Asymptotic scalability analysis of mobility protocols based on signalling overhead

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Abstract: Increasing demand for mobility in wireless data networks has given rise to various mobility management protocols. The protocols use signalling messages to maintain reachability of mobile nodes. Increase in the number of mobile nodes gives rise to the scalability issues that need to be dealt with to avoid performance degradation of the network. In this paper, we have developed analytical models to obtain the asymptotic mobility signalling overhead on mobility management entities of two mobility protocols in terms of network size, mobility rate and traffic rate. These asymptotic overhead models have been used to compute mobility scalability factors of the protocols. We have presented numerical parameters to validate the analytical model. Results show that the mobility protocols exhibit asymptotically identical mobility signalling overhead on the network.

Keywords: mobility protocols; scalability analysis; mobility signalling overhead; mathematical modelling.

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1 Introduction

Mobility management protocols are used to facilitate delivery of data packets to hosts and networks that are in motion. IETF proposed Mobile IPv6 (Johnson et al., 2004) and Hierarchical Mobile IPv6 (HMIPv6) (Soliman et al., 2008) to support host-mobility. But these protocols have high handover latency, packet loss, and inefficient routing path, giving rise to deployment issues. To address these drawbacks, Fu and Atiquzzaman (2006) proposed SIGMA, a seamless IP-diversity-based mobility protocol.

In a mobile computing environment, a number of *network parameters* (such as, network size, mobility rate, traffic rate) influence signalling overheads relating arising from mobility protocols. These *mobility signalling overheads* (MSOs) include costs related to updating home agent (HA)/location managers about the change of location, sending updates to hosts with ongoing communication, periodic refreshing updates and processing and lookup costs by various mobility agents. The expansion of network size incurs additional signalling load on various mobility management entities, resulting in the performance degradation of mobility protocols. Hence, scalability of mobility protocols has become a major issue (Gwon et al., 2004; Philip et al., 2004; Santivanez et al., 2002) for the research community. Mobility protocols must be analysed with respect to their scalability to ensure their smooth operation with increased load.

The scalability of a protocol can be defined as its ability to support the continuous increase of its network parameters without degrading the network performance (Santivanez et al., 2002). There has been a number of research works on scalability analysis of networking protocols (see Section 2). But most of the existing scalability analyses have been carried out for ad hoc networks, in addition to a few simulation-based scalability analysis on mobility management protocols. The authors are not aware of any research work that quantitatively analyses the asymptotic scalability of the mobility protocols which is required to visualise the effects of future network expansion on the network. We believe this to be the *first such work*. This work will help in finding out the impact of network parameters on mobility management entities.

The *objective* of this work is to analyse the scalability of two mobility protocols (HMIPv6 and SIGMA) based on mobility signalling overhead on different network entities. We have chosen HMIPv6 in our analysis as it is designed to reduce the signalling cost of the base MIPv6, and it has the lowest signalling cost in all versions of MIPv6 enhancements. We have used the notion of scalability factors (Santivanez et al., 2002) as an asymptotic measure of scalability, and have computed the mobility scalability factors (MSFs) of the protocols. We have validated the analytical results by analysing the pattern of the MSO graphs based on numerical parameters.

The *contributions* of this work are:

1 developing a mathematical model to estimate MSOs on mobility management entities of SIGMA and HMIPv6

2 computing and comparing the asymptotic scalability factors of the protocols in terms of network size, mobility rate and traffic rate

3 validating the calculated asymptotic scalability factors by the observed scalability factors obtained from the graphical analysis.

Our results show that the mobility protocols have asymptotically identical MSO on the network. The graphical validation also support this claim, though some deviations are found between the observed MSF and calculated MSF.

The rest of the paper is organised as follows. Section 2 contains the literature review. In Section 3, a brief description of the mobility protocols is given. In Section 4, analytical models for estimating the MSO on various entities are presented along with the computation of scalability factors of SIGMA and HMIPv6. Section 5 analyses the numerical results and compares the calculated MSFs and observed MSFs. Finally, Section 6 has the concluding remarks.

