# Signalling Cost Analysis of SINEMO: Seamless IP-diversity based NEtwork MObility

**Abu S Reaz, Pulak K Chowdhury, Mohammed Atiquzzaman**

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Telecommunication & Network Research Lab

School of Computer Science

THE UNIVERSITY OF OKLAHOMA

200 Felgar Street, Room 160, Norman, Oklahoma 73019-6151
(405)-325-0582, atiq@ou.edu, www.cs.ou.edu/˜netlab

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**Abu S Reaz**, **Pulak K Chowdhury**, **Mohammed Atiquzzaman**
Telecommunications and Networks Research Lab, School of Computer Science
University of Oklahoma, Norman, OK 73019-6151, USA
Email: {`sayeem_reaz, pulak, atiq`}`@ou.edu`

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*Abstract*— **IETF has proposed Mobile IPv6-based Network Mobility (NEMO) basic support protocol (BSP) to support network mobility. NEMO BSP inherits all the drawbacks of Mobile IPv6, such as inefficient routing path, single point of failure, high handover latency and packet loss, and high packet overhead. To address these drawbacks, we proposed an IP diversity-based network mobility management scheme called Seamless IP-diversity based NEtwork MObility (SINEMO). In this paper, we develop an analytical model to analyze and compare the signalling costs of SINEMO and and NEMO BSP. Our analysis shows that SINEMO reduces the signalling cost by a factor of two when compared to NEMO BSP.**

## I. INTRODUCTION

The Internet connectivity of mobile hosts has been studied extensively for the last few years. We are currently witnessing the emergence of mobile networks, a set of IP nodes that move collectively as a unit. Space satellites can be an example of a mobile network which can contain several IP enabled network nodes like telescopes, computers, etc. IETF recently proposed a new architecture called Network Mobility (NEMO) basic support protocol (BSP) [1] in order to answer the requirements of network mobility. This is an extension of Mobile IPv6 [2], and allows all nodes in the mobile network to continue ongoing connection while the network moves. In the NEMO BSP architecture, a Mobile Router (MR) takes care of all the nodes within the Mobile Network (MN). The MR is a piece of software that resides in a network router. Mobile Router allows an entire network to roam; thus a device connected to the MR does not need to be aware of mobility.

As the NEMO BSP is based on Mobile IPv6, it inherits all the drawbacks of Mobile IPv6. In NEMO BSP, all the packets should be routed through the HA of the mobile router. Thus, when the mobile network moves further away from the HA of the mobile router, all the packets should follow a far, inefficient routing path. Packet overhead also increases for encapsulating packet twice. During handover, the MR has to acquire its new care of address in the foreign network and register the new address with its HA which increases handover latency due to multiple level of indirection; incurring packet loss during handover period. A number of proposal to improve performance of NEMO BSP have been introduced in the literature. Perera et al. [3] discuss different implementation designs and issues for network mobility, including BSP. Kim et al. [4] proposed route optimization to reduce latency and Ryu et al. [5] proposed improved handover technique for NEMO BSP. A secured, spoofing-proof extension of NEMO BSP is proposed by Kim and Chae [6]. But none of these proposals completely address the issues regarding NEMO BSP [7].

To address these drawbacks of NEMO BSP, we propose an IP diversity based scheme called SINEMO (Seamless IP diversity based NEtwork MObility). In our scheme, we mainly *focus* on solving the problems associated with NEMO BSP and propose a seamless IP-diversity based communication protocol for mobile networks to reduce handover latency and packet losses. The *difference* between NEMO BSP and SINEMO is, SINEMO is an end-to-end solution instead of a network layer solution of network mobility. SINEMO, therefore, can cooperate with IPv4 or IPv6 infrastructure without the support of Mobile IPv6. Moreover, SINEMO can exploit IP diversity [8] for keeping the old path alive during the process of setting up the new path to achieve a seamless handover between adjacent access points rather than having a hard handover [8]. In addition to seamless handover, SINEMO has a number of advantages such as easier deployment because of no required change in the Internet infrastructure, co-operation with Internet security protocols, efficient utilization of network bandwidth due to the absence of tunnelling, etc [7].

