# Signalling Cost Analysis of SINEMO: Seamless End-to-End Network Mobility [*]

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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.

## Keywords

Network Mobility, Mobility Management, IP Diversity, Location Management

## 1. INTRODUCTION

The Internet connectivity of mobile hosts for data communication has been studied extensively for the last few years. We are currently witnessing the emergence of mobile networks, a set of IP enabled mobile hosts that move collectively as a unit. Satellites containing several IP enabled nodes like telescopes, computers, etc are example of mobile networks. Other examples include trains, ships and aircrafts containing many IP-enabled devices. IETF recently proposed Network Mobility (NEMO) Basic Support Protocol (BSP) [3] to answer the requirements of network mobility. It is an extension of Mobile IPv6, and allows all nodes in a mobile network to maintain ongoing connections when 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, and allows an entire network to roam; thus devices connected to the MR are not aware of mobility.

As the NEMO BSP [3] is based on Mobile IPv6, it inherits all the *drawbacks* of Mobile IPv6, such as inefficient routing, change in the Internet infrastructure etc. During handoff, NEMO BSP suffers from delay due to registration which results in packet loss [7]. To address these drawbacks of NEMO BSP, an IP diversity based scheme called SINEMO (Seamless IP diversity based NEtwork MObility) has been proposed [2]. SINEMO differs from NEMO BSP as followed: i) SINEMO supports IP diversity based soft handoff, ii) does not require change in the Internet infrastructure, and iii) works with both IPv4 and IPv6.

A number of proposals to improve performance of NEMO BSP have been proposed in the literature. Perera et al. [7] discuss different implementations and design issues for network mobility, including NEMO BSP. Kim et al. [5] proposed route optimization to reduce latency and Ryu et al. [9] proposed an 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 research papers discusses the issue of signalling cost for NEMO BSP.

The *objective* of this paper is to compare the signalling cost of SINEMO and NEMO BSP. Signalling is one of the major design considerations and performance measure for mobility in data network [4]. Signalling messages are generated during handoff by mobile host (MH) to update locations and correspondent nodes (CN) and by CN to perform lookups that increase the volume of traffic in the network. In case of network mobility, this is a major concern because of expensive wireless bandwidth being consumed by signalling. SINEMO generates signalling messages to update CNs, but reduces messages for location updates. The utilization of the wireless links of SINEMO is efficient, i.e., most of the wireless bandwidth is dedicated to user data (i.e. minimum signalling) because the MHs inside the MN are unaware of mobility, and only MR performs the required signalling. On the other hand, NEMO BSP performs location updates for MHs and MRs in the MN for every handoff but does not update the CN. So, its *not clear* which scheme (NEMO BSP and SINEMO) has less signalling cost. Thus, our *contributions* in this paper are (i) developing analytical model of signalling cost for NEMO BSP and SINEMO; and (ii)

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evaluating and comparing signalling cost between these two schemes to determine design efficiency of SINEMO.

The rest of the paper is organized as follows: Sec. 2 describes our proposed SINEMO architecture and signalling timeline. Sec. 3 briefly discusses NEMO BSP. In Sec. 4, we develop analytical morel of the signalling costs of SINEMO and NEMO BSP. Sec. 5 compares the signalling cost of SINEMO and NEMO BSP. Finally, concluding remarks are given in Sec. 6.