2 Literature review

A number of researches on scalability analysis of networking protocols can be found in the literature. Santivanez et al. (2002) present a novel framework to study the scalability of routing algorithms in ad hoc networks. Philip et al. use the same framework for the scalability analysis of location management protocols of MANETs. Alazzawi et al. (2008) also use that framework to analyse the effect of several factors on the scalability of wireless sensor network. In our work, we use the notion of scalability factors (from Santivanez et al., 2002) since it is an excellent framework for asymptotic scalability analysis.

Makaya and Pierre (2008) and Fülöp et al. (2008) present performance analysis of IPv6-based mobility protocols. Onwuka et al. (2004) have presented an analytical model showing the benefits of multi-level hierarchy for scalable mobility management. Kwak et al. (2004) derive an upper bound of the diameter of an ad hoc network that guarantees scalability. These works focused on obtaining the optimal hierarchical level for scalable mobile networks. They do not analyse the effect of various system parameters on the performance of the overall network.

Thakkar et al. (2004) analysed the performance and scalability of mobile, base-station-oriented wireless networks using large-scale discrete event simulation with respect to routing and mobility models. Gwon et al. (2004) present an analysis on scalability and robustness of MIPv6, Fast MIPv6, HMIPv6 using a large-scale simulation. Hautala et al. (2003) present a study on the scalability of Mobile IPv6 in a wireless LAN laboratory test bed where multiple users handover simultaneously. All of these works lack mathematical modelling for scalability analysis. 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 behaviour of the system being analysed.

3 Mobility protocols

Here, we give a brief description of two mobility protocols: SIGMA and HMIPv6.

3.1 SIGMA

SIGMA [proposed by Fu and Atiquzzaman (2006)] utilises IP-diversity to achieve a seamless handover of a MOBILE HOST (MH), and is designed to solve the drawbacks of Mobile IP. The architecture of SIGMA is shown in Figure 1. The location manager (LM) is responsible for keeping location database of mobile hosts. Whenever any correspondent node (CN) wants to send data to a MH, it must first send a query message to the LM to obtain its current IP address. Hence, every MH must send its new IP address in a network it has moved to the LM; these are termed as Location Updates. Moreover, every subnet crossing triggers binding updates; after handover each MH needs to send a binding update to every CN it is communicating with.

Figure 1 SIGMA architecture (see online version for colours)

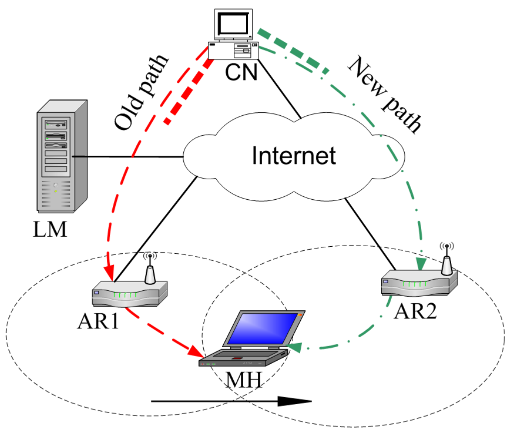
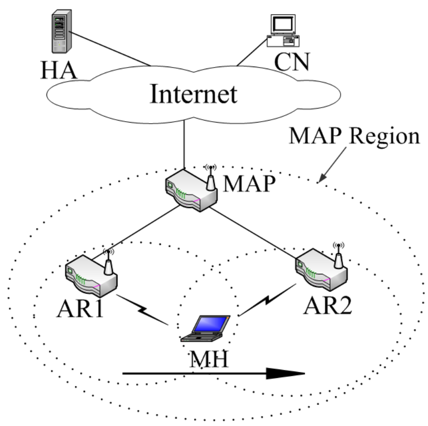


Figure 2 HMIPv6 architecture (see online version for colours)



3.2 Hierarchical mobile IPv6

Enhancement to MIPv6 has resulted in HMIPv6 (Soliman et al., 2008) where a new network element, called mobility anchor point (MAP), is used to introduce hierarchy in mobility management (see Figure 2). A MAP, essentially a local HA, covers several subnets under its domain, called a region. An MH entering a MAP domain receives Router Advertisements containing information on one or more local MAPs. The MH updates HA with an address assigned by the MAP, called regional care-of-address, as its current location. The MAP intercepts all packets sent to the MH, encapsulates and forwards them to the MH's current address.

