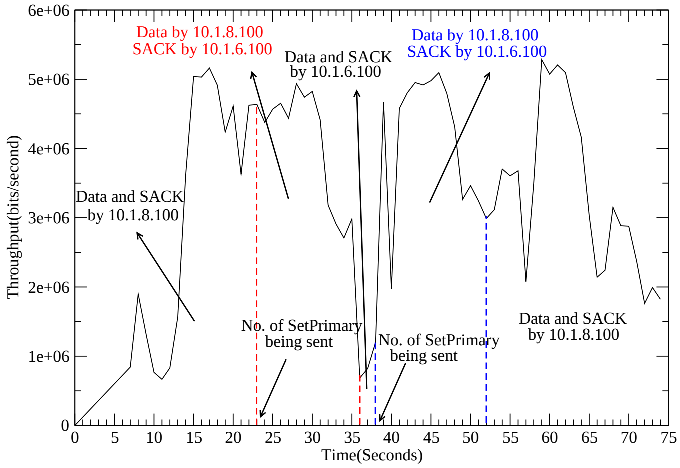

Fig. 2. Throughput for the Handoff Scheme without using the hysteresis and route cache.

5) After this, the MN is completely under wireless network-1, so it goes to stable state from 52 seconds onwards. So, you can see from Fig. 6, the MN is in unstable state for a longer period, which is due to the number of set primaries that are being sent to the CN (discussed in Sec II) because of number of handoff and due to the route cache (which is discussed in Section V). We want to reduce the time for which the MN is in unstable state, because if one of the access point goes down, during which the MN is using both interfaces, one for receiving data and another for sending SACK, then there would have been a packet loss during that time. This unstable state can be eliminated by using an efficient handoff policy. So we will analyze various previous work on efficient handoff scheme in the next section.

IV. Previous Work

In Sec, III, we have shown that the instability of the `SIGMA` is due to too many handoffs and inefficient handoff scheme. In this section, we describe previous work on reducing the number of handoff and latency per handoff.

A. Previous work on reducing number of handoff

One of the first and basic work is given by [25], this one gives the basic algorithms used to trigger the Layer 2 handoff, so that to reduce the number of handoff. The various algorithms that can be used to trigger layer 2 handoff are given below [25].

- *Relative Signal Strength (RSS)*: The BS with the strongest received signal strength is chosen for handover (choose the new BS if $RSS_{new} > RSS_{old}$).
- *RSS plus Threshold*: A handoff is decided if the RSS of a new BS exceeds that of the current one and the signal strength of the current BS is below a threshold *T* (choose the new BS if $RSS_{new} > RSS_{old}$ and $RSS_{old} < T$).
- *RSS plus Hysteresis:* A handoff takes place if the RSS of a new BS $>$ old BS by a hysteresis margin H (choose the new BS if $RSS_{new} > RSS_{old} + H$).
- *RSS, Hysteresis and Threshold:* A handoff is decided if the RSS of a new BS exceeds that of the current BS by a hysteresis margin H and the signal strength of the current BS is below a threshold *T* (choose the new BS if $RSS_{new} > RSS_{old} + H$ and $RSS_{old} < T$).
- *Dwell Timer:* A dwell timer can also be used with the above algorithms. A timer is started at the instant the condition in the algorithm is true. If the condition continues to be true until the timer expires, a handoff is performed.

B. Previous work on reducing handoff latency

There are many previous works, which are focused to reduce the handoff latency. Most of the previous works depend on architectural features such as Mobile IP, Cellular IP etc. We categorize these works based on architectural features.
1) Reducing handoff latency in Mobile IP: In [26], they have designed a scheme for Mobile IP. The advantage of this method is, it prevent from the ping-pong effect, decrease the handoff delay to a little extent and decreases the packet loss to a little degree by employing the multi-tunnel. Multi-tunnel is the concept that HA copies the same IP

packet destined to MN and sends them to multi destination through multi-tunnel. The disadvantages of this, the HA should send many copies of the same IP packet to many destinations. It wastes some bandwidth.

In [27], they present pure IPv6 Soft Handover mechanisms, based on IPv6 flows duplication and merging in order to offer pure IP-based mobility management over heterogenous networks. This solution requires the introduction of new component called Duplication & Merging Agent (D&M) agent to reduce the handoff latency.