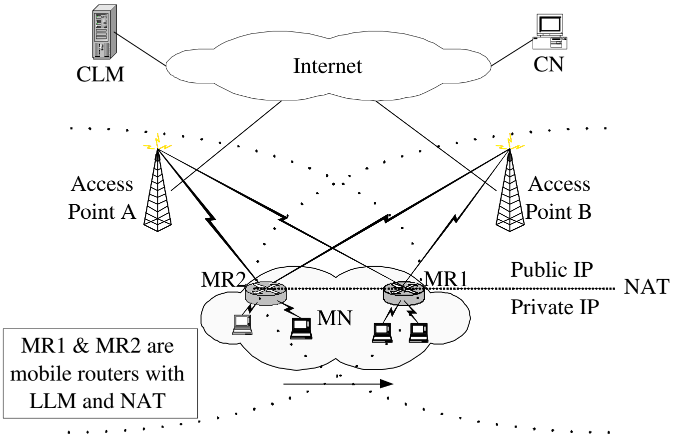

**Figure 1: Architecture of SINEMO.**

## 2. ARCHITECTURE OF SINEMO

Fig. 1 the architecture of SINEMO. It consists of a multihomed Mobile Router (MR) which is connected to two wireless networks through access points A and B. Correspondent node (CN) sends traffic (for example, file or image downloading) to a Mobile Host (MH) inside the Mobile Network (MN). A central location manager (CLM) maintains the IP addresses of MRs in an MN. A local location manager (LLM), co-located with the MR, inside the MN is used to keep the IP addresses of the hosts inside the MN. Hosts inside the MN can be fixed host (FH) or mobile hosts (MH).

MR in an MN acts as gateways between all the hosts in MN and the Internet. When MN moves into the coverage area of access point A, MR obtains a public IP address from that access point. An MR is also delegated with one or more public address prefixes to allocate IP addresses to the hosts within the MN.

MR provides each host inside the MN with a private IP address from a predefined private IP address space, and also reserves a public IP address for the host. The hosts are not aware of their public IP addresses; they use only the private IP addresses for connectivity. An MR manages the public address space on behalf of its hosts; it also contains one to one mapping of the public and private IP addresses of its hosts.

In Fig. 1, when an MH moves into the MN, it sends a registration message to MR and the LLM is updated with the new public address of the MH. MR also updates the CLM with the new public address of MH. When MN changes subnet, MR gets a new public IP address and prefixes from the new access point. Only the public addresses are changed in the address mapping at MR, the private IP addresses of the hosts remain unchanged. MR thus hides mobility from the hosts inside the MN. NAT (Network Address Translator) is used to translate between the host's private and public (globally reachable) IP addresses MR intercepts the data packets, translate the IP addresses and forward the packets to and from MHs.

Providing MHs with private IP address and mapping with public IP address results in efficient routing support and, most importantly, has the advantage of reducing signalling across air interface [4] as the hosts will not generate any dynamic updates or binding updates while the MN moves. MR updates the CLM with the IP address of the LLM, and updates the LLM with IP addresses of MHs. As the LLM is co-located with the MR, an MR does not generate any signalling; the location update is done locally. On the other hand, when an MH moves across MRs within an MN, the MH changes its IP address and updates the LLM. Thus, LLM always has the most recent addresses of MHs.

When CN wants to send data to a host inside the MN, it queries the CLM; the query is forwarded to the LLM. LLM responds with the public IP address of the MH directly to the CN.

## 3. ARCHITECTURE OF NEMO BSP

In NEMO BSP [3], MR ensures continuous connectivity of all the nodes inside the MN even as the MR moves and changes its point of attachment to the Internet. An MR has its unique IP address, and has one or more prefixes that it advertises to the MHs attached to it. Unlike SINEMO, there is no public to private address mapping of hosts in NEMO BSP. Hosts inside the MN retains the same IP address (like the private IP addresses in SINEMO) while MN changes network. MR thus provides complete transparency of network mobility to the hosts inside the MN. MR establishes a bi-directional tunnel with its Home Agent (HA-H) to pass all the traffic between MHs and the CN.

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 and sends a binding update to the HA of the MR (HA-M). As soon as the HA-M 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 an MH in the MN, they are routed to the HA of the mobile router. HA-M looks at its cache entry, encapsulates and forwards the data packets to the MR using the bidirectional channel. Finally, MR receives the packets, decapsulates and forwards them to the host in the mobile network. While in SINEMO, all the packets from CN are routed directly to the hosts in the MN, in NEMO BSP, all data packets go through the HA-M. An inefficient routing path of data packets results when the MN is far away from the home network.

## 4. SIGNALLING COST ANALYSIS

Signalling cost of a mobile network has two major components: (i) signalling cost related to mobility of the MH and their corresponding updates within the MN, and (ii) the signalling cost related to the movement of the MN itself. Both of these costs are *significant* because an MN is likely to have multiple subnets with multiple MRs (e.g., in a train) and any MH should be able to move within the MN. In this section, we analyze the signalling cost of both NEMO BSP and SINEMO for both the above components.