4 Scalability analysis

In this section, we analyse the scalability of two mobility protocols: SIGMA and HMIPv6. First, we define the *scalability* in Section 4.1. The assumptions and notations are listed in Sections 4.2 and 4.3. Next, we estimate MSO on various entities of SIGMA and HMIPv6 in Sections 4.4 and 4.5, respectively.

4.1 Definition of scalability

Mobility protocol's scalability can be defined as the ability to support continuous increase of limiting network parameters without degrading the performance of various network entities that are responsible for mobility management. This definition is similar to that by Santivanez et al. (2002). Let $\Gamma^X(\lambda_1,\ \lambda_2,\ \ldots)$ be the total overhead induced by mobility protocol X, dependent on parameters $\lambda_1,\ \lambda_2,\ \ldots$(such as, network size, mobility rate, traffic rate, etc). So the protocol X's MSF with respect to a parameter λ_i is defined to be:

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

Protocol X is said to be more scalable than protocol Y with respect to parameter λ_i if $\rho^X_{\lambda_i} \leq \rho^Y_{\lambda_i}$. For the asymptotic scalability analysis, we focus on the following three network parameters:

- network size, represented by the number of MHs (N_m)
- speed of MHs, (V)
- traffic rate, represented by average number of CNs (N_c) with which a MH is communicating.

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 node. Thus, we find that $T_r \propto (1/V)$.

4.2 Assumptions

Following are the assumptions of the model:

- all mobile hosts are identical and uniform

- uniform distribution of mobile hosts over the region of the network
- session arrival rate for each mobile host is equal
- the data (file) size in each session is equal
- refreshing binding updates are considered having light weight compared to location updates during handoff
- similar mobility model, network topology are assumed for the two protocols.

4.3 Notations

The notations to be used in this paper are listed as follows.

4.3.1 Notations that apply to both protocols

N_m number of mobile hosts

N_c average number of CNs with which a MH is communicating

δ_L per hop transmission cost for location update message

δ_B per hop transmission cost for binding update message

σ proportionality constant of signalling cost over wired and wireless link

η weighing factor for refreshing binding updates

l_{mc} average number of hops between MH and CN

ψ linear coefficient for lookup cost

T_r subnet residence time

T_L binding lifetime

λ_s average session arrival rate

S number of sessions.

4.3.2 Notations that apply only to SIGMA

l_{ml} average number of hops between MH and LM

γ_l processing cost at LM.

4.3.3 Notations that apply only to HMIPv6

l_{mh} average distance between MAP and HA (in hops)

l_{mm} average distance between MH and MAP (in hops)

γ_h processing cost for each location update at HA

γ_m processing cost for each location update at MAP

m number of access routers in a row

n number of access routers a column

R number of subnets under a MAP

τ encapsulation cost

P maximum transmission unit

F session length (filesize).

4.4 SIGMA

Here, the MSFs of various entities of SIGMA: LM, MH and the complete network are computed after deriving expressions of MSO on each of them.

4.4.1 Location manager

In SIGMA, every subnet crossing (that happens every T_r seconds) by an MH, triggers a location update message to be sent to LM. In addition, periodic binding refresh messages are sent so that binding entry is not expired while MH is within the subnet. Moreover, the location database lookup involves processing at LM. The MSO on LM is thus

$$\begin{aligned}\Gamma_{LM}^{S} &= N_m \frac{2\delta_L + \gamma_l}{T_r} + N_m^2 N_c \frac{\psi \lambda_s}{S} + 2N_m \left\lfloor \frac{T_r}{T_L} \right\rfloor \eta \delta_L \\ &= \frac{\Delta_1 N_m}{T_r} + \Delta_2 N_m^2 N_c + \Delta_3 N_m\end{aligned} \tag{2}$$

