Scalability Analysis of a Multihomed Network Mobility Protocol

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***Abstract*—Previous studies have analyzed cost and performance of multihomed network mobility management protocols, such as, Seamless IP diversity-based Network Mobility management scheme (SINEMO). However, increase in the number of mobile nodes raises scalability issues which can result in its performance degradation. In this paper, we have developed analytical models for scalability analysis of SINEMO in terms of network size, mobility rate, and traffic rate. We have used numerical results to validate the analytical model and compared scalability with basic Network Mobility (NEMO) protocol. Results show that the network-mobility protocols exhibit asymptotically identical scalability for the network though the mobility agent of SINEMO scales better than NEMO. This scalability model can help in quantitative scalability analysis of other mobility protocols, thereby visualizing the effects of future network expansion on the performance of the mobility protocols.**

***Index Terms*—Mobility Protocols, Scalability analysis, Network Mobility, Mathematical Modeling, Multihoming.**

I. INTRODUCTION

To facilitate continuous Internet connectivity to hosts moving together, Internet Engineering Task Force (IETF) proposed NEtwork MObility (NEMO) basic support protocol [1]. NEMO has a number of limitations including high handover latency, packet loss, and inefficient routing path. To address these drawbacks, we earlier proposed SINEMO [2], a multihoming-based network-mobility management scheme. SINEMO uses multihoming features (i.e., having multiple IP addresses) to reduce packet loss and handover delay.

In a mobile computing environment, a number of *network parameters* (such as, network size, mobility rate, traffic rate) influence the signaling cost required for mobility management. With the proliferation of mobile computing, increasingly larger number of nodes will require support from the *mobility management entities* (e.g., home agent, location manager, mobile router, etc). Thus the expansion of network size incurs additional signaling load on these mobility management entities, resulting in the performance degradation of mobility protocols. Hence, scalability of mobility protocols has become a major issue [3]–[5] for the research community.

A number of researches on scalability analysis of networking protocols can be found in the literature. Santivanez et al. [3] present a novel framework to study the scalability of routing algorithms in ad hoc networks. Similar framework has been used in [4] and [6] for scalability analysis of mobile ad hoc network and wireless sensor network, respectively. A few simulation and testbed-based scalability analysis have also been performed on IP-mobility protocols [5], [7]. However, simulation results represent only a particular scenario being simulated for a given set of system parameters. In contrast, analytical models represent general scenarios which provide better insights into the behavior of the system being analyzed. The authors are not aware of any research work that quantitatively analyzes the scalability of the mobility protocols, which is required to visualize the effects of future network expansion on the performance of the protocols.

The *objective* of this work is to perform quantitative scalability analysis of SINEMO based on signaling overhead. We have performed entity-based scalability analysis for SINEMO since these key mobility entities are subject to resource limitations in a mobility environment.

The *contributions* of this work are: (i) developing a mathematical model to derive the asymptotic cost expressions for mobility management entities of SINEMO, (ii) performing scalability analysis of SINEMO in terms of network size, mobility rate, and traffic rate by comparing it with NEMO, and (iii) validating the results of the developed model through numerical analysis.

Our results show that the network-mobility protocols (NEMO and SINEMO) have asymptotically identical mobility signaling overhead on the network. The numerical validation also support this claim, though some deviations are found between the observed and calculated results.

The rest of the paper is organized as follows. In Section II, a brief description of SINEMO is given, followed by the scalability analysis in Section III. Section IV presents the numerical results. Finally, Section V has the concluding remarks.

II. SINEMO

The architecture of SINEMO [2] is shown in Fig. 1. SINEMO utilizes IP-diversity to achieve a seamless handover of mobile network. It consists of a multi-homed Mobile Router (MR) which can be connected to two wireless networks. MR acts as a gateway between a Mobile Network Node (MNN)

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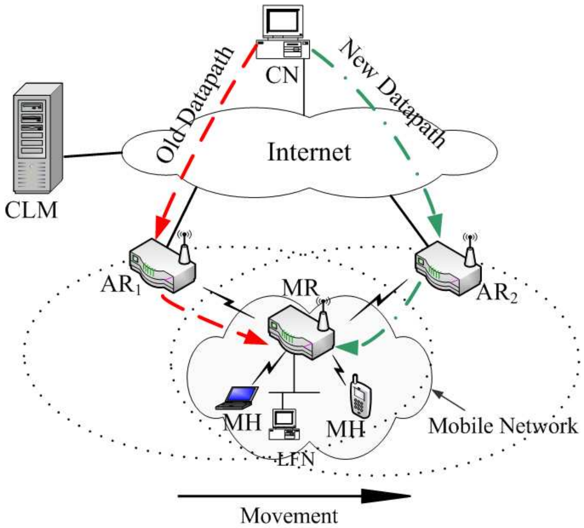