### 4.1 Variables for NEMO BSP and SINEMO

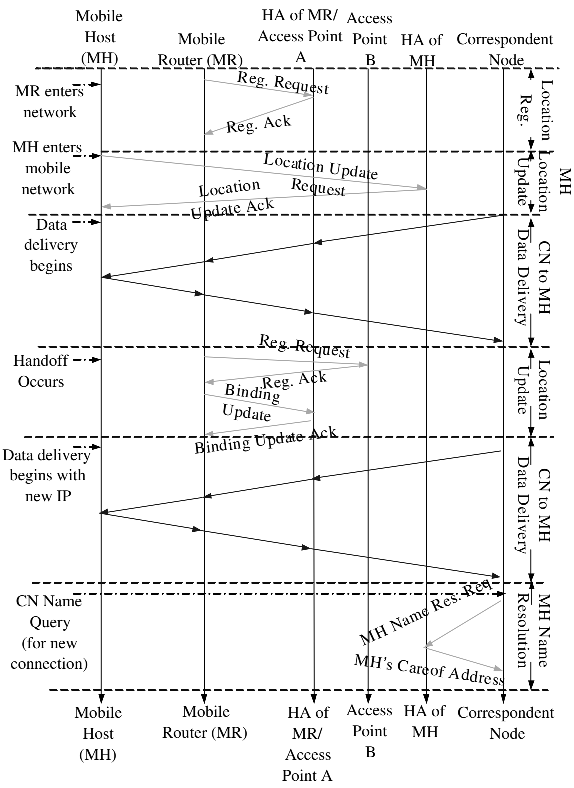

**Figure 2: Signalling protocol of NEMO BSP.**

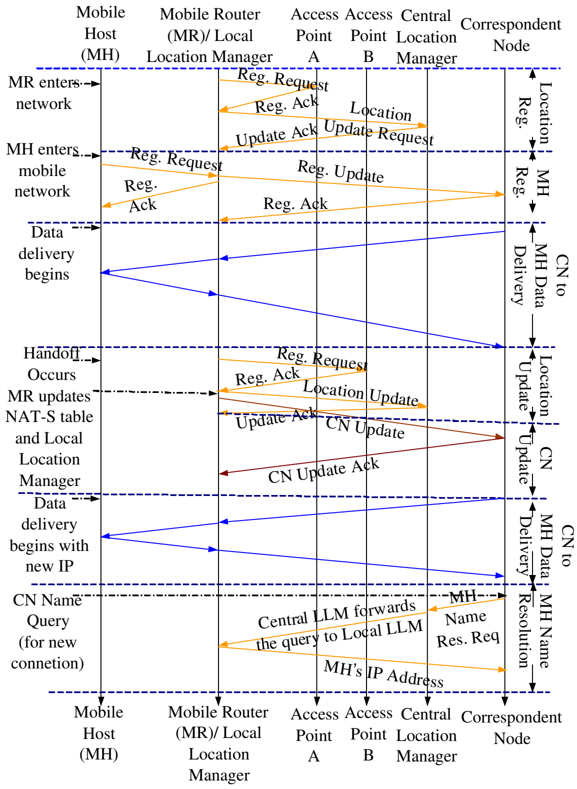

**Figure 3: Signalling protocol of SINEMO.**

**Variables common to NEMO BSP and SINEMO:**

$N_{mh}$ = total number of MHs in MN, at any instance of time, $N_{mh}$ = all the existing MHs + new MHs

$N_{fh}$ = total number of FH

$N_h$ = total number of hosts

$N_{mr}$ = 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

$\theta$ = proportionality constant of signalling cost over wired and wireless link

$\delta_{LU}$ = per hop location update message transmission cost

$\psi$ = linear coefficient of number of MH to lookup cost; number of MH is proportional to the lookup cost

$\lambda_s$ = session arrival rate or number of connection initiation request at MH from CN per second

**Variables for NEMO BSP only:**

$\Psi_{BSP}^{LU}$ = total location update cost

$\Psi_{BSP}^{LUP}$ = total location lookup cost

$\Psi_{BSP}^{TOT}$ = total signalling cost

For MH mobility:

$b\Psi_{MH}^{LU}$ = location update cost in unit time at HA of MH (HA-H)

$LU_{mh}$ = transmission cost of one location update from MH to HA-H

$\gamma_h$ = update processing cost at HA-H

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

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

$\lambda_p$ = packet arrival rate at MH

$\tau$ = encapsulation cost at HA-H

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

For MR mobility:

$b\Psi_{MR}^{LU}$ = location update cost in unit time at HA of MR (HA-M)

$LU_{mr}$ = transmission cost of one location update from MR to HA-M

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

$\gamma_r$ = processing cost and binding update at HA-M

**Variables for SINEMO only:**

$\Psi_{SN}^{LU}$ = total location update cost

$\Psi_{SN}^{BU}$ = total binding update cost

$\Psi_{SN}^{LUP}$ = total location lookup cost

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

$v_l$ = LM look up cost per sec for each association

For MH mobility:

$s\Psi_{MH}^{LU}$ = total location update cost in unit time at LLM

$LU_{ml}$ = transmission cost of one location update from MH to LLM

$\gamma_l$ = processing cost at LM (both LLM and CLM)

$s\Psi_{MH}^{BU}$ = 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 CLM and LLM

$LU_{rl}$ = Transmission cost of one location update from MR to CLM
$l_{rl}$ = avg. no. of hops between MR and CLM
$s\Psi_{MR}^{BU}$ = 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., $N_{mh} = N_h$ where $N_{fh} = 0$.

## 4.2 Signalling cost of NEMO BSP

Signalling in NEMO BSP takes place when MR move from the coverage of one subnet to another one and has to update its location; when MH moves within MN; when CN wants to send a packet to MH, the HA-H intercepts the packet and sends to HA-M.

1. **Location update cost**:

   In NEMO BSP, location update takes place in two situations. As we see from Fig. 2, when the MR moves to a new subnet, it updates the HA-M. A location update cost includes the transmission cost and processing cost at HA for all the MHs. When an MH moves within the MN, for each subnet crossing, it updates HA-H. Thus,

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

   It is known that the wireless link cost is higher than wired link cost. Any message generated at MH and going outside the MN travels two wireless links (one in MN and another from MR to an access point) and some wired network. Thus, $LU_{mh} = 2(l_{mh} - 2 + 2\theta)\delta_{LU}$ where, $(l_{mh} - 2)$ represents the number of wired hops.

   When MR crosses subnets, it updates its HA-M, which includes the prefix and binding update (fig. 2). This location update cost for MR is given by:

   $$b\Psi_{MR}^{LU} = N_{mr}\frac{LU_{mr} + \gamma_r}{T_{mr}} \tag{2}$$

   where $LU_{mr} = 2(l_{mr} - 1 + \theta)\delta_{LU}$. Here $(l_{mr} - 1)$ represents the number of wired hops and $\gamma_r$ includes the prefix and binding update cost. Combining Eqs. (1) and (2) gives the total location update cost,

   $$\Psi_{BSP}^{LU} = b\Psi_{MH}^{LU} + b\Psi_{MR}^{LU} \tag{3}$$

2. **Lookup cost**:

   For NEMO BSP, there is no lookup cost associated with 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 (Fig. 2). Thus, lookup cost for MH:

   $$b\Psi_{MH}^{LUP} = N_{mh}N_{cn}\lambda_p v_h \tag{4}$$

   As lookup processing cost at HA-H 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 no lookup cost involved with MR, essentially, from Eq. (4),

   $$\Psi_{BSP}^{LUP} = b\Psi_{MH}^{LUP} = N_{mh}N_{cn}\lambda_s\frac{F}{P}(\psi N_{mh} + \tau) \tag{5}$$

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

$$\Psi_{BSP}^{TOT} = \Psi_{BSP}^{LU} + \Psi_{BSP}^{LUP} \tag{6}$$

where values of $\Psi_{BSP}^{LU}$ and $\Psi_{BSP}^{LUP}$ can be obtained from Eqs. (3) and (5), respectively.

## 4.3 Signalling cost of SINEMO

SINEMO has similar signalling scenario as NEMO BSP described in Sec. 4.2. Additionally for SINEMO, CNs have to be updated when MH or MR cross subnets.

1. **Location update cost**:

   As Fig. 3 describes, when MR changes its location, CLM has to be updated by MR as well as the entries at LLM co-located at MR. When MH moves across subnets, it updates the LLM. For MH movement, we have

   $$s\Psi_{MH}^{LU} = N_{mh}\frac{LU_{ml} + \gamma_l}{T_{mh}} \tag{7}$$

   As LLM is co-located with MR, the update message will travel only one wireless hop. So, $LU_{ml} = 2\theta\delta_{LU}$.