In Polimand (Policy based handoff policy) [14], to reduce handoff latency, it accelerate the handoff process through a combination of MIP signaling and link layer hits. The link layer hits are the information got from GLL (General Link Layer). The advantage of this method is it increases the performance of vertical Mobile IP handoff up to sevenfold and reduces ping-pong effect.

In [10], they try to reduce Layer 2 handoff latency by buffering Layer2 in the driver and card of the AP1 and will be forwarded to AP2. In [28], they are trying to reduce the MAC Layer handoff latency the method selective scanning and caching. In the selective scanning, when a MN scans APs, a channel mask is built. In the next handoff, during the scanning process, this channel mask will be used. In doing so, only a well-selected subset of channels will be scanned, reducing the probe delay. In caching AP built a cache table which uses the MAC address of the current AP as the key. Corresponding to each key entry in the cache is a list of MAC addresses of APs adjacent to current one which were discovered during scanning. This list is automatically created while roaming. Combination of these reduces the handoff latency.

In [15],the service user sends a list of available wireless cells (i.e. ESSIDs) to the service program. The service program itself resides on the MN and constantly monitors the signal quality of its current wireless link. It reacts upon a change of these values (e.g. falling below a threshold)and alerts the affected service user.So that it initiate fast handover reducing handoff latency. The S-MIP [29], a seamless handoff architecture for Mobile IP, is based on movement pattern detection and its own architectural features of Mobile IP.

2) Reducing handoff latency in Cellular IP: Minimum power algorithm [8], which is designed for Cellular IP makes use of algorithm in which mobile nodes constantly search for a combination of base and channel assignmen that minimizes the uplink transmitted power. The advantages of this method is, it reduces call dropping. The disadvantages of this method is that the number of handoffs increases (i.e.) ping pong effect. RSS and BER based algorithm [9] is designed for Cellular IP. They compiled a radio propagation and BER database for handover simulation in typical city microcellular radio systems, so as to provide realistic data for handover simulation, thus minimizing inaccuracies due to inadequacies in propagation modelling. The advantage of this algorithm is a reliable handoff can be achieved. The disadvantages being, a low threshold value reduces the handoff request probability, an RSS hysteresis delays handoff significantly.

Velocity adaptive algorithm [7] is designed for Cellular IP, which makes use average receiving power (i.e.) calculating signal strength time averages from N neighboring base stations and reconnect the mobile subscriber to an alternate BS whenever the signal strength of the alternate BS exceeds that of the serving BS by at least H dB. The advantage of this method is provides good performance for MNs with different velocities by adjusting the effective length of the averaging window (i.e.) number of neighboring base stations.

Fuzzy logic based Handoff [12] is designed for Cellular IP. It uses fuzzy logic based algorithm to reduce handoff latency. The advantage of this method is uniform distribution between cells, fair QoS and better response time, easy implementation. The disadvantages being, uses lots of data as input, so all data collected should be reliable and should be without errors, they are not robust at all.

Neural handoff algorithms [13] is designed for Cellular IP. The disadvantages of this method is Learning capabilities of several paradigms of neural networks have not been utilized effectively in conjunction with handoff algorithms to date. The disadvantage of most of the proposed neural techniques have shown only preliminary simulation results.

C. Suitability of previous work in reducing instability in `SIGMA`

As discussed above, most of the previous work focussed on techniques to reduce the number of handoffs and handoff latency. The techniques used to reduce number of handoffs, which is described in [25], can be applied to `SIGMA`. Because to reduce the number of handoff, the information from Layer 2 is enough, since in `SIGMA` we can get the Layer 2 information, these techniques to reduce number of handoff is applicable to `SIGMA`.

But those previous works to reduce the latency per handoff is not applicable to `SIGMA` due to the following reasons:

– Some of the previous work [10] [28], developed techniques to reduce handoff latency at layer 2 level. Since in `SIGMA` we are doing a handoff at layer 4 level, this is not applicable to `SIGMA`.
– Other previous works developed their scheme based on their architectural features, for example [26] [27] [14] [29] [15] developed their scheme based on Mobile IP. Similarly [12] [7] [8] [9] [13] makes use of Cellular IP architecture. Since `SIGMA` has a different architecture (discussed in Sec II), these techniques cannot be applied to `SIGMA`.
– None of the previous work has instability problem (discussed in Sec III) like `SIGMA`.

