A Network-based Seamless Handover Scheme for Multi-homed Devices

Md. Shohrab Hossain and Mohammed Atiqzzaman
School of Computer Science, University of Oklahoma, Norman, OK 73019
Email: {shohrab, atiq}@ou.edu

***Abstract*—Terminal-based mobility protocols require mobile devices to participate in mobility signaling that consumes lots of processing power and memory. Network-based mobility protocol solves this problem by excluding low-end mobile devices from signaling requirement. We earlier proposed SEMO6, a terminal-based mobility protocol which exploits multiple network interfaces to achieve seamless handover. In this paper, we have proposed a network-based mobility solution for SEMO6. We have performed a thorough cost analysis of its major mobility entities that participate in mobility management and also obtained their efficiency based on signaling overhead. Results show interesting relationships among various network parameters. Our signaling analysis can be used by network engineers to estimate the resource requirements of its entities in actual deployment.**

***Index Terms*—Mobility management, Proxy Mobile IPv6, multihoming, seamless handover.**

I. INTRODUCTION

Proliferation in mobile computing has drawn significant attention of the research community and Mobile IPv6 (MIPv6) [1] was standardized to facilitate Internet connectivity to mobile devices. However, as a host-based mobility solution, Mobile IPv6 requires low-end mobile devices to perform all mobility related signaling to maintain connectivity. Therefore, Internet Engineering Task Force (IETF) proposed Proxy Mobile IPv6 (PMIPv6) [2], a Network-based Localized Mobility Management (NetLMM) solution which provides Internet connectivity to low power mobile devices without requiring them to get involved in mobility signaling.

With the convergence of next generation wireless access technologies, such as 802.11, WiMAX, GPRS, 3G, etc, mobile devices are now getting equipped with multiple network interfaces that can facilitate increased availability, fault tolerance. This capability of communicating through multiple network interfaces is sometimes termed as *multihoming*. Though PMIPv6 supports multihoming, it has not been specified clearly how to achieve seamless handover in multihoming scenario.

Multi-homed mobile devices can maintain seamless connectivity with multiple wireless access networks, thereby benefitting the ongoing sessions with its peers. We, therefore, proposed SEamless MObility using Shim6 (SEMO6) [3], [4], a network-layer based solution that provides seamless connectivity to multi-homed mobile devices. However, SEMO6 is a terminal-based protocol and it requires involvement of the low-power mobile devices for mobility management.

A few works on PMIPv6 and related protocols have been reported in the literature. Iapichino et al. [5] propose a multi-homing solution combining Host Identity Protocol with PMIPv6. Lee et al. [6] compares HMIPv6 and PMIPv6. Kim et al. [7] performed handover analysis of PMIPv6. Iapichino et al. [8] performed experimental evaluation of PMIPv6. However, none of the exiting works [6]–[8] exploited the multihoming feature of mobile devices to improve the performance of PMIPv6. Although there exists a few entity-wise cost evaluation of mobility protocols [9], [10] in the literature, no such evaluation for PMIPv6 has been attempted. Such an entity-wise evaluation is very crucial as mobility management entities are very resource restricted and overloading of these entities may result in complete outage for the whole system.

Our *objective* of this work is to propose a network-based mobility architecture that ensures seamless handover of mobile devices through its multihoming feature. We have proposed a novel mobility architecture combining the idea of PMIPv6 and SEMO6 [4] and named it *Proxy-SEMO6* that exploits make-before-break strategy to achieve seamless handover in localized mobility domain. In addition, we have performed entity-wise cost evaluation of the proposed scheme.

The *contributions* of this work are: (i) proposing a network-based seamless mobility solution for SEMO6, (ii) developing an analytical model to perform signaling analysis of its key entities, and presenting numerical results.

Our results show the impact of various network parameters on the total overhead and performance of the mobility management entities of Proxy-SEMO6. Our proposed scheme can guide design engineers to improve the handoff performance of network-based mobility protocols that have received significant attention with the convergence of next generation all-IP networks.

The rest of the paper is organized as follows. Section II explains basic SEMO6 [3] architecture in brief. In Section III, the proposed Proxy-SEMO6 architecture is explained along with its protocol operation and timing diagram. Section IV presents a cost analysis of all the entities of Proxy-SEMO6, followed by the numerical results in Section V. Finally, we conclude the paper in Section VI.