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

   $$s\Psi_{MR}^{LU} = \frac{N_{mr}(LU_{rl} + \gamma_l) + N_{mh}\gamma_l}{T_{mr}} \tag{8}$$

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

   We get total location update cost from Eqs. (7) and (8),

   $$\Psi_{SN}^{LU} = s\Psi_{MH}^{LU} + s\Psi_{MR}^{LU} \tag{9}$$

   from summing up Eqs. (7) and (8).

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

   $$s\Psi_{MH}^{BU} = N_{mh}N_{cn}\frac{BU_{mc}}{T_{mh}} \tag{10}$$

   As these binding updates are generated at MHs and destined to CNs, it has two wireless hops. Therefore, $BU_{mc} = 2(l_{mc} - 2 + 2\theta)\delta_{BU}$

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

   $$s\Psi_{MR}^{BU} = N_{mh}N_{cn}\frac{BU_{mr}}{T_{mr}} \tag{11}$$

   Here, binding update messages from MR are carried over only one wireless network. Thus, substituting the

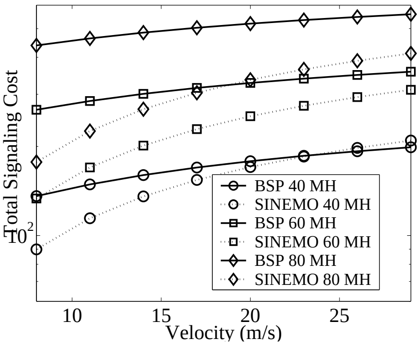

**Figure 4: Signalling cost for NEMO BSP and SINEMO vs. MR velocity for number of MH.**

path cost of one wireless hop, we get $BU_{mr} = BU_{mc} - 2(\theta\delta_{BU} + 1)$. Combining Eqs. (10) and (11), we get the total binding update cost to be

$$\Psi_{SN}^{BU} = s\Psi_{MH}^{BU} + s\Psi_{MR}^{BU} \tag{12}$$

3. **Lookup cost**:

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

$$\Psi_{SN}^{LUP} = s\Psi_{MH}^{LUP} = \omega N_{mh} N_{cn} v_l = \omega N_{mh}^2 N_{cn} \frac{\psi \lambda_s}{S} \tag{13}$$

From Eqs. (9), (12) and (13), we get the total signalling cost for SINEMO as:

$$\Psi_{SN}^{TOT} = \Psi_{SN}^{LU} + \Psi_{SN}^{BU} + \Psi_{SN}^{LUP} \tag{14}$$

# 5. PERFORMANCE ANALYSIS

In Sec. 4, 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. First, in Sec. 5.1, we use Random Waypoint Model [1], a widely used mobility model to simulate mobility pattern and determine residence time of an MH in a subnet, to compute $T_{mh}$ and $T_{mr}$ (Eqs. (1), (2), (7), (8), (10) and (11)). Then, we show the result of our performance analysis in Sec. 5.2.

## 5.1 Residence Time Calculation

We assume Mhs move according to Random Waypoint model [1], which is the most frequently used model in mobile networking research. In this mobility model, an MR or an MH randomly selects a destination point in the topology area according to uniform distribution, then moves towards this point at a random speed again uniformly selected between ($v_{min}$, $v_{max}$). One movement is called an *epoch*, and the elapsed time and the distance moved during an epoch are called *epoch time* and *epoch length*, respectively. At the destination, the MR or MH stays stationary for a period of time, called *pause time*, after that a new epoch starts.

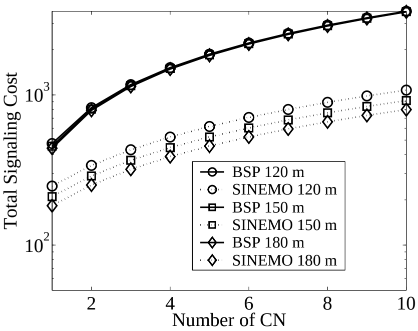

**Figure 5: Signalling cost for BSP and SINEMO vs. number of CN for different epoch lengths.**

Let,
$E(T)$ = expected value of *epoch time.*
$E(P)$ = expected value of MH pause time between movements.
$E(L)$ = expected value of *epoch length.*
$E(C)$ = expected number of subnet crossings per *epoch.*
$v$ = moving speed of MH.