SINEMO follows all the important protocol design characteristics for a mobile network. The defining characteristic of network mobility is the notion of a set of nodes moving as a unit. The mobile network may contain both “mobility aware” and “mobility unaware” or fixed nodes. “Mobility aware”nodes can perform handover inside the network; thus exhibiting nested mobility. SINEMO provides complete transparency of network mobility to the nodes in the mobile network. Signalling is one of the major design considerations and performance measure in network mobility [7]. In SINEMO, the utilization of the wireless links is efficient, i.e., the majority of the bandwidth dedicated to user data (i.e. minimum signalling). The *objective* of this paper is to develop an analytical model of the signalling cost of SINEMO and NEMO BSP and compare its signalling costs. Our *contributions* in this paper are (i) proposing SINEMO, an end-to-end, IP diversity based solution to network mobility, and (ii) developing analytical model of

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NEMO BSP and SINEMO to evaluate and compare signalling cost these two schemes to determine design efficiency of SINEMO.

The rest of the paper is organized as follows: Sec. II describes the SINEMO architecture and signalling timeline. Sec. III briefly discusses NEMO BSP. In Sec. IV, we develop analytical morel of the signalling cost of SINEMO and NEMO BSP. Sec. V compares the signalling cost performance of SINEMO with NEMO BSP. Finally, concluding remarks are given in Sec. VI.

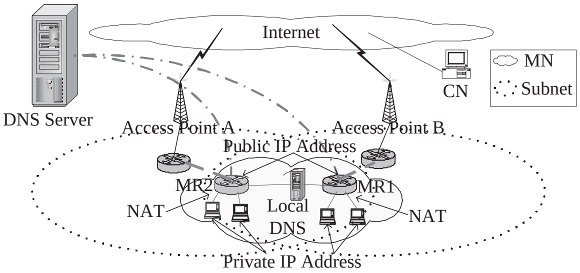

Fig. 1. Architecture of SINEMO.

## II. ARCHITECTURE OF SINEMO

Figure 1 depicts a typical SINEMO operational scenario of a mobile network (like bus, train, satellite, etc.) equipped with several IP enabled devices where the mobile router onboard is a multi-homed node connected through two wireless access networks. Correspondent node (CN) is a single-homed node sending traffic (for services like file or image downloading etc) to one host inside the Mobile Network (MN).

The MR in the mobile network acts as a gateway between all the hosts inside the MN and the Internet. The MR obtains an IP address from the current base station A when the MN moves into the coverage of that station. It is also delegated one or more prefixes to allocate IP addresses to the hosts within the MN. Hosts inside the MN can be fixed (FH) or mobile (MH). Each host inside the MN has both public and private IP addresses. The MR provides each host a private IP address from a predefined private IP address space, and also reserves a public IP address for it. It contains a one to one mapping between the public and private IP address of each host. The hosts are not aware of their public IP addresses, MR manages this address space on behalf of them. In that way, the MR hides the mobility from the devices inside the network. This option implies the use of NAT (Network Address Translator) to translate between the host's private address and a public (globally reachable) address. A NAT mechanism is implemented in MR to swap the IP addresses in the network and transport headers of the packets [9]. This strategy provides efficient routing support and, most importantly, has the advantage of reducing signalling across air interface [7] as the hosts will not generate any dynamic DNS updates or binding updates while the MN moves.

When CN wants to send data to a host inside the MN, it gets the public IP address of the host and send data directly to the host. The MR intercepts the data packets, translates the IP addresses and forwards the packets to the hosts.

### A. Handover Management

When the MN moves into the overlapping radio coverage area of two adjacent access points (AP), the handover preparation begins. Once the MR receives the advertisement from the new AP B, it should begin to obtain its own new IP address and one or more new IP address prefixes for the hosts inside the MN.