Considering all these above facts, we want to develop our own handoff scheme to avoid the instability and to enhance stability in SIGMA by making use of the architectural features of the SIGMA.

V. Handoff scheme to enhance stability in SIGMA

In Section III we described the instability of SIGMA. This instability depends on two factors. The fluctuation of the signal strength is one of the factor which increases the number of handoff, called ping pong effect. This ping pong effect can be avoided by using one of the techniques to reduce number of handoff (which is discussed in Section IV-A).

The route cache is another factor which induces the instability in SIGMA. *Route cache* [30], is the effect that the kernel searches for a matching entry for the destination first in the routing cache and then the main routing table. The routing cache is also known as the forwarding information base (FIB). The routing cache stores recently used routing entries in a fast and convenient hash lookup table, and is consulted before looking up the routing tables. If the kernel finds a matching entry during route cache lookup, it will forward the packet immediately and stop traversing the routing tables. Because the routing cache is maintained by the kernel separately from the routing tables, manipulating the routing tables may not have an immediate effect on the kernel's choice of path for a given packet.

To avoid a non-deterministic lag between the time that a new route is entered into the kernel routing tables and the time that a new lookup in those route tables is performed, use *IP route flush cache*. Once the route cache has been flushed, new route lookups (if not by a packet, then manually with IP route get) will result in a new lookup to the kernel routing tables. So we designed a handoff scheme called SINHYR-handoff scheme, to avoid the instability of the SIGMA.

SINHYR-handoff scheme for SIGMA*:*

In order to avoid the instability of SIGMA a SINHYR-handoff scheme is designed which makes use of Signal-to-Noise Ratio (SNR), the reason to choose SNR is given in Sec I. It also makes use of hysteresis to reduce the number of handoff, as discussed in the Sec IV-A and route cache flushing to reduce the route caching effect discussed in Sec V. We present here the pseudo code for the SINHYR-handoff scheme.

The pseudo code for the SINHYR-handoff scheme:

SNR1 = Signal to Noise Ratio of AP1

SNR2 =Signal to Noise Ratio of AP2

Hyst = Maximum value of the differences of the two signals, in overlapping region
while(1) {

Calculate SNR1 = (SignalStrenth/NoiseStrength) for AP1

Calculate SNR2 = (SignalStrenth/NoiseStrength) for AP2

If (SNR2 greater than SNR1)and (SNR2 - SNR1 >Hyst)

Issue set primary to set IP2 as primary address in CN

If (SNR1 greater than SNR2)and (SNR1 - SNR2 > Hyst)

Issue set primary to set IP1 as primary address in CN

Change the routing table of MN and flush route cache

}

For the hysteresis to implement in the scheme, we need to know the optimum value of the hysteresis that fits our experimental setup.

Optimum value for Hysteresis:

In here, we will analyze how to obtain optimum hysteresis value for the experimental test bed using the signal strength fluctuations. The varying Signal-to-Noise Ratio which is based on signal strength is shown in Fig. 3
The Fig. 3, is drawn by calculating the SNR of the access points, by moving the MN from wireless network 1 to wireless network 2 and back to wireless network 1. To have a optimum hysteresis value, we need to find the maximum fluctuations of the signal strengths between the two access points. This can be found by having close look at the ping pong region of the Fig. 3. The Fig. 4 shows the zoomed in view of the SNR values. From the Fig. 4, we can see that the fluctuation between the access point's SNRs are 2 dB and 3 dB during the ping pong