II. SEMO6 ARCHITECTURE

To achieve seamless handover of multihomed mobile devices, we earlier proposed SEMO6 [3], a terminal-based

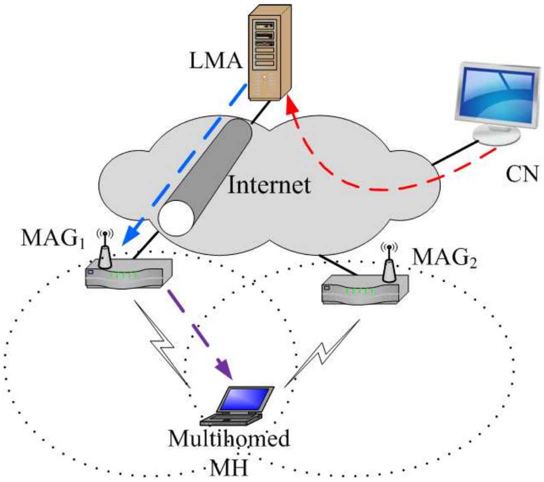

Fig. 1. Proxy-SEMO6 architecture.

mobility solution in network layer. SEMO6 is based on Shim6 [11] and it decouples upper layer session identifier from locator, thereby tries to reduce the impact of mobility on upper layer protocols, e.g., transport and application layers. SEMO6 focuses on providing a single platform for mobility and multihoming. Moreover, it exploits multi-homing feature of Mobile Host (MH) to minimize handover latency which is a very crucial factor for any handover protocol. However, as a terminal-based mobility solution, the MH is responsible for all the mobility-related signaling in SEMO6; thus, it consumes significant amount of power – a major concern for any mobile device. Therefore, it is essential to design a network-based mobility solution that relieves MH from mobility related signaling in addition to achieving seamless handover for multi-homed mobile devices.

III. PROXY-SEMO6 ARCHITECTURE

Fig. 1 shows the Proxy-SEMO6 architecture which is similar to Proxy MIPv6. The main difference is the support of seamless mobility for the multi-homed MH. Location Mobility Anchor (LMA) keeps track of the MH in the localized mobility domain and all traffic destined to the MH from any Correspondent Node (CN) are routed through the LMA. The Mobility Anchor Gateway (MAG), usually the access router of the MH, performs all mobility related signaling on behalf of the MH, thereby saving MH's resources. In our proposed scheme, we assumed that LMA will allocate separate binding cache entry per interface of the MH.

A. Timing diagram

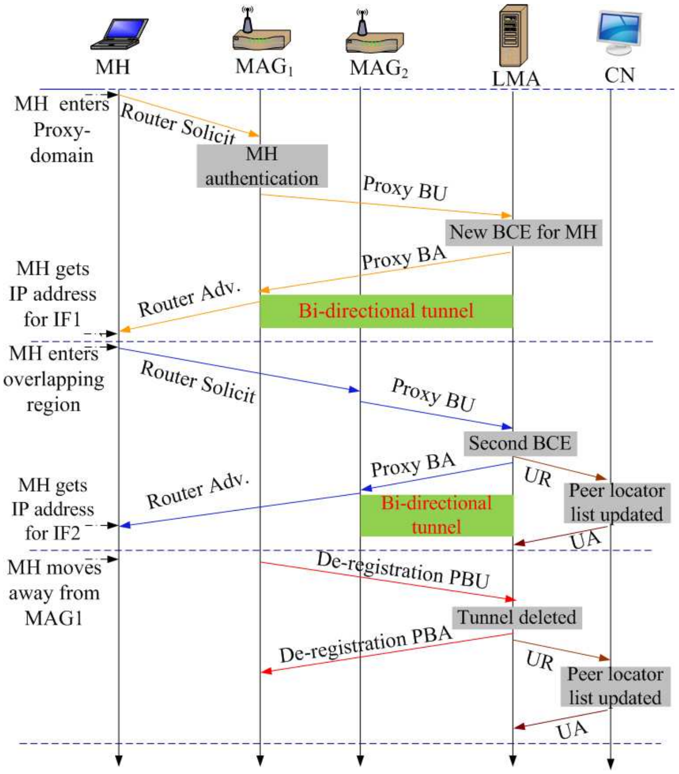

Fig. 2. Timing diagram of Proxy-SEMO6 signaling.