Fig. 1. SINEMO architecture [2].

and the Access Router (AR) for Internet access. There are two types MNNs: Local Fixed Node (LFN) and Mobile Host (MH). Correspondent Node (CN) sends traffic to a MNN. A Central Location Manager (CLM) maintains the IP address of the MR. The MR acts as the local location manager and keeps the IP addresses of the MNNs. When a mobile network moves into one subnet, MR obtains its own public IP address and one or more address prefixes. Thus, MR provides and reserves an IP address for each MNN. The MNNs are not aware of their public IP addresses; they use only the private IP addresses for connectivity. MR thus hides mobility from the hosts.

III. Scalability Analysis

In this section, we perform an entity-wise scalability analysis of SINEMO. We have chosen the CLM and the MR for the entity-wise evaluation since CLM is involved in every session between a CN and a MNN, and all communications with the mobile network are carried out through the MR.

A. Definition

Santivanez et al. [3] present a novel framework to study the scalability of routing algorithms in ad hoc networks. We use this notion of scalability (from [3]) since it is an excellent framework for asymptotic scalability analysis which is also used in [4] and [6]. Mobility protocol's scalability can thus be defined as the ability to support continuous increase of network parameter values without degrading the performance of various network entities that are responsible for mobility management. Examples of such limiting parameters are network size, mobility rate, traffic rate, etc.

Let $\Gamma^X(\lambda_1, \lambda_2, ...)$ be the total overhead induced by mobility protocol X, dependent on parameters λ_1, λ_2, and so on. Therefore, the protocol X's mobility scalability factor with respect to a parameter λ_i is defined as follows:

$$\rho^X_{\lambda_i} = \lim_{\lambda_i \to \infty} \frac{\log \Gamma^X(\lambda_1, \lambda_2, ...)}{\log \lambda_i} \quad (1)$$

Protocol X is said to be more scalable than protocol Y with respect to parameter λ_i if $\rho^X_{\lambda_i} \leq \rho^Y_{\lambda_i}$.

B. Assumptions

Following are the assumptions of the model:

- Session arrival rate for each MNN is equal.
- Each session length is equal.
- Each CN has one ongoing session with a MNN.
- Binary search is used to search location database.

C. Notations

The notations used in this paper are listed below.

N_f	Number of LFNs,
N_m	Number of mobile hosts,
N_c	Number of CNs communicating with all MNNs,
δ_L	Per hop transmission cost for Location Update (LU),
δ_{AL}	Per hop transmission cost for aggregated location update message,
δ_B	Per hop transmission cost for Binding Update (BU),
δ_Q	Per hop transmission cost for query message,
δ_R	Per hop transmission cost for registration message,
δ_{DT}	Per hop transmission cost for each data packet,
δ_{DA}	Per hop transmission cost for each (data) Ack packet,
δ_{RR}	Per hop transmission cost for Return Routability (RR) message,
δ_{DH}	Per hop transmission cost for DHCPv6 message,
σ	Proportionality constant (for transmission cost) of wireless link over wired link,
ψ	Linear coefficient for lookup cost,
γ_l	Unit processing cost at CLM,
T_r	Subnet residence time,
h_p	Average number of hops between Internet to arbitrary CN or CLM or AR,
h_{in}	Average number of hops in the Internet,
λ_s	Average session arrival rate,
κ	Maximum transmission unit,
α	Average session length (data file size).
λ_p	Average packet arrival rate, i.e., $\lambda_p = \lambda_s \times \lceil \frac{\alpha}{\kappa} \rceil$

D. Scalability parameters

For the scalability analysis of SINEMO, we focus on the following network parameters:

- Network size: This will be represented by the number of mobile hosts (N_m) and number of LFNs (N_f).
- Speed of the mobile network (V).
- Traffic rate: This will be represented by the average number of CNs (N_c) and packet arrival rate (λ_p).