where, $\Delta_1 = 2\delta_L + \gamma_l$, $\Delta_2 = \frac{\psi \lambda_s}{S}$, $\Delta_3 = 2\left\lfloor \frac{T_r}{T_L} \right\rfloor \eta \delta_L$. Δ_1, Δ_2 and Δ_3 are constants as far as scalability analysis is concerned. Since $T_r \propto (1/V)$, we find:

$$\Gamma_{LM}^{S} = \Theta(N_m V + N_m^2 N_c) \tag{3}$$

Now, SIGMA's MSFs for LM with respect to N_m, V, and N_c are:

$$\rho_{N_m}^{S(LM)} = \lim_{N_m \to \infty} \frac{\log(N_m V + N_m^2 N_c)}{\log N_m} = 2 \tag{4}$$

$$\rho_{V}^{S(LM)} = \lim_{V \to \infty} \frac{\log(N_m V + N_m^2 N_c)}{\log V} = 1 \tag{5}$$

$$\rho_{N_c}^{S(LM)} = \lim_{N_c \to \infty} \frac{\log(N_m V + N_m^2 N_c)}{\log N_c} = 1 \tag{6}$$

4.4.2 Mobile host

Every MH in SIGMA is required to send location update to LM and binding updates and refreshing binding updates to CNs after each subnet crossing. Thus, the MSO on each MH is:

$$\Gamma_{MH}^{S} = \frac{2\sigma\delta_L}{T_r} + N_c \frac{2\sigma\delta_B}{T_r} + 2\sigma N_c \left\lfloor \frac{T_r}{T_L} \right\rfloor \eta \delta_L = \Theta(V + N_c V) \tag{7}$$

SIGMA's MSF for each MH with respect to N_m, V, and N_c are thus:

$$\rho_{N_m}^{S(MH)} = \lim_{N_m \to \infty} \frac{\log(V + N_c V)}{\log N_m} = 0 \tag{8}$$

$$\rho_{V}^{S(MH)} = \lim_{V \to \infty} \frac{\log(V + N_c V)}{\log V} = 1 \tag{9}$$

$$\rho_{N_c}^{S(MH)} = \lim_{N_c \to \infty} \frac{\log(V + N_c V)}{\log N_c} = 1 \tag{10}$$

4.4.3 Complete network

The total cost on the network has four components: location update cost, binding update cost, lookup cost (Fu and Atiquzzaman, 2005), and refreshing binding update cost (Makaya and Pierre, 2008).

$$\begin{aligned}\Gamma^S = {} & N_m \frac{2(l_{ml} - 1 + \sigma)\delta_L + \gamma_l}{T_r} + N_m N_c \frac{2(l_{mc} - 1 + \sigma)\delta_B}{T_r} \\ & + N_m^2 N_c \frac{\psi \lambda_s}{S} + N_m \left\lfloor \frac{T_r}{T_L} \right\rfloor 2(l_{ml} - 1 + \sigma)\eta\delta_L \\ & + N_m N_c \left\lfloor \frac{T_r}{T_L} \right\rfloor 2(l_{mc} - 1 + \sigma)\eta\delta_L \\ = {} & \Theta(N_m N_c V + N_m^2 N_c)\end{aligned} \tag{11}$$

Therefore, SIGMA's MSFs with respect to N_m, V, and N_c are 2, 1, and 1, respectively.

4.5 HMIPv6

We now derive the MSO expressions for the MAP, HA, MH and the complete network for HMIPv6 and compute corresponding MSF.

4.5.1 Mobility anchor point

As total MHs in the foreign network is N_m, the fraction of mobile hosts under an MAP is ωN_m, where $\omega = \frac{R}{mn}$. In HMIPv6, an MH only registers with MAP as long as it is within MAP domain. So every subnet crossing within a MAP triggers a registration message to the MAP. In addition, for every packet sent from CN to MH, processing costs (for location database lookup, decapsulation, and encapsulation) is incurred at the MAP. Moreover, refreshing binding updates are sent periodically. Thus, the signalling overhead on MAP is:

$$\begin{aligned}\Gamma_{MAP}^H &= \omega N_m \left(\frac{2\delta_L + \gamma_m}{T_r} + N_c \lambda_s \frac{F}{P} (\psi \omega N_m + 2\tau) + 2N_c \left\lfloor \frac{T_r}{T_L} \right\rfloor \eta \delta_L \right) \\ &= \Theta(N_m V + N_m^2 N_c)\end{aligned} \tag{12}$$

HMIPv6's MSFs for MAP with respect to N_m, V, and N_c are thus 2, 1 and 1, respectively.