The objective of this section is to find the average residence time for MR and MH ($T_{mr}$ and $T_{mh}$, respectively) in a subnet which can be estimated by the time between two successive movements (*epoch time* plus *pause time*) divided by the number of subnet crossings during this epoch, as shown in Eqn. (15):

$$T_{mr} = T_{mh} = \frac{E(T) + E(P)}{E(C)} \tag{15}$$

Since *epoch length* ($L$) and movement speed ($v$) are independent, we first compute $E(T)$:

$$E(T) = E(L/v) = E(L)E(1/v) \tag{16}$$

Substituting epoch time from Eqs. (16) into Eqn. (15), we can get the expression for $T_{mh}$ and $T_{mr}$ [1].

## 5.2 Results

For numerical calculations, we use the following parameter values used in previous work [8]: $\gamma_l = 30$, $\psi = 0.3$, $S = 10$, $F = 10$kb, $P = 576$b, $\theta = 10$, $l_{rl} = 35$, $l_{mc} = 35$, $\gamma_h = 30$, $\gamma_r = 1.5 \times \gamma_h$, $\lambda_s = 0.01$, $\delta_{LU} = 0.2$, $\delta_{BU} = 0.2$, $\omega = 0.5$, $\tau = 0.5$, $l_{mh} = 35$, $l_{mr} = 35$. Here, we assume the per hop cost for all types of signalling messages to be the same, and 50% of the MHs are servers.

From Random Waypoint Model (Sec. 5.1), we obtain the residence time of MH and MR for different velocity. Fig. 4 illustrates variation of signalling cost with MR velocity (Eq. (16)) for varying number of MHs (Eqns. (6) and (14)). Values used here are $N_{cn} = 1$, $v$ from 10 to 30 m/sec, and $N_{mh} = 40$, 60 and 80. It is seen that the signalling cost increases with velocity because higher velocity results in lower residence time and thus frequent handoffs.

Next, for a constant velocity $v = 10$ m/sec, we vary the average movement length or epoch length (Sec. 5.1) $L = 60$, 120 and 180 m. For the same configuration, if we fix $N_{mh}$ = 80 and vary $N_{cn}$ from 1 to 10 we observe from Fig. 5 that the signalling cost decreases with epoch time because

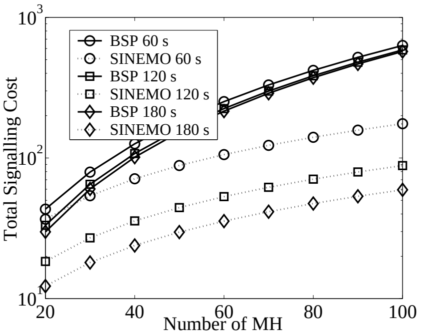

**Figure 6: Signalling cost for NEMO BSP and SINEMO vs. number of MH for different residence time.**

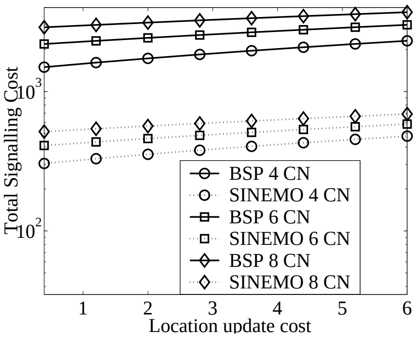

**Figure 7: Signalling cost for BSP and SINEMO vs. number location update cost for different CN.**

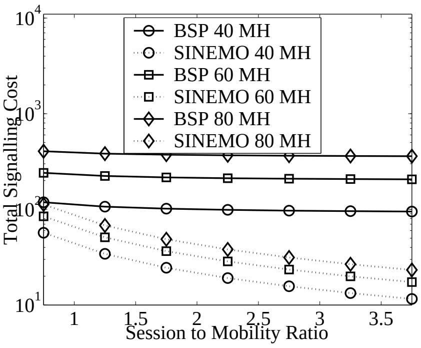

**Figure 8: Signalling cost for BSP and SINEMO vs. session to mobility ratio for different number of MH.**

longer epoch time means higher residence time and thus less frequent handoffs and fewer signalling messages.