As the MR has two interfaces, it can receive data using its old IP address while using the other interface for registering with the new AP and getting new address prefixes. After registration, it updates the public to private address mapping of the hosts with the new address prefixes. The MR also updates all the CNs which are communicating with the hosts in the MN. After getting the update, CNs can start sending data to the hosts inside the MN using the new IP addresses. When MR moves out of the coverage of AP A, it detaches its interface from that base station. Unlike NEMO BSP, in our scheme, the MR can receive data packets using the old interface during handover period; thus it reduces handover data losses.

If the MN has more than one MR, then MN consists of more than one subnets and exhibits nested mobility. If MHs in the MN cross subnets, handovers occur between coverage of different MRs. The handover of MHs within the MN are same as MR handover between access points.

### B. Location management of SINEMO

SINEMO needs to set up a location manager which is not restricted to the same subnet as MR's home network (in fact, SINEMO has no concept of home or foreign network). If we use the domain name as hosts identity, we can merge the Location Manager (LM) into a DNS server. The idea of using a DNS server to locate mobile users can be traced back to [10], and performance analysis of DNS as LM can found in the works of Reaz et al. [11], [12]. This will make the deployment of SINEMO much more flexible than NEMO BSP. Compared to NEMO BSP's requirement that each subnet must have a location management entity (HA), SINEMO can reduce system complexity and operating cost significantly due to not having such a requirement. We use hierarchical location management for locating a host inside a mobile network.

When a host first enters a mobile network, it registers with the local DNS server associated with the mobile network and gets a temporary name [12]. This local DNS server in the MN is co-located with the MR. It creates an entry for this host with a mapping between the temporary name and a public address. The MR delegates a private IP address to the host. MR also creates a mapping between public and private IP address for this host to forward packets. After registration of the name, the host sends name updates to the central DNS server. When CN sends a query for IP address of a host in the mobile network, the central DNS server forwards the query to the local DNS server inside the MN. The local DNS server responds with the public address of the host. After getting the IP address, the CN can start communication with the host in the mobile network. This approach makes use of new dynamic DNS low latency secure updates developed within IETF.

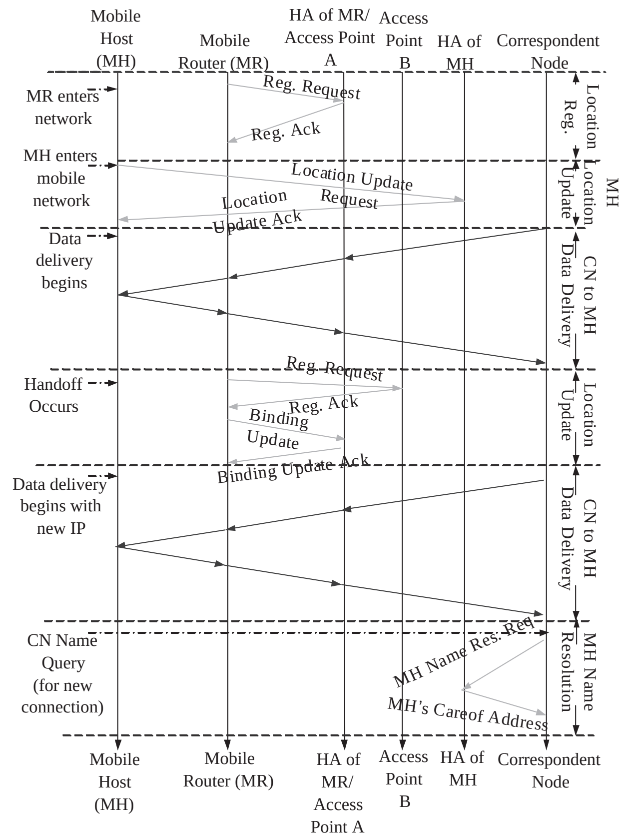

Fig. 2. Signalling protocol of NEMO BSP.