4.5.2 Home agent

For every region crossing between MAPs (happens every MT_r seconds, MH needs to register with HA. In addition, for every packet sent from CN to MH, processing cost (location database lookup and encapsulation) is incurred at the HA. Thus the mobility signalling overhead on the HA is:

$$\begin{aligned}\Gamma_{HA}^{H} &= N_m \frac{2\delta_L + \gamma_h}{MT_r} + N_m N_c \lambda_s \frac{F}{P}\left(\psi N_m + \tau\right) + 2N_m \left\lfloor \frac{MT_r}{T_L} \right\rfloor \eta \delta_L \\ &= \Theta(N_m V + N_m^2 N_c)\end{aligned} \tag{13}$$

HMIPv6's MSFs for HA with respect to N_m, V, and N_c are therefore 2, 1, and 1, respectively.

4.5.3 Mobile host

Every subnet crossing by the MH, either within MAP or between MAPs, leads to location update message to be sent to MAP or HA, respectively. Moreover, periodic binding refresh messages are sent to the CNs. Therefore, the MSO on each MH is:

$$\Gamma_{MH}^{H} = \frac{2\sigma\delta_L}{T_r} + \frac{2\sigma\delta_L}{MT_r} + 2\sigma N_c \left\lfloor \frac{T_r}{T_L} \right\rfloor \eta \delta_L = \Theta(V + N_c) \tag{14}$$

So HMIPv6's MSFs for each MH with respect to N_m, V, and N_c are 0, 1 and 1.

4.5.4 Complete network

Finally, the MSO on the complete network in HMIPv6 are composed of location update, lookup cost (Fu and Atiquzzaman, 2005), and refreshing binding update cost (Makaya and Pierre, 2008).

$$\begin{aligned}\Gamma^{H} =\ & N_m \Bigg(\frac{2(l_{mm} - 1 + \sigma)\delta_L + \gamma_m}{T_r} \\ & + \frac{2(l_{mm} + l_{mh} - 1 + \sigma)\delta_L + \gamma_h + 2\gamma_m}{(M+1)T_r} \Bigg) \\ & + N_m N_c \lambda_s \frac{F}{P}\left(\psi N_m \frac{mn + R}{mn} + 3\tau\right) + N_m \left\lfloor \frac{T_r}{T_L} \right\rfloor 2(l_{mm} - 1 + \sigma)\eta\delta_L \\ & + N_m \left\lfloor \frac{MT_r}{T_L} \right\rfloor 2(l_{mm} + l_{mh} - 1 + \sigma)\eta\delta_L \\ & + N_m N_c \left\lfloor \frac{T_r}{T_L} \right\rfloor 2(l_{mc} - 1 + \sigma)\eta\delta_L \\ =\ & \Theta(N_m V + N_m^2 N_c)\end{aligned} \tag{15}$$

Therefore, HMIPv6's MSFs for the complete network with respect to N_m, V, and N_c are 2, 1 and 1, respectively.

4.6 Summary of scalability analysis

Table 1 summarises the MSOs of SIGMA and HMIPv6 for different mobility management entities. In Table 1, SIGMA and HMIPv6's MSFs are listed with respect to N_m, V and N_c. It is found that the MSFs of the overall network for these two host-mobility protocols are identical (2, 1 and 1, respectively) which means these two mobility management schemes exhibit identical signalling overhead on the network. Similar result is obtained for the LM of SIGMA, and for MAP and HA of HMIPv6. Each mobile host in HMIPv6 scales better than that of SIGMA with respect to N_c.