Fig. 6 shows the impact of number of MHs for different subnet residence times on total signalling cost of BSP and SINEMO (Eqns. (6) and (14)) for $N_{cn} = 1$, $N_{mh}$ from 20 to 100, and $T_{mh} = T_{mr} = 60$, 120 and 180 sec. Rate of handover increases with smaller residence time, leading to an increase in the signalling cost. We can see that the signalling cost of SINEMO is lower than BSP by up to a factor of three due to the fact that the LLM update does not incur any data transmission cost (Eq. 9).

Next, we examine the impact of total number of CN and per hop transmission costs for location update messages. We fix $T_{mh} = T_{cn} = 60$, $N_{cn} = 4$, 6 and 8, and $N_{mh} = 80$ and vary $\delta_{LU}$ from 0.4 to 6. The effect of number of CN and $\delta_{LU}$ on signalling cost is shown in Fig. 7. Total signalling cost increases with increase of number of CN and increase of location update cost (Eqns. (1), (2), (7), (8)) while the signalling cost for SINEMO remains lower than NEMO BSP by 50% to 75%. This is because SINEMO does not update the CLM for MR handoffs while NEMO BSP needs to update HA-H and HA-M for every handoff.

Session to Mobility Ratio (SMR) is a mobile packet network's counterpart of Call to Mobility Ratio (CMR) in PCS networks. SMR is defined as session arrival rate per mobility ($1/T_{mh}$) or $\lambda_s \times T_{mh}$. 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 $\sigma$.

From Figs. 4 to 8, we see that SINEMO has less signalling cost than NEMO BSP for different velocity, residence time, location update cost, number of MH and CN and mobility. Thus, SINEMO is a better solution than NEMO BSP for network mobility in terms of signalling costs.

## 6. CONCLUSION

Mobile IPv6-based NEMO BSP to support network mobility has the drawback of generating excessive signalling cost. We proposed SINEMO that mitigate this drawback of NEMO BSP by using IP diversity based handover and local location management. In this paper, we developed analytical model for SINEMO and NEMO BSP, and compared the signalling cost of SINEMO and BSP based on the Random Waypoint mobility model. Our analysis shows that signalling cost of SINEMO is only 50% to 75% of the signalling cost of NEMO BSP. Thus, we conclude that, SINEMO, as solution to network mobility, has lower signalling cost than NEMO BSP.

## 7. REFERENCES

[1] C. Bettstetter, H. Hartenstein, and X. Prez-Costa. Stochastic properties of the random waypoint mobility model. *Wireless Networks*, 10(5):555–567, September 2004.

[2] P. K. Chowdhury, M. Atiquzzaman, and W. Ivancic. SINEMO: An IP-diversity based approach for network mobility in space. In *NASA SMC-IT*, pages 109 – 115, Pasadena, CA, July 17-21, 2006.

[3] V. Devarapalli, R. Wakikawa, A. Petrescu, and P. Thubert. Network Mobility (NEMO) basic support protocol. IETF RFC 3963, January 2005.

[4] T. Ernst. Network mobility support goals and requirements. IETF Draft draft-ietf-nemo-requirements-05, October 2005.

[5] H. Kim, G. Kim, and C. Kim. S-RO: Simple route optimization scheme with NEMO transparency. In *ICOIN*, pages 401 – 411, Jeju Island, Korea, Jan 31-Feb 2, 2005.

[6] M. Kim, E. Kim, and K. Chae. A scalable mutual authentication and key distribution mechanism in a NEMO environment. In *ICCSA*, pages 591 – 600, Singapore, May 9 - 12, 2005.

[7] E. Perera, V. Sivaraman, and A. Seneviratne. Survey on network mobility support. *Mobile Computing and Communications Review*, 8(2):7 – 19, April 2004.

[8] A. S. Reaz and M. Atiquzzaman. P-SIGMA: Paging in end to end mobility management. In *IEEE ICC*, Istanbul, Turkey, June 11-15, 2006.

[9] H. Ryu, D. Kim, Y. Cho, K. Lee, and H. Park. Improved handoff scheme for supporting network mobility in nested mobile networks. In *ICCSA*, pages 378 – 387, Singapore, May 9 - 12, 2005.