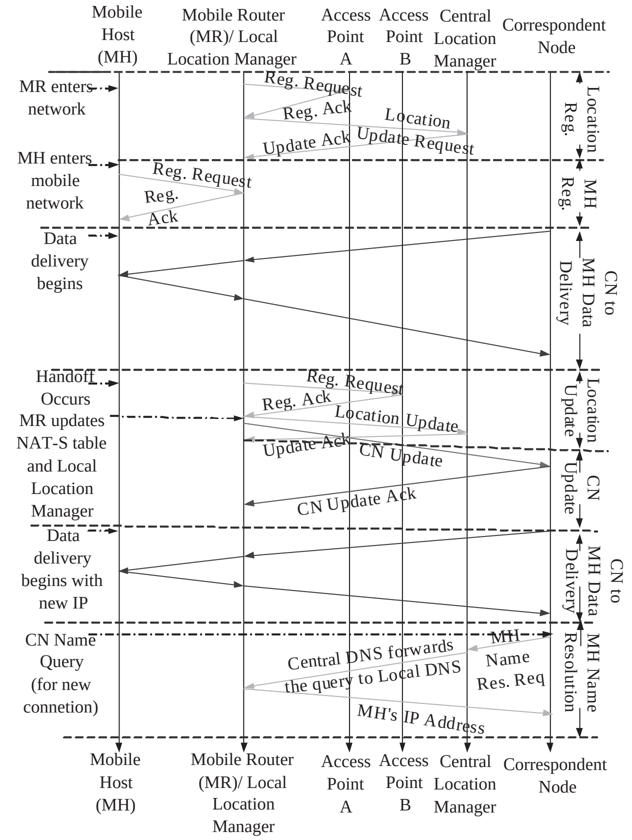

Fig. 3. Signalling protocol of SINEMO.

If an MH crosses subnet within MN, it updates the local DNS while the central DNS entry remains unchanged. This reduces signalling load for local mobility.

## III. ARCHITECTURE OF NEMO BSP

In NEMO BSP [1], the Mobile Router (MR) takes care of all the nodes in the Mobile Network (MN) by ensuring continuous connectivity of all the nodes inside the MN even as the MR moves and changes its point of attachment to the Internet. A Mobile Router (MR) has its unique IP address and has one or more prefixes that it advertises to the MNs attached to it. MR provides complete transparency of network mobility to the nodes inside the MN. It establishes a bi-directional tunnel with its Home Agent (HA) to pass all the traffic between the mobile network nodes and the correspondent nodes.

When a MR moves away from its home network and changes its point of attachment, it acquires a new care-of-address from the visited network. After acquiring the address, it sends a binding update to its HA. As soon as the HA receives the binding update, it creates a cache entry binding MR's home address with its care-of-address. When a correspondent node sends data to a node in the MN, it is routed to the HA of the mobile router. The HA of MR looks at its cache entry and forwards the packet to the MR using the bidirectional channel. Finally, MR receives the packet, decapsulates it, and forwards it to the corresponding node in the mobile network.

## IV. SIGNALLING COST ANALYSIS

Signalling cost of mobility management for a mobile network has two major components: signalling cost related to mobility of the MH and their corresponding updates within the MN, and the signalling cost related to the movement of the network itself. In this section, we analyze the signalling cost of both NEMO BSP and SINEMO.

### A. Variables for NEMO BSP and SINEMO

**Variables common to NEMO BSP and SINEMO:**
$N_{mh}$ = total number of hosts in MN
$N_{mh}$ = total number of MH
$N_{fh}$ = total number of FH
$N_{mr}$ = total number of MR in MN
$N_{cn}$ = avg. number of CN communicating with a MH
$T_{mh}$ = Subnet residence time of MH
$T_{mr}$ = Subnet residence time of MR
$\theta$ = wireless proportionality constant
$\delta_{LU}$ = per hop location update message transmission cost
$\psi$ = linear coefficient of no. of MH to lookup cost
$\lambda_s$ = session arrival rate
$\sigma$ = session-mobility ratio defined as $\lambda_s \times T^{mh}$.
**Variables for NEMO BSP only:**
$\Psi^{LU}_{BSP}$ = Location update cost per sec
$\Psi^{LUP}_{BSP}$ = Lookup cost per sec
$\Psi^{TOT}_{BSP}$ = Total signalling cost
For MH mobility:
$b\Psi^{LU}_{MH}$ = Location update cost per sec at HA of MH