Let us first consider the effect of mobility rate on subnet residence time, T_r. The reciprocal of subnet residence time gives the handoff frequency which is typically proportional to the speed (V) of a mobile network. Thus, $T_r \propto (1/V)$.

E. Central Location Manager

In SINEMO, the CLM has the tasks of a) processing query messages from CNs and searching the location database,

b) processing RR messages, c) processing LU messages from MR, and d) processing refreshing BU messages.

- Every CN needs the IP address of the MNN before establishing a session. Hence, CN sends query message to CLM requiring transmission cost. This query request triggers a lookup at CLM which is proportional to the logarithm of the number of MNNs.
- To prevent session hijacking, RR messages are exchanged among the MH, CLM and CN before each BU message. Therefore, transmission cost is incurred at the CLM for sending and forwarding RR messages.
- In every subnet crossing, MR acquires new IP address from the foreign network and notifies CLM using LU message requiring transmission and processing cost.
- Moreover, to prevent the binding entry from expiring, MR sends refreshing BU to the CLM and all the CNs during T_r and the frequency is η_r (= $\lfloor \frac{T_r}{T_e} \rfloor / T_r$), where T_e is the lifetime of each binding entry.

Therefore, the total cost of CLM can be obtained as follows. For details description of these cost expressions, readers are referred to the technical report [8].

$$\begin{aligned}\Gamma_{CLM} &= \Gamma_{CLM}^{QR} + \Gamma_{CLM}^{RR} + \Gamma_{CLM}^{LU} + \Gamma_{CLM}^{RBU} \\ &= 2N_c\delta_Q\lambda_s + N_c\psi\lambda_s \log_2(N_m + N_f) + 4N_c\delta_{RR}/T_r \\ &+ \frac{(\delta_{AL} + \delta_L) + \gamma_l}{T_r} + \eta_r(\delta_{AL} + \delta_L) \\ &= \Theta(VN_c + N_c \log(N_m + N_f))\end{aligned} \tag{2}$$

We have expressed the total cost on CLM using the Θ notation[1]. Therefore, SINEMO's mobility scalability factors for the CLM with respect to N_m, N_f, λ_p, V, and N_c can be computed as follows:

$$\rho_{N_m}^{S(CLM)} = \lim_{N_m \to \infty} \frac{\log(VN_c + N_c \log(N_m + N_f))}{\log N_m} = 0 \tag{3}$$

$$\rho_{N_f}^{S(CLM)} = \lim_{N_f \to \infty} \frac{\log(VN_c + N_c \log(N_m + N_f))}{\log N_f} = 0 \tag{4}$$

$$\rho_{\lambda_p}^{S(CLM)} = \lim_{\lambda_p \to \infty} \frac{\log(VN_c + N_c \log(N_m + N_f))}{\log \lambda_p} = 0 \tag{5}$$

$$\rho_{V}^{S(CLM)} = \lim_{V \to \infty} \frac{\log(VN_c + N_c \log(N_m + N_f))}{\log V} = 1 \tag{6}$$

$$\rho_{N_c}^{S(CLM)} = \lim_{N_c \to \infty} \frac{\log(VN_c + N_c \log(N_m + N_f))}{\log N_c} = 1 \tag{7}$$

F. Mobile Router

In SINEMO, the main tasks of the MR are: a) IP address and prefix acquisition, b) processing RR messages, c) sending LUs to the CLM, d) sending refreshing BU messages, e) processing data (ACK) packets to and from MNNs, and f) sending updates to the CNs. Here, we explain these costs in brief.

- In every handoff, MR acquires IP addresses and prefixes from the AR in the foreign network by exchanging DHCPv6 request-reply messages. MR then reserves public IP addresses for the MNNs and modifies NAT table.
- To prevent session hijacking RR messages are exchanged through MR, thereby incurring transmission cost.
- In each handoff, MR sends LUs to CLM informing newly acquired IP address and prefixes.
- After acquiring the IP address and prefixes in every handoff, the MR uses the newly assigned public addresses (to the MNNs in the NAT table) to modify the session table of size proportional to number of sessions. In addition, MR sends BUs to CNs incurring more transmission cost.
- MR sends refreshing BU to CLM and the CNs with a frequency of η_r.
- In every CN-MNN session, $\lceil \frac{\alpha}{\kappa} \rceil$ data packets are sent along with corresponding ACK. Each data packet arriving from CN is intercepted by MR which modifies the destination address by private IP address searching the NAT table.