The timing diagram for the proposed Proxy-SEMO signaling is shown in Fig. 2. When any multihomed MH enters the Proxy-SEMO6 domain, it attempts to attach to the access network (L2 attachment) through one of its interfaces (e.g., IF$_1$) and sends router solicitation to the access router (e.g., MAG$_1$). Upon receiving the solicitation, the MAG uses MH's identification (e.g., MAC address) to determine whether the MH is authorized to use the localized mobility support. The MAG then registers the MH's one interface (IF$_1$) with the LMA through Proxy Binding Update (PBU) which associates MAG$_1$'s address with MH's IF$_1$. The LMA adds a Binding Cache Entry (BCE) into its table and establishes a bi-directional tunnel with the MAG$_1$ if one does not already exist. The LMA also sends Proxy Binding Acknowledgement (PBA) to the MAG$_1$ along with the assigned prefix. Upon receiving the PBA, the MAG$_1$ sends the MH Router Advertisement (that includes the allocated prefix), allowing MH to configure its IF$_1$ address through stateless auto-configuration.

When the MH moves in a region that is covered by two access networks, it attempts to acquire another IP address from the MAG$_2$ for its second interface (IF$_2$) in a similar way mentioned above (see Fig. 2). Thus, when the LMA receives the PBU from the MAG$_2$, the LMA inserts another BCE into its table corresponding to the MH's IF$_2$ and establishes similar bi-directional tunnel with the MAG$_2$. In addition, the LMA sends MH's CN a SEMO6 Update Request (UR) message to add this new IP address into CN's peer locator list.

Thus, during the handoff, when the MH moves away from the MAG$_1$ link, the (L2 detachment) event is detected by the MAG$_1$ (for example, through IPv6 neighbor unreachability detection event). The MAG$_1$ then informs the LMA about this event through the deregistration PBU which results in possible tunnel deletion (if not needed for any other MH). At this point, the LMA sends CN UR message so that CN can modify its peer locator list by removing the MH's unreachable IP address. The CN can still continue the session using the unique ULID (through the other locator corresponding to IF$_2$), thereby reducing handoff latency and packet loss.

B. *Proxy-SEMO6 vs. PMIPv6*

Proxy-SEMO6 attempts to reduce handover latency of PMIPv6 by exploiting the following strategies:

- Proxy-SEMO6 exploits the make-before-break strategy, that is, attempts to connect through new MAG before disconnecting with the old MAG.
- It decouples the upper layer session identifier from the location-based IP address, thereby ensuring session continuity, even though the MH's IP address varies due to the change of attachment point.

However, Proxy-SEMO6 reduces handover latency of PMIPv6 at the cost of some additional signaling (e.g., sending UR message to CN by the LMA).

IV. SIGNALING COST ANALYSIS

In this section, we perform entity-wise cost analysis of Proxy-SEMO6.

A. *Assumptions and Notations*

To make the model analytically tractable, the following assumptions have been made:

- Session arrival at each MH is equal.
- All session lengths are of equal size.
- Searching an entry in binding cache is assumed to use binary search.
- Our cost analysis ignores standard IP switching costs.

The notations used in the analysis are listed below.

N_m	Number of MHs in the LMA-domain,
N_c	Average number of CNs per MH,
m	Number of MAGs in the LMA-domain,
β_M	Unit transmission cost for message type M = {PBU, PBA, UR, UA, ... }
σ	Proportionality constant of wireless link over wired link,
ω	Linear coefficient for lookup cost,
T_r	Subnet residence time,
λ_s	Average session arrival rate,
κ	Maximum transmission unit,
α	Average session size,
δ_X	Processing cost at entity X.

B. *Local Mobility Anchor*

In Proxy-SEMO6, the major costs for LMA are 1) initial registration cost, 2) binding update cost, 3) context establishment cost, 4) CN update cost, and 5) data delivery cost.

1) Initial registration cost: We assume that ϵ fraction of MHs enters into the LMA-domain from outside at a rate of θ_d. Thus, a total of $\epsilon N_m \theta_d$ MHs enters into the LMA-domain per second. When a MH enters the LMA-domain, the MAG tracks it and sends PBU to the LMA. The LMA processes the PBU, allocates prefix for the MH, updates the binding cache and sends back PBA to the MAG. This incurs transmission costs (β_{PBU} and β_{PBA}) and processing cost (δ_{LMA}) on the LMA. Thus, the cost incurred at the LMA is,

$$\Lambda^{Reg}_{LMA} = \epsilon N_m \theta_d \big(\beta_{PBU} + \beta_{PBA} + \delta_{LMA}\big) \tag{1}$$