$LU_{mh}$ = Transmission cost of one location update from MH to HA

$\gamma_h$ = Processing cost at HA

$l_{mh}$ = avg. no. of hops between MH and HA

$b\Psi_{MH}^{LUP}$ = Lookup cost for MH per sec

$\lambda_p$ = packet arrival rate

$v_h$ = processing cost of each packet at HA

$\tau$ = encapsulation cost at HA

$\xi_h$ = per location database lookup cost at HA

For MR mobility:

$b\Psi_{MR}^{LU}$ = Location update cost per sec at HA

$LU_{mr}$ = Transmission cost of one location update from MR to HA

$l_{mr}$ = avg. no. of hops between MH and HA

$\gamma_r$ = Processing cost and binding update at HA

**Variables for SINEMO only:**

$\Psi_{SN}^{LU}$ = Location update cost per sec

$\Psi_{SN}^{BU}$ = Location update cost per sec

$\Psi_{SN}^{LUP}$ = Lookup cost per sec

$\Psi_{SN}^{TOT}$ = Total signalling cost

For MH mobility:

$s\Psi_{MH}^{LU}$ = Location update cost per sec at local LM

$LU_{ml}$ = Transmission cost of one location update from MH to local LM

$\gamma_l$ = Processing cost at LM

$s\Psi_{MH}^{BU}$ = Binding update cost per sec at CN for MH

$BU_{mc}$ = Transmission cost of one binding update from MH to CN

$l_{mc}$ = avg. no. of hops between MR and CN

$\delta_{BU}$ = per hop binding update message transmission cost

$s\Psi_{MH}^{LUP}$ = Lookup cost per second in LM

$\omega$ = ratio of MHs that are servers to total MH

$\xi_l$ = per location database lookup cost at LM

$S$ = number of sessions

For MR mobility:

$s\Psi_{MR}^{LU}$ = Location update cost per sec at both central and local LM

$LU_{rl}$ = Transmission cost of one location update from MR to central LM

$l_{rl}$ = avg. no. of hops between MR and cental LM

$s\Psi_{MR}^{BU}$ = Binding update cost per sec at CN for MR

$BU_{mr}$ = Transmission cost of one binding update from MR to CN

In a real life scenario, $N_h = N_{fh} + N_{mh}$. FH has essentially less signalling cost than MH as not local movement and wireless interface involved. In our case, we consider the worst possible signalling case, where all the hosts are mobile, i.e., $N_h = N_{mh}$.

### *B. Signalling cost of NEMO BSP*

Signalling in NEMO BSP takes place when MH moves from the coverage of one subnet to another one and has to update its location; when CN wants to send a packet to MH, the HA has to perform a lookup.

1) **Location update cost**:
   In NEMO BSP, location update takes place in two situations. First, when MH moves within the mobile network, it updates the HA of MH; and second, when the MN moves to a new subnet, it updates the HA of MN. A location update cost includes the transmission cost and processing cost at HA for all the MHs. When MH moves within the MN, for each subnet crossing, it updates its HA. Thus,

$$b\Psi_{MH}^{LU} = N_{mh}\frac{LU_{mh} + \gamma_h}{T_{mh}} \tag{1}$$

   Now, we know that the wireless link cost is higher than wired link cost. Any message going outside the MN generated at MH travels two wireless networks (one in MN and another is the subnet of MN) and some wired network. Thus we can compute

$$LU_{mh} = 2(l_{mh} - 2 + 2\theta)\delta_{LU} \tag{2}$$

   where $(l_{mh} - 2)$ represents the number of wired hops.
   When MR crosses subnets, it updates its HA, which includes the prefix and binding update. That gives location update cost for MR to be