Therefore, the total cost on the MR can be obtained as follows:

$$\begin{aligned}&\Gamma_{MR} = \Gamma_{MR}^{Acq} + \Gamma_{MR}^{RR} + \Gamma_{MR}^{BU} + \Gamma_{MR}^{LU} + \Gamma_{MR}^{RBU} + \Gamma_{MR}^{DD} \\ &= \frac{1}{T_r}\Big(2\sigma\delta_{DH} + \psi(N_m + N_f)\log_2(N_m + N_f) \\ &+ 4\sigma(N_m + N_f)\delta_{RR} + N_c \log_2 N_c + 2\sigma\delta_B N_c \\ &+ \sigma(\delta_{AL} + \delta_L)\Big) + \sigma\eta_r(\delta_{AL} + \delta_L)(1 + N_c) \\ &+ \lambda_p N_c\Big(\psi \log_2(N_m + N_f) + \sigma(\delta_{DT} + \delta_{DA})\Big) \\ &= \Theta(V(N_m + N_f) + \lambda_p \log_2(N_m + N_f) + VN_c \log_2 N_c))\end{aligned} \tag{8}$$

Hence, SINEMO's mobility scalability factors for the MR with respect to N_m, N_f, λ_p, V, and N_c are $\rho_{N_m}^{S(MR)} = 1$, $\rho_{N_f}^{S(MR)} = 1$, $\rho_{\lambda_p}^{S(MR)} = 1$, $\rho_{V}^{S(MR)} = 1$ and $\rho_{N_c}^{S(MR)} = 1$.

G. Complete Network

In order to compute the total cost of the network as a whole, we consider all the resources (such as, bandwidth, processing power, etc.) consumed in all network entities. This includes cost incurred for query messages exchanged between CLM and CN, local registration of MHs, RR messages, LU messages, BUs to CNs, and data delivery cost.

- The query-reply messages between CN and CLM are transmitted through h_w (= $h_p + h_{in} + h_p$) wired hops and the lookup at CLM incurs processing cost.
- In every handoff, the MR acquires IP address for the MNNs and reserves public IP addresses for the MNNs and modifies the NAT table whose size is proportional to $(N_m + N_f)$.
- RR messages are exchanged among MH, CN and CLM before sending BU.
- In each handoff, MR sends LUs to the CLM (h_w wired hops and one wireless hop away) to inform the newly acquired IP address and prefixes. Moreover, to ensure session continuity, BUs are sent by the MR to the CNs in each handoff.
- Each MR sends η_r refreshing BUs to CLM and all CNs in every T_r,
- The data and ack packets travel directly through h_w wired and one wireless hops to reach the MR which updates destination address and forward it to MNN

Therefore, total cost on complete network due to SINEMO protocol can be obtained as:

[1]Standard asymptotic notation has been used. A function $f(n) = \Theta(g(n))$ if there exists some positive constants c_1, c_2, and n_0 such that $c_1 g(n) \leq f(n) \leq c_2 g(n)$ for all $n \geq n_o$.

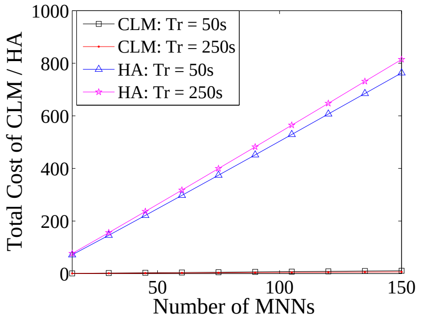

Fig. 2. Impact of Number of MNNs on total cost of SINEMO's CLM and NEMO's HA.

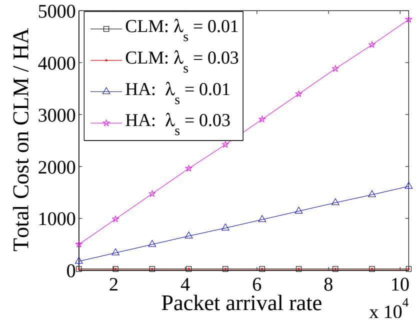

Fig. 3. Impact of packet arrival rate on total cost of SINEMO's CLM and NEMO's HA.