Table 1 MSOs and MSFs of SIGMA and HMIPv6

Protocols	*Entity*	*MSO*	$\rho^X_{N_m}$	ρ^X_V	$\rho^X_{N_c}$
SIGMA	LM	$\Theta(N_m V + N_m^2 N_c)$	2	1	1
	MH	$\Theta(V + N_c V)$	0	1	1
	Complete Net.	$\Theta(N_m N_c V + N_m^2 N_c)$	2	1	1
HMIPv6	MAP	$\Theta(N_m V + N_m^2 N_c)$	2	1	1
	HA	$\Theta(N_m V + N_m^2 N_c)$	2	1	1
	MH	$\Theta(V + N_c)$	0	1	1
	Complete Net.	$\Theta(N_m V + N_m^2 N_c)$	2	1	1

These analytical values for scalability will help researchers to visualise the effect of future expansion of network size on the performance of these protocols, and to identify and improve entities that do not scale well.

5 Validation by graph analysis

In this section, we use numerical results to obtain the graphical pattern of the MSOs of the two mobility protocols. The values for the system parameters have been taken from the previous works (Fu and Atiquzzaman, 2005; Reaz et al., 2006): δ_L = δ_B = 0.2, σ = 10, λ_s = 0.01, γ_l = γ_h = γ_m = 30, γ_r= 45, N_c = 1, l_{ml} = l_{mc} = l_{mh} = 35, l_{mm} = 2, T_r = 70s, T_L = 180 s, η = 0.5 τ= 0.5, ψ = 0.3, S =10, m = 10, n = 10, R = 10, F = 10 Kb and P = 576 b.

5.1 MSO on mobility agents

In Figure 3, the MSO on the mobility agents are shown as a function of number of MHs. The MSO curve for HA of HMIPv6 is found to be quadratic in nature whereas other two show linear relation with N_m. The reason behind this deviation is that the MSOs of LM (SIGMA) and MAP (HMIPv6) have a lookup cost component proportional to N_m^2 with a very small weighing factor as lookup table inside the computer requires much less time than sending location update packet over the network.

In Figure 4, the MSO on the LM of SIGMA, MAP and HA of HMIPv6 are shown for varying speed of MH. Here, the mobility signalling overheads shows a linear relation with the mobility rate (speed) though the rate of change in the MSO of MAP is very small due to small number of MHs under its domain.

Figure 3 Number of MHs vs. MSO on mobility agents (see online version for colours)

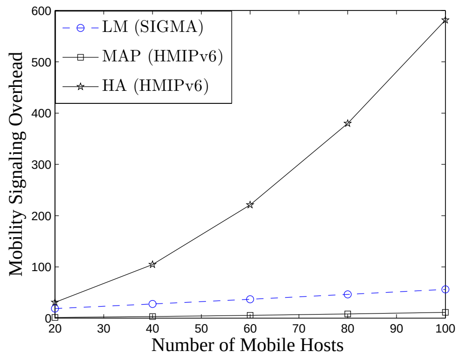


Figure 4 Speed of MH vs. MSO on mobility agents (see online version for colours)

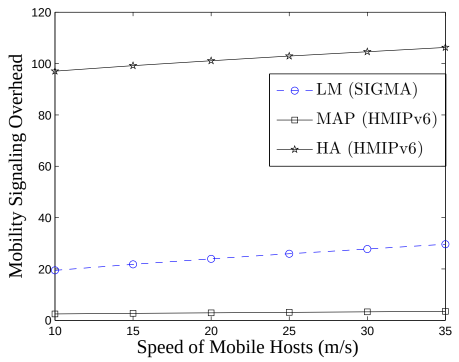
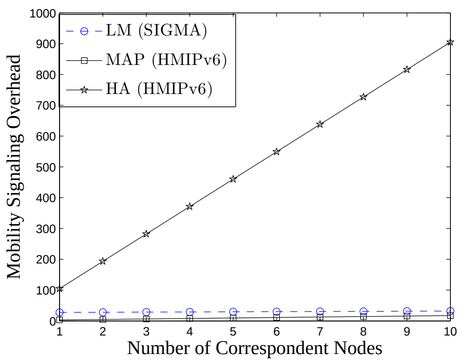


Figure 5 Number of CNs vs. MSO of mobility agents (see online version for colours)