2) Binding update cost: When the MH moves within the LMA-domain and crosses subnets (in every T_r seconds), the concerned (new) MAG detects it and sends the PBU to the LMA. In addition, MAGs send periodic refreshing updates to the LMA for extending the binding lifetime so that the entries are not removed from the cache. Let the binding lifetime be T_l. Hence, frequency of sending periodic refreshing updates are $\eta_r = \lfloor \frac{T_r}{T_l} \rfloor / T_r$, and total frequency of sending LU and refreshing PBU is $\eta_t = \Big(1 + \lfloor \frac{T_r}{T_l} \rfloor\Big)/T_r$, This incurs transmission cost (β_{PBU} and β_{PBA}) and lookup cost ($\omega \log_2 N_m$) at the LMA. Hence,

$$\Lambda^{PBU}_{LMA} = \eta_t N_m \big(\beta_{PBU} + \beta_{PBA} + \omega \log_2 N_m\big) \tag{2}$$

3) Context establishment cost: The LMA establishes Shim6 context with the MH so that LMA can subsequently send update to CN about the locator change (when MH moves to a new MAG-region). During the context establishment phase, the LMA is informed about the ULID, locator list and current locator used by the MH. Thus, it incurs transmission cost for Shim6 Context (β_{SC}) and processing by the LMA. Hence,

$$\Lambda^{SC}_{LMA} = \lambda_s N_m \big(2\beta_{SC} + \delta_{LMA}\big) \tag{3}$$

4) CN update cost: In order to modify the CN's peer locator list, LMA sends UR message to CN whenever any new binding entry is inserted corresponding to MH's second interface. Furthermore, when MAG sends deregistration message to the LMA, the LMA deletes corresponding binding entry and informs CN through UR message. Thus, the cost on LMA regarding UR message is as follows:

$$\Lambda^{UR}_{LMA} = \frac{N_m N_c}{T_r} \big(\beta_{UR} + \beta_{UA}\big) \tag{4}$$

5) Data delivery cost: In a session between the CN and MH, an average of $\lceil \frac{\alpha}{\kappa} \rceil$ data packets (and corresponding ACK) are transmitted. The total data packet arrival rate to the LMA is $\lambda_p = N_m N_c \lambda_s \lceil \frac{\alpha}{\kappa} \rceil$. Data packets received by the LMA are tunneled through the respective MAG to the destination MH. This incurs transmission cost for data and Ack packet (β_{DP} and β_{DA}) including extra IP-header (β_{IP}), and lookup cost. Therefore, data delivery cost for the LMA is given by,

$$\Lambda^{DD}_{LMA} = \lambda_p \big(\beta_{DP} + \beta_{DA} + \beta_{IP} + \omega \log_2 N_m\big) \tag{5}$$

6) Total Cost on LMA: Thus, the total cost on the LMA can be obtained by adding Eqns. (1), (2), (3), (4) and (5):

$$\Lambda_{LMA} = \Lambda^{Reg}_{LMA} + \Lambda^{PBU}_{LMA} + \Lambda^{UR}_{LMA} + \Lambda^{SC}_{LMA} + \Lambda^{DD}_{LMA} \tag{6}$$

C. *Mobility Anchor Gateway*

The major costs for each MAG are 1) MH authentication cost, 2) binding update cost, and 3) data delivery cost.

1) MH authentication cost: For every registration request from an incoming MH, the MAG is responsible for authentication. Based on the credentials (AAA information) of the MH, the MAG either accepts or rejects the registration request. As a total of $\epsilon N_m \theta_d$ MHs enters into the LMA-domain per second and if there are m MAGs in the LMA-domain, therefore each MAG processes $\epsilon N_m \theta_d / m$ authentication requests. Hence,

$$\Lambda^{AAA}_{MAG} = \frac{\epsilon N_m \theta_d}{m} \times \delta_{MAG} \tag{7}$$

2) Binding update cost: Assuming MHs are uniformly distributed in the LMA-domain, each MAG sends PBU and refreshing PBU messages (receives corresponding PBA) on behalf of N_m/m MHs. Moreover, the MAG has to detect the movement of the MH inside its domain in to sense its arrival or departure, thereby requiring processing cost at MAG (δ_{MAG}). Hence, cost incurred at each MAG for binding updates can be obtained as follows:

$$\Lambda_{MAG}^{PBU} = \frac{\eta_t N_m}{m}\big(\beta_{PBU} + \beta_{PBA} + \delta_{MAG}\big) \tag{8}$$