$$b\Psi_{MR}^{LU} = N_{mr}\frac{LU_{mr} + \gamma_r}{T_{mr}} \tag{3}$$

   where

$$LU_{mr} = 2(l_{mr} - 1 + \theta)\delta_{LU} \tag{4}$$

   Here $(l_{mr} - 1)$ represents the number of wired hops and $\gamma_r$ includes the prefix and binding update cost.
   Values from Eqs. (2) and (4) can be evaluated in Eqs. (1) and (3), respectively. Sum of Eqs. (1) and (3) gives the total location update cost,

$$\Psi_{BSP}^{LU} = b\Psi_{MH}^{LU} + b\Psi_{MR}^{LU} \tag{5}$$

2) **Lookup cost**:
   For NEMO BSP, there is no lookup cost associated to MR. We only consider lookup cost and the tunnelling cost of MH. For each packet sent to CN from MH, processing cost involves HA lookup for MH and MR and encapsulation of the packet.

$$b\Psi_{MH}^{LUP} = N_{mh}N_{cn}\lambda_p v_h \tag{6}$$

   As lookup processing cost at HA of MH involves location database lookup and encapsulation, $v_h = \xi_h + \tau = \psi N_{mh} + \tau$. If $F$ = size of the file being transferred at each session and $P$ is the maximum transmission unit of the path, then $\lambda_p = \lambda_s \frac{F}{P}$. As there is not lookup cost involved with MR, essentially, from Eq. (6),

$$\Psi_{BSP}^{LUP} = b\Psi_{MH}^{LUP} = N_{mh}N_{cn}\lambda_s\frac{F}{P}(\psi N_{mh} + \tau) \tag{7}$$

Thus, the total signalling cost of NEMO BSP can be calculated as

$$\Psi_{BSP}^{TOT} = \Psi_{BSP}^{LU} + \Psi_{BSP}^{LUP} \tag{8}$$

where values of $\Psi_{BSP}^{LU}$ and $\Psi_{BSP}^{LUP}$ can be obtained from Eqs. (5) and (7), respectively.

### *C. Signalling cost of SINEMO*

SINEMO has similar signalling scenario as NEMO BSP described in Sec. IV-B. Moreover, for SINEMO, for CNs need to be updated when MH or MR cross subnets.

1) **Location update cost**:
When MR changes its location, central LM has to be updated by MR as well as the entries at local LM co-located at MR. When MH moves across subnets, it updates the local LM. For MH movement, we have

$$s\Psi_{MH}^{LU} = N_{mh}\frac{LU_{ml}+\gamma_l}{T_{mh}} \tag{9}$$

As local LM is co-located with MR, the update message will travel only one wireless hop. So,

$$LU_{ml} = 2\theta\delta_{LU} \tag{10}$$

On the other hand, when MR crosses subnets, it updates the central LM with the current address of local LM and the entries for MHs at local LM. Therefore,

$$s\Psi_{MR}^{LU} = \frac{N_{mr}(LU_{rl}+\gamma_l)+N_{mh}\gamma_l}{T_{mr}} \tag{11}$$

where

$$LU_{rl} = 2(l_{rl}-1+\theta)\delta_{LU} \tag{12}$$

Values from Eqs. (10) and (12) can be evaluated in Eqs. (9) and (11), respectively. We get total location update cost

$$\Psi_{SN}^{LU} = s\Psi_{MH}^{LU} + s\Psi_{MR}^{LU} \tag{13}$$

from summing up Eqs. (9) and (11).

2) **Binding update cost**:
When MRs or MHs change their location, every CN corresponding to each MH needs to be updated. We do not consider the processing cost of the binding updates at CNs as they are processed at the end terminals and do not contribute to network load. For binding update cost associated to MH movement, we have

$$s\Psi_{MH}^{BU} = N_{mh}N_{cn}\frac{BU_{mc}}{T_{mh}} \tag{14}$$

As these binding updates are generated at MHs and destined for CNs, it has two wireless hops. Therefore,