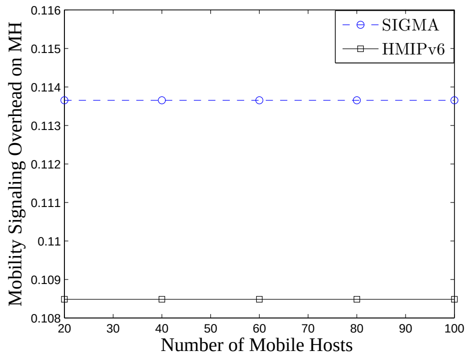
In Figure 5, the MSO on the LM of SIGMA, MAP and HA of HMIPv6 are shown for varying number of CNs. Here, the MSO shows a linear relation with N_c for HA and MAP of HMIPv6, but the MSO remains almost constant for LM of SIGMA since the lookup term (which is realted to N_c) is very small compared to the other term in the

MSO expression. Thus although the calculated MSF of SIGMA's LM (with respect to N_c) is 1 (see Table 1), no relation has been found in Figure 5 between their MSO and N_c, i.e., Observed MSF is zero.

5.2 MSO on each Mobile Host

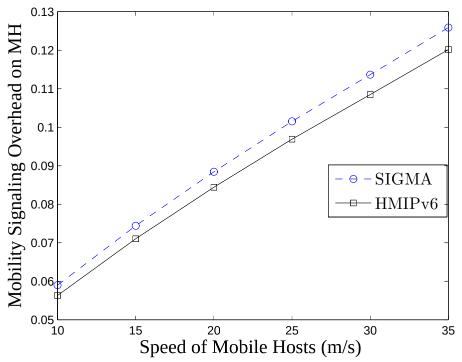
In Figure 6, the MSO on each MH of SIGMA and HMIPv6 are shown as a function of number of MHs. Both of them are invariant of N_m. Hence their observed MSFs are zero with respect to N_m, which are also the calculated MSFs.

Figure 6 Number of MHs vs. MSO on each MH (see online version for colours)



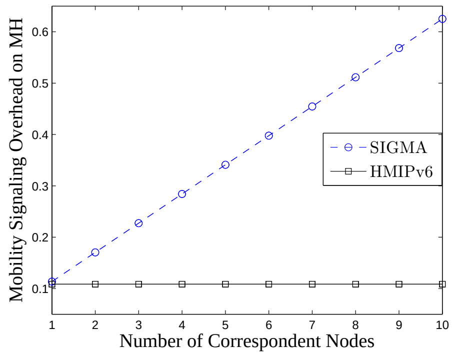
In Figure 7, the MSO on each MH of SIGMA and HMIPv6 are shown for varying speed of MH. Both of them have a linear relationship with V. Hence, their observed MSFs are 1 with respect to V, which are also the calculated MSFs.

Figure 7 Speed vs. MSO on each MH (see online version for colours)



In Figure 8, the MSO on the MH of SIGMA and HMIPv6 are shown for varying number of CNs. Among them, the MSO graph for each MH of SIGMA is linearly related to N_c; whereas that of HMIPv6 invariant of N_c which is different from the calculated MSF (1). This is because the binding lifetime and subnet residence time that we have considered are 70 sec and 180 sec, respectively and the ratio of these two ($\lfloor \frac{T_r}{T_L} \rfloor$) produces zero binding refresh cost. Thus it becomes independent of N_c.

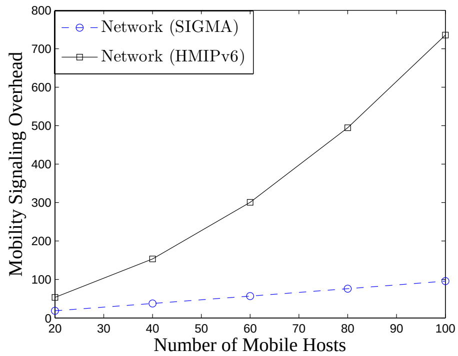
Figure 8 Number of CNs vs. MSO on each MH (see online version for colours)



5.3 *MSO on complete network*

In Figure 9, the MSO on the complete network of SIGMA, and HMIPv6 are shown as a function of number of MHs. Among them, the MSO graph of HMIPv6 is found to be quadratic in nature, which matches the calculated MSF in Table 1. But the MSO graph of SIGMA shows a linear relationship with N_m. Again, this is due to the very small lookup cost, making it negligible when compared to location update and binding update cost.