3) Data delivery cost: Each MAG receives data packets tunneled from the LMA and decapsulate them and sends them to the corresponding MH. So the data delivery cost at each MAG is given by,

$$\Lambda_{MAG}^{DD} = \frac{N_m N_c}{m}\left\lceil\frac{\alpha}{\kappa}\right\rceil \lambda_s\big(\beta_{DP} + \beta_{DA} + \beta_{IP}\big) \tag{9}$$

4) Total Cost on MAG: Thus, the total cost on each MAG can be obtained by adding Eqns. (7), (8) and (9):

$$\Lambda_{MAG} = \Lambda_{MAG}^{AAA} + \Lambda_{MAG}^{PBU} + \Lambda_{MAG}^{DD} \tag{10}$$

D. Mobile Host

As a network-based mobility solution, Proxy-SEMO6 incurs least cost at the MH. As all the encapsulation and decapsulation are performed by the MAG (for the packets to and from the MH), the wireless access network is not affected by the extra IP headers. Other than packet delivery, the only task a MH is required to do is to establish Shim6 context with the LMA after registers with the LMA-domain. Thus, the total cost for each MH is as follows:

$$\Lambda_{MH} = \sigma N_c \left\lceil\frac{\alpha}{\kappa}\right\rceil \lambda_s\big(\beta_{DP} + \beta_{DA}\big) + 2\lambda_s\beta_{SC} \tag{11}$$

E. Efficiency

We define a new metric called *efficiency* to measure the performance of Proxy-SEMO6. It is defined as the ratio of net data delivery cost (excluding all overheads) to the total cost (that includes signaling and data delivery costs).

The net data delivery cost of LMA can be expressed as follows:

$$\Lambda_{LMA}^{Net-DD} = \lambda_p\big(\beta_{DP} + \beta_{DA}\big) \tag{12}$$

Hence, the efficiency of LMA is given by,

$$\xi_{LMA} = \frac{\Lambda_{LMA}^{Net-DD}}{\Lambda_{LMA}} \tag{13}$$

The net data delivery cost of MAG can be expressed as follows:

$$\Lambda_{MAG}^{Net-DD} = \frac{N_m N_c}{m}\left\lceil\frac{\alpha}{\kappa}\right\rceil \lambda_s\big(\beta_{DP} + \beta_{DA}\big) \tag{14}$$

Hence, the efficiency of MAG is given by,

$$\xi_{MAG} = \frac{\Lambda_{MAG}^{Net-DD}}{\Lambda_{MAG}} \tag{15}$$

The net data delivery cost of the MH can be expressed as follows:

$$\Lambda_{MH}^{Net-DD} = \sigma N_c \left\lceil\frac{\alpha}{\kappa}\right\rceil \lambda_s\big(\beta_{DP} + \beta_{DA}\big) \tag{16}$$

Hence, the efficiency of MH is given by,

$$\xi_{MH} = \frac{\Lambda_{MH}^{Net-DD}}{\Lambda_{MH}} \tag{17}$$

V. NUMERICAL RESULTS

In this section, we present numerical results showing impact of various system parameters on Proxy-SEMO6 entities. The parameter values used in numerical analysis are derived using similar approaches used in [9], [10]; each cost metric is a relative quantity and is based on the specific packet size (unit cost for 100 bytes [9]). For example, β_{PBU} = 0.76, since the size of PBU packet is 76. Therefore, we have set the parameters as follows: β_{PBA} = 0.76, β_{IP} = 0.40, β_{DP} = 5.72, β_{DA} = 0.60, $\epsilon = 20\%, \theta_d = 0.10$, σ = 10, η = 0.3, η = 0.3, λ_s = 0.01, δ_{LMA} = 0.3, δ_{MAG} = 0.3, κ = 512 bit/sec, α = 10240 bits. The default values of other parameters are m = 10, T_r = 70 sec, N_m = 4000, N_c = 1. It can be noted that while computing the total overhead of the LMA and MAG, we have considered all the factors considered including tunneling overhead, except payload delivery cost.