$$BU_{mc} = 2(l_{mc}-2+2\theta)\delta_{BU} \tag{15}$$

When MR crosses subnets, it updates all the CNs of each MHs. This gives

$$s\Psi_{MR}^{BU} = N_{mh}N_{cn}\frac{BU_{mr}}{T_{mr}} \tag{16}$$

Here, binding update messages from MR are carried over only one wireless network. Thus, substituting the path cost of one wireless hop from Eq. (15) gives

$$BU_{mr} = BU_{mc} - 2(\theta\delta_{BU}+1) \tag{17}$$

Substituting Eqs. (15) and (17) in Eqs. (14) and (16) respectively, we get the total binding update cost to be

$$\Psi_{SN}^{BU} = s\Psi_{MH}^{BU} + s\Psi_{MR}^{BU} \tag{18}$$

3) **Lookup cost**:
If the MH is a server, the CN is the connection initiator and requires to perform a DNS lookup. This lookup would take place $S/\lambda_s$ seconds when each session duration time is independent from each other. We assume the number of MHs is linearly related to location database search cost. So we would get $v_l = \frac{\xi_l\lambda_s}{S} = \frac{\psi N_{mh}\lambda_s}{S}$. Moreover, lookup cost is not related to MR or MH movement. Therefore, the total database lookup cost would be

$$\Psi_{SN}^{LUP} = s\Psi_{MH}^{LUP} = \omega N_{mh}N_{cn}v_l = \omega N_{mh}^2 N_{cn}\frac{\psi\lambda_s}{S} \tag{19}$$

So, from Eqs. (13), (18) and (19), we get the total signalling cost for SINEMO,

$$\Psi_{SN}^{TOT} = \Psi_{SN}^{LU} + \Psi_{SN}^{BU} + \Psi_{SN}^{LUP} \tag{20}$$

## V. PERFORMANCE ANALYSIS

In Sec. IV, we developed signalling cost analysis models for NEMO BSP and SINEMO. In this section, we evaluate and compare the signalling costs of the two architectures. For the numerical calculation, we use the following parameter values used in previous work [13]: $\gamma_l$ = 30, $\psi$ = 0.3, $S$ = 10, $F$ = 10kb, $P$ = 576b, $\theta$ = 10, $l_{rl}$ = 35, $l_{mc}$ = 35, $\gamma_h$ = 30, $\gamma_r = 1.5\times\gamma_h$, $\lambda_s$ = 0.01, $\delta_{LU}$ = 0.2, $\delta_{BU}$ = 0.2, $\omega$ = 0.5, $\tau$ = 0.5, $l_{mh}$ = 35, $l_{mr}$ = 35. Here we assumed that the per hop cost for every kind of signalling message is same, and 50% of the MHs are servers.

Fig. 4 shows the impact of number of MHs for different subnet residence times on total signalling cost of BSP and SINEMO (Eqns. (8) and (20)). Values used here are $N_{cn}$ = 1, $N_{mh}$ from 20 to 100, and $T_{mh}$ = $T_{cn}$ = 60, 120 and 180 sec. When the residence time is lower, it increases the rate of handover, leading to the increase of per second signalling cost. Here we can see that the signalling cost of SINEMO is lower than BSP due to the fact that the local DNS update does not have any data transmission cost (Eq. 12), and per packet lookup cost of BSP is higher (Eq. 7).

For the same configuration, if we fix $N_{mh}$ = 80 and vary $N_{cn}$ from 1 to 10, we see that the signalling cost of BSP does not change for different residence time. However, signalling cost of SINEMO increases with higher residence time and number of CNs. We can see the effect of $N_{cn}$, $T_{mh}$ and $T_{cn}$ in Fig. 5.

Next, we examine the impact of total number of MH and per hop transmission costs for location update messages. We fix $T_{mh}$ = $T_{cn}$ = 60, $N_{mh}$ = 40, 60 and 80, and $N_{cn}$ = 1 and vary $\delta_{LU}$ from 0.4 to 6. The effect of number of MH and $\delta_{LU}$ on signalling cost is shown in Fig. 6. Total signalling cost increases with increase of number of MH and increase of location update cost (Eqns. (2), (4), (10), (12)).