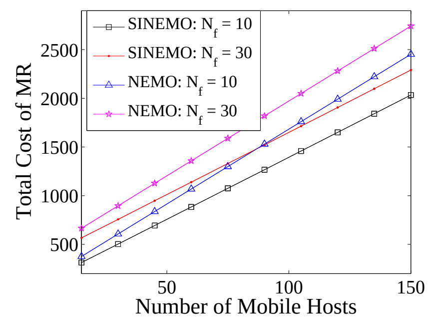

Fig. 4. Total cost of MR vs. number of MHs for different number of LFNs.

TABLE I
ASYMPTOTIC COST EXPRESSIONS FOR SINEMO ENTITIES.

Entity	Asymptotic Cost Expressions
CLM	$\Theta(VN_c + N_c \log(N_m + N_f))$
MR	$\Theta(V(N_m + N_f) + \lambda_p \log_2(N_m + N_f) + VN_c \log_2 N_c))$
Network	$\Theta((\lambda_p N_c + N_m + N_f) \log_2(N_m + N_f) + VN_c \log_2 N_c)$

TABLE II
MOBILITY SCALABILITY FACTORS OF SINEMO AND NEMO.

Protocols	$\rho^X_{N_m}$	$\rho^X_{N_f}$	$\rho^X_{\lambda_p}$	ρ^X_V	$\rho^X_{N_c}$	Entity
SINEMO	0	0	0	1	1	CLM
	1	1	1	1	1	MR
	1	1	1	1	1	Complete Network
NEMO	1	0	1	1	1	HA
	1	1	1	1	1	MR
	1	1	1	1	1	Complete Network

$$
\begin{aligned}
&\Gamma_{Net} = \Gamma^{QR}_{Net} + \Gamma^{NAT}_{Net} + \Gamma^{RR}_{Net} + \Gamma^{LU}_{Net} + \Gamma^{BU}_{Net} + \Gamma^{DD}_{Net} \\
&= 2\lambda_s N_c h_w \delta_Q + \psi \lambda_s N_c \log_2(N_m + N_f) \\
&+ \frac{1}{T_r}\Big(\psi(N_m + N_f)\log_2(N_m + N_f) + 2N_c\delta_{RR}(3h_w + 2\sigma) \\
&+ (\delta_{AL} + \delta_L)(h_w + \sigma) + \gamma_l + 2\delta_B N_c(h_w + \sigma) + N_c \log_2 N_c \\
&+ \eta_r(\sigma + h_w)(\delta_{AL} + \delta_L + 2N_c\delta_B)\Big) \\
&+ \lambda_p\Big(\psi \log_2(N_m + N_f) + (h_w + \sigma)(\delta_{DT} + \delta_{DA})\Big) \\
&= \Theta((\lambda_p N_c + N_m + N_f)\log_2(N_m + N_f) + VN_c \log_2 N_c)
\end{aligned} \tag{9}
$$

Hence, SINEMO's mobility scalability factors for the complete network with respect to N_m, N_f, λ_p, V, and N_c are $\rho^S_{N_m} = 1$, $\rho^S_{N_f} = 1$, $\rho^S_{\lambda_p} = 1$, $\rho^S_V = 1$ and $\rho^S_{N_c} = 1$.

H. Summary of Scalability Analysis

Table I summarizes the asymptotic cost expressions of the mobility management entities of SINEMO. A similar analysis has been done for NEMO in [9]. In Table II, SINEMO and NEMO's computed scalability factors (derived from analytical model) are listed with respect to N_m, N_f, λ_p, V and N_c (Home Agent (HA) for NEMO corresponds to SINEMO's CLM). It is found that the mobility scalability factors of the overall network for these two protocols are identical. However, SINEMO's CLM is found to be scale better than NEMO's HA with respect to N_m and λ_P. This is because SINEMO uses optimal route for data traffic between any MNN and CN, whereas in NEMO, all data traffic are transmitted through the HA.

IV. VALIDATION

In this section, we use numerical analysis to obtain the observed scalability factors for SINEMO and NEMO. The values for the system parameters are consistent with previous works [9], [10]: δ_L = 0.6, δ_{AL} = 1.4, δ_B = 0.6, δ_Q = 0.6, δ_{DH} = 1.4, δ_{RR} = 0.6, δ_{DT} = 5.72, δ_{DA} = 0.60, σ = 10, λ_s = 0.01, γ_t = 10, N_c = 30, h_{in}= 5, h_p= 1, T_r = 70s, T_e = 60s, ψ = 0.3, α = 10Kb, and κ = 576b, N_f = 20, N_m =40.