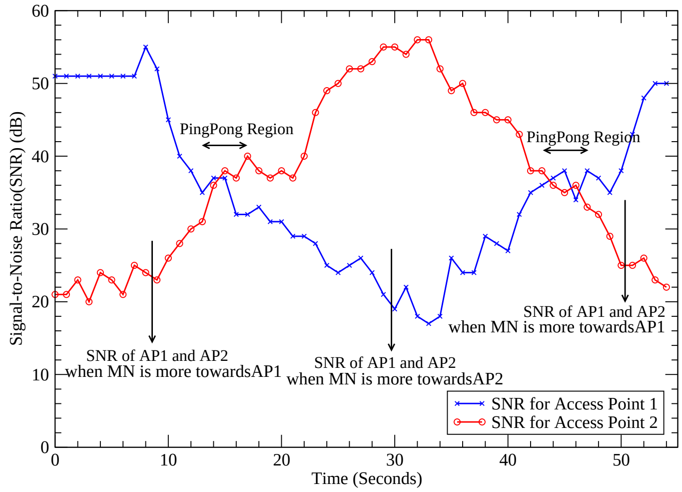

Fig. 3. Varying Signal-to-Noise-Ratio(SNR) of the Access Points.

region. If the hysteresis value is less than 2 dB or if there is no hysteresis, than many unnecessary handoff would have taken place at time=45, 46 second etc in the Fig. 4. So an optimum hysteresis value of 4 is assigned in our experimental test bed to reduce the ping pong effect.

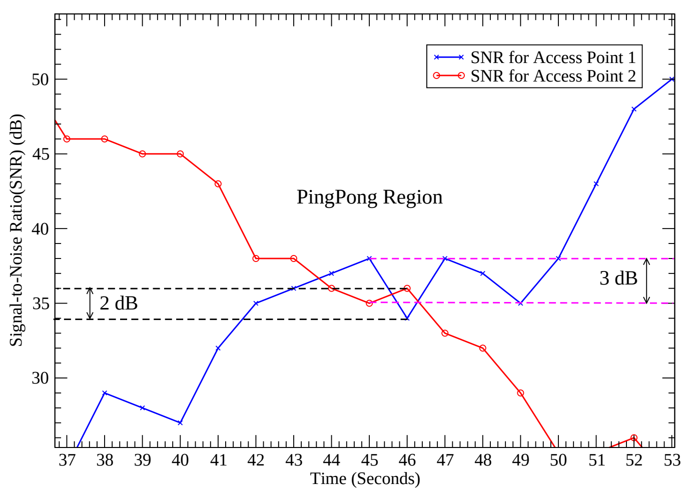

Fig. 4. Zoomed-in view of ping pong region of the Access Point's SNRs.

This SINHYR-handoff scheme is implemented in the MN, and results are obtained using the experimental setup discussed in the next section.

VI. Experimental Setup

In this section, we describe the experimental test bed that has been used to implement the SINHYR-handoff scheme discussed in Sec V. Fig. 5 shows the topology of our test bed.

As shown in Fig. 5, we have a Correspondent node (CN), a Gateway 1 and a Gateway 2 which is connected to the CS network at University of Oklahoma. Gateways are used to form different sub-networks. Each Gateway has two interface, one interface (Eth0) connects to the CS network , and other interface (Eth1) connects to the Access Points (AP). Gateway 1 connects to the AP1 and Gateway 2 connects to the AP2. Wireless Network 1 is the area covered by AP1 and Wireless Network 2 is the area covered by AP2. Mobile Node (MN) has two interfaces. One interface will be connected to one of the APs and other will always try to find and connect to other APs depending on the position of the MN. So when the MN is in Wireless Network 1, one of the interface of MN will be connected to AP1 and other interface will be searching for new APs. When MN is in Wireless

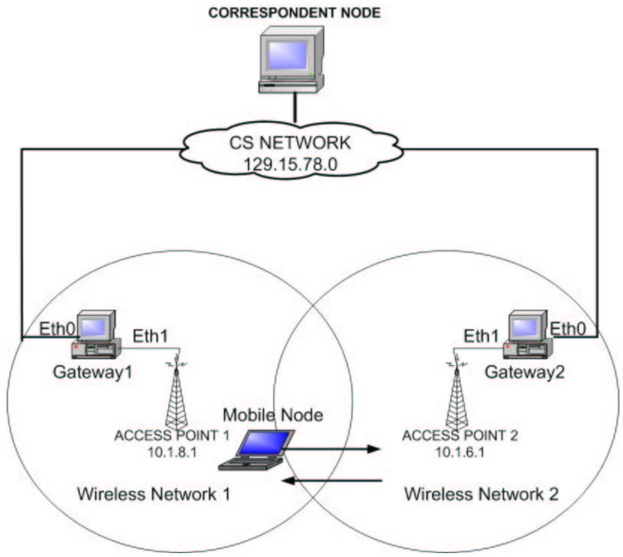

Fig. 5. Experimental testbed.