Figure 9 Number of MHs vs. MSO on the network (see online version for colours)



In Figure 10, the MSO on the complete network of SIGMA and HMIPv6 are shown for varying speed of MHs. Both of them are linear in nature which matches the calculated MSFs in Table 1.

In Figure 11, the MSO on the complete network of SIGMA and HMIPv6 are shown for varying number of CNs. Both of them are linear in nature (with different slope) which matches the calculated MSFs in Table 1.

Figure 10 Speed of MHs vs. MSO on the network (see online version for colours)

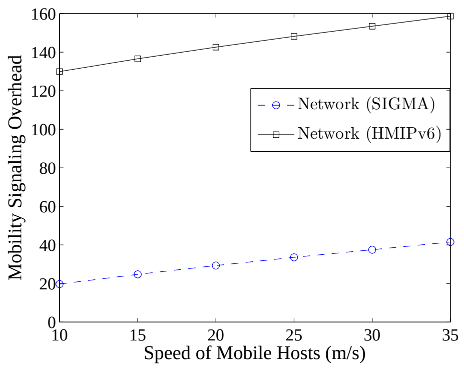


Figure 11 Number of CNs vs. MSO on the network (see online version for colours)

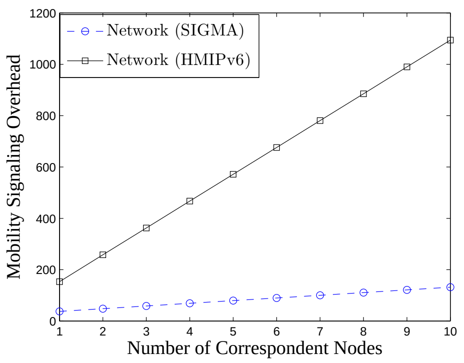


Table 2 Calculated and observed MSFs for SIGMA and HMIPv6

Protocols	$\rho^X_{N_m}$		ρ^X_V		$\rho^X_{N_c}$		*Entity*
	Cal	*Obs*	*Cal*	*Obs*	*Cal*	*Obs*	
SIGMA	*2*	*1*	1	1	*1*	*0*	LM
	0	0	1	1	1	1	MH
	2	*1*	1	1	1	1	Complete net.
HMIPv6	*2*	*1*	1	1	1	1	MAP
	2	2	1	1	1	1	HA
	0	0	1	1	1	0	MH
	2	2	1	1	1	1	Complete net.

5.4 *Comparison between observed and calculated MSFs*

In Table 2, we list the calculated MSFs (obtained from analytical model) and observed MSFs (obtained from the analysis of MSO graphs) of the two mobility protocols. Most of the observed MSFs match with the calculated values, thus validating the analytical model. The observed MSFs that do not match with the calculated MSFs are shown as highlighted entries in Table 2. The reason behind these deviations are mainly due to the fact that the MSO has a lookup cost proportional to N_{mh}^2 with a very small weighing factor as the searching time for table lookup is much faster than sending location update packet over the network. Moreover, from the graphs, it is also evident that mobility signalling overhead of SIGMA are much less than that of HMIPv6.

6 Conclusions

In this paper, we have developed a mathematical model to determine the MSOs on various mobility entities of two host-mobility protocols in terms of network size, mobility rate, and traffic rate. The asymptotic load expressions of the model have been used to compute the mobility scalability factors of the mobility protocols. We have used numerical parameters to generate graphs for mobility signalling overload, and have obtained the observed mobility scalability factors analysing the pattern of the graphs. These observed MSFs have been used to validate the analytical model. Our results show that the mobility protocols exhibit asymptotically identical scalability when the complete network is considered though some of the mobility entities exhibit differences in terms of scalability. Our model thus can help in visualising the effects of future network expansion on the performance of mobility protocols.

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