Fig. 2 shows the impact of number of MNNs on the total cost of CLM and HA for different subnet residence times. The total cost of CLM is much less than that of HA. The cost on HA increases with the increase of MNNs since increased MNNs causes more data traffic to be routed through the HA (in NEMO) which is not the case for CLM (SINEMO). This is also evident from the scalability factors in Table II where SINEMO's scalability factor is 0 with respect to N_m whereas that of NEMO is 1.

In Fig. 3, the total costs of CLM and HA are shown as a function of packet arrival rate (λ_p) for different session arrival rates. Again, we can see that λ_p has no impact on the total cost of CLM whereas the cost of HA increases for higher values of λ_p. This verifies the scalability factors of SINEMO and NEMO with respect to λ_p which are 0 and 1, respectively (see Table II).

Fig. 4 shows the total cost of the MR as a function of number of mobile hosts for different number of LFNs in the mobile network. The cost of MR for both protocols increases with the increase of number of mobile hosts and are linear in nature. This validates the scalability factors for NEMO and SINEMO with respect to N_m which are 1 (see Table III).

Fig. 5 shows the cost of MR as a function of number of CNs for different session lengths. Again, both graphs are linear in nature, thereby validating their computed scalability factors (see Table III). However, cost of MR for NEMO is higher than SINEMO as the latter sends aggregated binding updates to the CLM unlike the former.

In Fig. 6, the total cost of the network are shown for varying number of LFNs with different values of N_c and number of hops in the Internet. It is found that cost of SINEMO does not vary significantly with respect to N_f since N_f only influences the query and NAT translation cost which are very

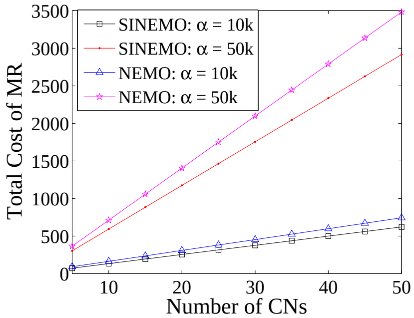

Fig. 5. Total cost of MR vs. number of CNs for different session lengths.

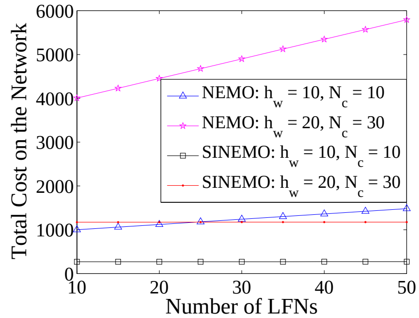

Fig. 6. Total cost of MR vs. number of LFNs for different number of CNs and number of Internet hops.

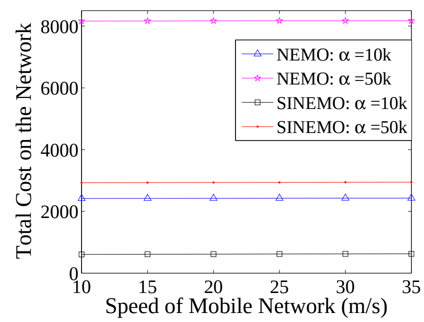

Fig. 7. Total cost of the network vs. speed of mobile network for different session lengths.

small compared to the data delivery cost. This is why we see the deviation between the computed and observed scalability factors of SINEMO with respect to N_f (see Table III).

In Fig. 7, the total cost of the network are shown as a function of speed of mobile network for different session lengths. Here, we find that speed has very little impact on the total cost. Higher speed produces more signaling packets which are insignificant when compared to data packets. That is, data delivery cost dominates over mobility signaling costs. Due to the same reason the calculated scalability factors for NEMO and SINEMO does not match the observed ones (see the columns for ρ_V^X in Table III).

TABLE III
CALCULATED AND OBSERVED MOBILITY SCALABILITY FACTORS

Protocol	$\rho^X_{N_m}$ Cal	$\rho^X_{N_m}$ Ob	$\rho^X_{N_f}$ Cal	$\rho^X_{N_f}$ Ob	$\rho^X_{\lambda_p}$ Cal	$\rho^X_{\lambda_p}$ Ob	ρ^X_V Cal	ρ^X_V Ob	$\rho^X_{N_c}$ Cal	$\rho^X_{N_c}$ Ob	Entity
SINEMO	0	0	0	0	0	0	1	0	1	1	CLM
	1	1	1	1	1	1	1	0	1	1	MR
	1	1	1	0	1	1	1	0	1	1	Net.
NEMO	1	1	0	0	1	1	1	0	1	1	HA
	1	1	0	0	1	1	1	0	1	1	MR
	1	1	1	1	1	1	1	0	1	1	Net.