Node	Hardware	Software	Operating System
Gateways	Two Desktop		Redhat Linux 9 kernel 2.4.20
Mobile Node	Dell Inspiron-1100 Laptop, one Avaya 802.11b wireless card, one Netgear USB wireless card	File receiver	Redhat Linux 9 kernel 2.6.6
Correspondent Node	Desktop, one NIC	File sender	Redhat Linux 9 kernel 2.6.6

TABLE I
SIGMA TEST BED CONFIGURATIONS

Network 2, one of the interface of MN will be connected to AP2. When the MN is in the overlapping region, the MN will be connected to both the APs, one interface to each APs. The interface to which the CN has to send data to MN, is determined by the set primary that is being sent from the MN (discussed in Sec. II).
The table I shows the test bed's machine configuration used to collect the results. The various IP addresses are shown in Table II.

The experiment procedure to carry out seamless handoff in SIGMA is given below:

a) Start with the MN in wireless network 1.
b) Run the SIGMA handoff program in the MN, which will monitor the link layer signal strength to determine the time to handoff.
c) Run file sender and file receivers (using SCTP sockets) on CN and MN, respectively.
d) Run Ethereal on the CN and MN to capture packets.

Node	Network Configuration
Gateway1	eth0: 129.15.78.171, gateway 129.15.78.172; eth1:10.1.8.1
Gateway2	eth0: 129.15.78.172 gateway 129.15.78.171; eth1: 10.1.6.1
Mobile Node	IP1: 10.1.8.100, IP2: 10.1.6.100
Correspondent Node	129.15.78.23

TABLE II
TRASH NETWORK CONFIGURATIONS

Hysteresis value (dB)	Number of Handoffs
0	greater than 15
1	7 to 15
2	4 to 8
3	2 to 4
4 and greater	1

TABLE III
RELATION BETWEEN HYSTERESIS VALUE AND NUMBER OF HANDOFFS

e) Move MN from wireless network 1 to wireless network 2 to perform handoff by `SIGMA` and back to wireless network 1. Capture all packets at the MN and CN.

The above stated experimental procedure is repeated for SINHYR-handoff scheme with hysteresis, without hysteresis, with route cache flushing and without route cache flushing to analyze their various effects. The results are obtained and analyzed in the next section.

VII. RESULTS FOR THE HANDOFF SCHEME

The various results are collected and analyzed, by moving the MN from the wireless network 1 to the wireless network 2, with the handoff program running in it. The results are collected using the Ethereal [31] in the MN. The collected results are analyzed using the libpcap analyzer [32]. The various effects of hysteresis are given below.

A. Effect of hysteresis on number of handoff

We collected results, by moving the MN from wireless region 1 to wireless region 2 with various hysteresis value. The Table III shows the different hysteresis value used and the their corresponding handoff frequencies, when the MN moves from wireless region 1 to wireless region 2 in the testbed shown in Fig. 5. From the Table III, we can see that keeping the hysteresis value 4 or above, reduces the number of handoff to one.

B. Effect of hysteresis on the data flow

To analyze the effect of hysteresis, the handoff algorithm is implemented with and without the hysteresis value. The MN is moved from wireless network 1 to the wireless network 2 with handoff program running in the MN. The throughput of the collected data of the handoff algorithm *without hysteresis* is shown in Fig. 6

The time duration for which the MN is in unstable state is of importance here, because its the region where the MN makes use of both the interface cards (i.e.) data being received from one IP address and SACK has been sent through another IP address. The duration of this regions (5 seconds and 20 seconds) respectively, are due to the excessive number of handoff which has taken place without using the hysteresis, when the MN moves in the overlapping region.