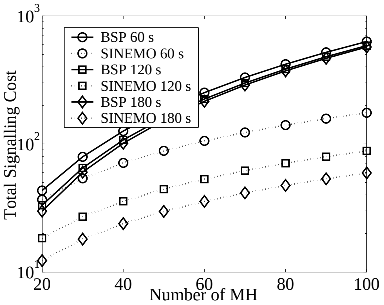

Fig. 4. Signalling cost for NEMO BSP and SINEMO vs. number of MH for different residence time.

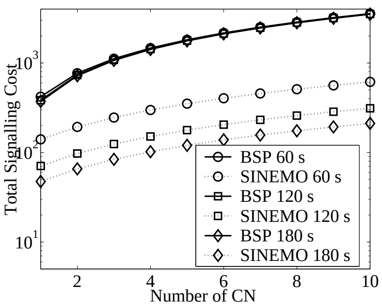

Fig. 5. Signalling cost for BSP and SINEMO vs. number of CN for different residence time.

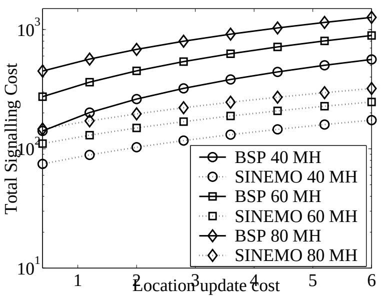

Fig. 6. Signalling cost for BSP and SINEMO vs. number location update cost for different MH.

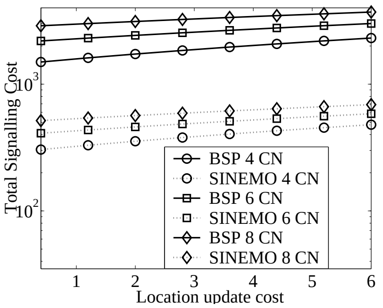

Fig. 7. Signalling cost for BSP and SINEMO vs. number location update cost for different CN.

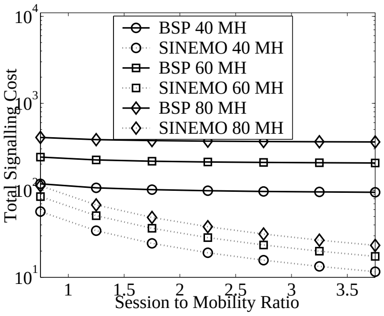

Fig. 8. Signalling cost for BSP and SINEMO vs. SMR for different number of MH.

We examine the impact of average number of CN communicating with an MH and varying location update cost on signalling cost. We keep rest of the values same as above and we fix $N_{mh}$ = 80 and $N_{mh}$ = 4, 6 and 8. Fig. 7 depicts the impact of increasing number of CN and location update cost on signalling cost. Higher number of CN, like number of MH, increases the signalling cost per second.

Session to Mobility Ratio (SMR) is a mobile packet network's counterpart of Call to Mobility Ratio (CMR) in PCS networks. We vary $T_{sub}^{res}$ from 75 to 375 seconds with $\lambda_s$ fixed at 0.01, which yields an SMR ($\sigma$) of 0.75 to 3.75. Fig. 8 shows the impact of SMR on total signaling cost for $N_{mh}$ = 40, 60 and 80. Higher value for $\sigma$ indicates low mobility, thus fewer number of updates and lower signalling cost. We can see that the signalling cost decreases with increase of $\sigma$.

## VI. CONCLUSION

Mobile IPv6-based NEMO BSP to support NEMO has several limitations resulting in high packet loss and delay. SINEMO, our proposed scheme to support network mobility, on the other hand, avoids the inherent drawbacks of BSP by using IP diversity based handover, and DNS as location manager. In this paper, we develop signalling cost analysis model for SINEMO and NEMO BSP, and compare the performance of SINEMO and BSP. Our analysis shows that signalling load of SINEMO is only 75% to 50% of that of signalling load of NEMO BSP.

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