A. Comparison of scalability factors

In Table III, we list all the calculated scalability factors (obtained from analytical model) and observed scalability factors (obtained from the analysis of graphs) of SINEMO and NEMO. However, we have not been able to present all the graphs due to the page limitation of the paper.

Most of the observed mobility scalability factors match with the calculated values, thus validating the analytical model. However, some of them do not match with the computed ones. One of them is with respect to speed of mobile network (see the columns for ρ_V^X in Table III). As explained earlier in this section, the deviation is due to the dominance of the data delivery cost over mobility signaling cost. The increase of signaling cost is insignificant when compared to the data delivery cost, thereby suppressing the impact of speed. This is an important *lesson learnt* from the numerical analysis. Moreover, from the graphs, it is also evident that costs of SINEMO are much less than that of NEMO.

V. CONCLUSION

In this paper, we have developed a mathematical model for the quantitative scalability analysis of SINEMO, a multihoming-based seamless network-mobility protocol with respect to network size, mobility rate, and traffic rate. We have used numerical results to validate the scalability model. We have also compared the scalability features of SINEMO with its IETF counterpart NEMO. Our results show that the network-mobility protocols exhibit asymptotically identical scalability feature as far as the complete network is concerned though some of the mobility management entities exhibit differences in terms of scalability feature. Our model can thus help in visualizing the effects of future network expansion on the performance of mobility protocols.

REFERENCES

[1] V. Devarapalli, R. Wakikawa, A. Petrescu, and P. Thubert, "NEtwork MObility (NEMO) basic support protocol," RFC 3963, Jan 2005.

[2] P. Chowdhury, M. Atiquzzaman, and W. Ivancic, "SINEMO: An IP-diversity based approach for network mobility in space," in *Second IEEE International Conference on Space Mission Challenges for Information Technology (SMC-IT)*, Pasadena, CA, Jul 17-21, 2006.

[3] C. Santivanez, B. McDonald, I. Stavrakakis, and R. Ramanathan, "On the scalability of Ad hoc routing protocols," in *IEEE INFOCOM*, New York, NY, June 23-27, 2002.

[4] S. J. Philip, J. Ghosh, S. Khedekar, and C. Qiao, "Scalability analysis of location management protocols for Mobile Ad hoc Networks," in *IEEE WCNC*, Atlanta, GA, Mar 21-25, 2004.

[5] Y. Gwon, J. Kempf, and A. Yegin, "Scalabilty and robustness analysis of Mobile IPv6, Fast Mobile IPv6, Hierarchical Mobile IPv6, and hybrid IPv6 mobility protocols using a large-scale simulation," in *IEEE ICC*, Paris, France, Jun 20-24, 2004.

[6] L. K. Alazzawi, A. M. Elkateeb, A. Ramesh, and W. Aljuhar, "Scalability analysis for wireless sensor networks routing protocols," in *22nd International Conference on Advanced Information Networking and Applications*, Okinawa, Japan, Mar 25-28, 2008.

[7] T. Hautala, T. Braysy, J. Makela, J. Lehtomki, and T. Saarinen, "Scalability of mobility signaling in IEEE 802.11 WLAN," in *IEEE Vehicular Technology Conference*, Orlando, FL, Oct 6-9, 2003.

[8] M. S. Hossain and M. Atiquzzaman, "Cost analysis of mobility management entities of SINEMO," University of Oklahoma, Technical report, TR-OU-TNRL-11-101, January 2011, http://cs.ou.edu/∼netlab/.

[9] ——, "Cost and scalability analysis of mobility management entities of NEMO," University of Oklahoma, Technical report, TR-OU-TNRL-11-102, February 2011, http://cs.ou.edu/∼netlab/.

[10] P. Chowdhury, A. Reaz, M. Atiquzzaman, and W. Ivancic, "Performance analysis of SINEMO: Seamless IP-diversity based Network Mobility," in *IEEE ICC 2007*, Glasgow, Scotland, Jun 24-28, 2007.