So we can see that the duration of time, for which the MN receive data from one IP and send SACK through another IP, depends on the number of handoff taking place, when MN moves between different wireless regions. If one of the access point goes down, during which the MN is using both interfaces, one for receiving data and another for sending SACK, then there would have been a data loss during that time. The throughput of the collected data of the handoff algorithm *with hysteresis* is shown in Fig. 7

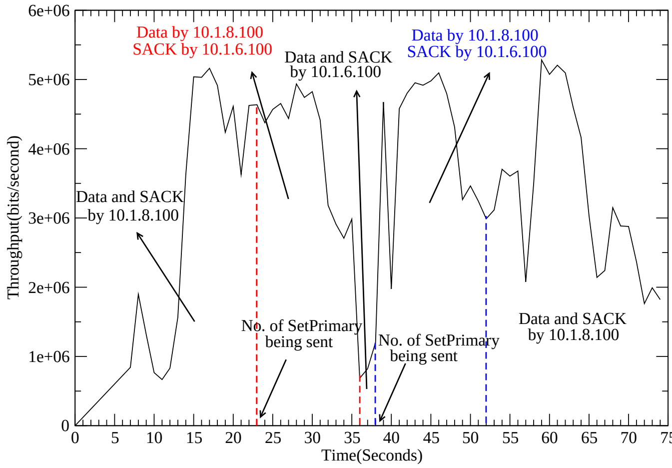

Fig. 6. Throughput for the Handoff

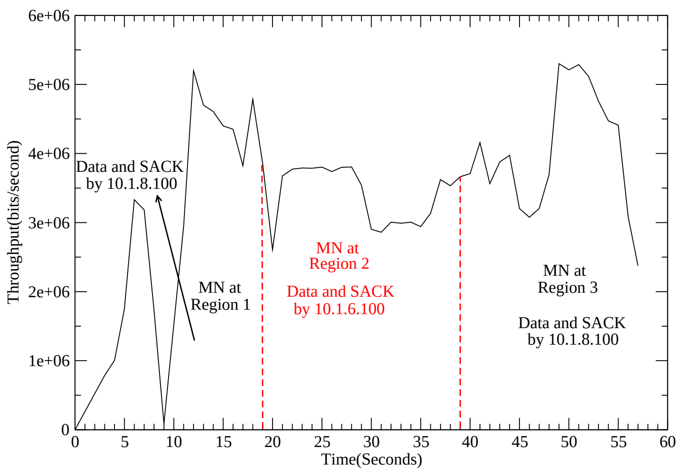

Fig. 7. Throughput for the Handoff Scheme with hysteresis and route cache flush.

As shown in the Fig. 7, the graph is only divided into 3 regions. From 0 to 19, it sends and receives data through IP1 (10.1.8.100) and from 19 to 39 seconds it receives and sends data through IP2 (10.1.6.100) and again from 39 onwards it receives and sends data through IP1 (10.1.8.100). From this we can infer that at any point of time MN will always be in stable state.

So, from the Fig. 6 and Fig. 7, we can see that the MN receives and sends packets through both the interfaces (i.e) MN is in unstable for a longer time, if the hysteresis is not used. If one of the access point goes down, during which the MN is using both interfaces, then there would have been a data loss due to the packet drop. And this situation is avoided by using the hysteresis and route cache flushing.

C. Effect of Route caching on the data flow

To show the effect of this route caching, we have collected the results with and without flushing the route cache. We collected the data using the ethereal in the MN, when MN is moving from wireless region 1 to wireless region 2 and back to wireless region 1, with the handoff program running in it without flushing the route. The throughput graph for the collected data is shown Fig. 8

As shown in the Fig. 6, the graph is divided into 5 regions where the MN will be in these two states alternatively. From time 0 to 20.57 seconds, the MN is in wireless network 1 during which the data is received and sends SACK through IP1 (10.1.8.100). From time 20.57 to 22.18 seconds, MN is said to be in unstable state, where the data is received from IP2 (10.1.6.100) and SACK is being sent from IP1 (10.1.8.100) due to the excessive number of handoff because of ping pong effect of the signal strengths. After this from 22.18 to 73.97 MN enters the wireless network-2 completely, during which the MN is in stable state again receiving data and sending through single IP (i.e)IP2 (10.1.6.100). When MN moves back from wireless network-2 to wireless network-1, it again goes to unstable state, so from time 74.97 to 75.50 the data is being received from IP1 (10.1.8.100) and SACK is being

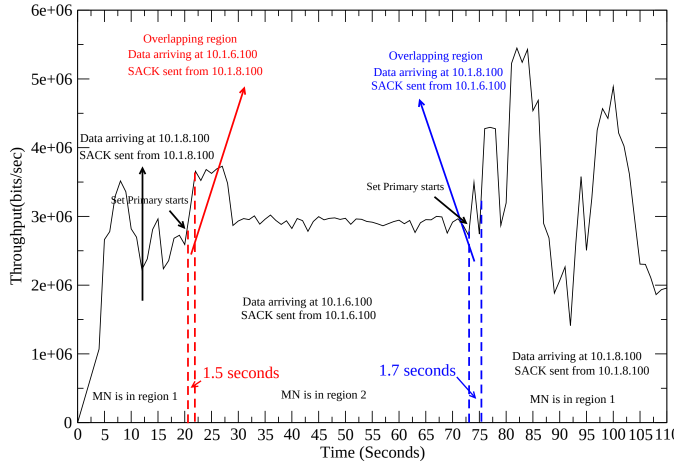

Fig. 8. Throughput for handoff scheme with hysteresis and without route cache flush.

sent from IP2 (10.1.6.100), which is again due to the number of handoff due to the ping pong effect. After this, the MN is completely under wireless network-1, so it goes to stable state from 75.50 seconds onwards.
The regions from 20.57 to 22.18 and from 74.97 to 75.50 in Fig. 8 is of importance here, because during this region the MN is in unstable state (i.e.) receives data through one interface, and sends SACK through another interface, even though hysteresis is implemented. This is due to the caching effect of the routing table, even though the number of handoff is just one.

The Fig. 7 shows the throughput of the data, when the handoff scheme with *route cache flush* being implemented. And we can see from Fig. 7 that, MN is always in stable state. during which the MN makes use of both interface cards, is being eliminated using the route cache flush.
Also, we repeated the experiment many times, to calculate the handoff latency for the new handoff scheme with route cache flush and hysteresis. Fig. 9 shows the handoff latency in milliseconds. As you can see, from the Fig. 9, the routing table change takes only few milliseconds, due to route cache flush, which would have been around 2 seconds if route cache is not flushed. So, routing table change only takes few milliseconds of the handoff latency compared to the RTT of the Setprimary, which is around 100 to 200 milliseconds. So major part of the handoff latency is due to the transmission delay between MN and CN, since the MN and the CN are connected via CS-Network as you can see in Fig. 5.

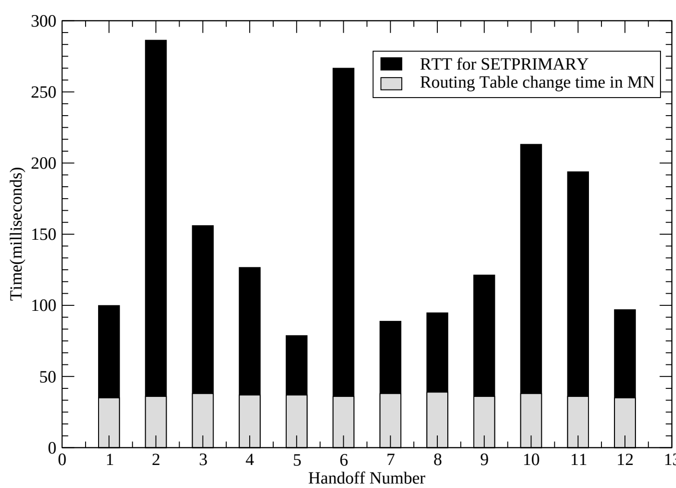

Fig. 9. Handoff latencies for number of handoff, showing different parts of handoff latencies.

VIII. Conclusion and Future work

From the results collected, we have analyzed the effect of hysteresis and route cache flush for Layer4 handoff. The handoff frequency (which is in the range of 10 to 20) for handoff algorithm without hysteresis, is greater than the handoff frequency (which is one) for handoff scheme with hysteresis. Also from the latency which is caused by the routing cache is avoided. So the instability of the SIGMA is completely avoided using the SINHYR-handoff scheme.

As a future work, we can implement dwell timer, threshold in the handoff scheme. The way of assigning values to the hysteresis can be made dynamic (i.e.) value can be assigned to the hysteresis, when the MN moves between the different wireless networks and making use of the information of signal's fluctuations.

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