A. LMA

Fig. 3 shows the impact of Session to Mobility Ratio (SMR) on the total overhead of LMA for different number of MHs in the LMA-domain. SMR is the product of subnet residence time (T_r) and session arrival rate (λ_s). We kept λ_s = 0.01 (fixed) while varying T_r value. Again higher number of MHs under the LMA-domain increases the data delivery overhead on the LMA, resulting in higher overhead on the LMA. However, with respect to SMR, the total overhead on LMA decreases very slowly. This is due to the fact that higher SMR (less mobility rate) causes reduction in PBU cost, which is very small compared to the data tunneling overhead. Hence the graphs are almost flat in nature. This is an interesting finding phenomena obtained from our analysis.

Fig. 4 shows the impact of number of CNs (per MH) on the total overhead of LMA. Total overhead increases for both increased number of CNs and higher session arrival rates. Higher session arrival affects data tunneling overhead since more data packets are required to be tunneled through LMA.

Fig. 5 shows the impact of SMR on the efficiency of LMA. We find that efficiency increases for higher session lengths, having more payload traffic compared to mobility signaling traffic. In addition, the efficiency of LMA increases slowly with the increase of SMR since higher SMR (less mobility) causes reduced signaling traffic for the LMA. However, efficiency falls a little bit when the value of T_r is 120 sec (SMR = 1.2) and again in SMR = 2.4 due to rise in signaling traffic caused by refreshing updates.

B. MAG

Fig. 6 shows the impact of subnet residence times on the total overhead of each MAG, for different number of MHs in the PMIPv6-domain. The total overhead on each MAG decreases for higher values of T_r, producing less PBUs. However, there are some additional refreshing PBU sent to the LMA by the MAG, to keep the binding entry valid and those refreshing PBUs causes the overhead on MAG to rise in 120 sec and then 240 sec, which are multiple of binding entry lifetime.

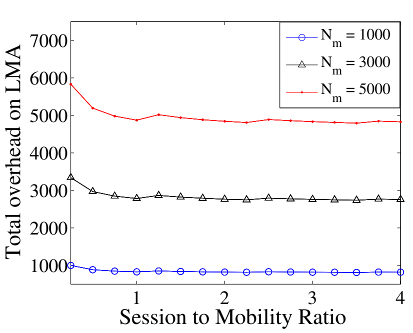

Fig. 3. Impact of SMR on the total overhead of LMA for different number of MHs.

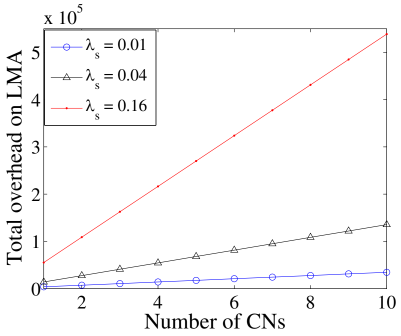

Fig. 4. Impact of number of CNs on total cost of LMA for different session arrival rates.

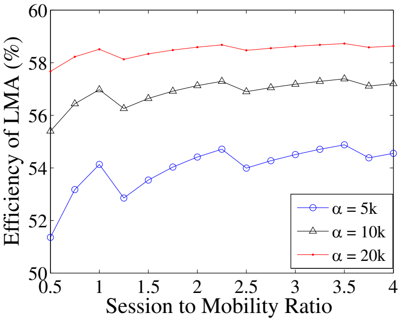

Fig. 5. Impact of SMR on the efficiency of LMA for different session lengths.

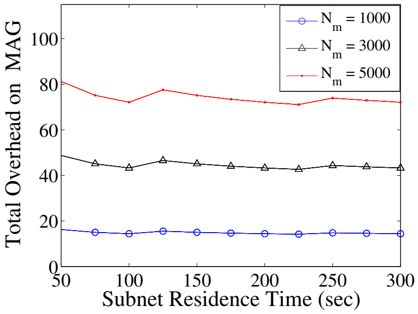

Fig. 6. Impact of subnet residence times on total overhead of each MAG for different number of MHs in the PMIPv6-domain.

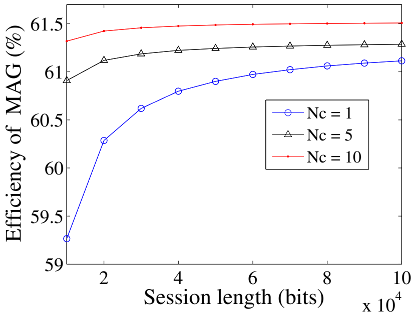

Fig. 7. Impact of session lengths on the efficiency of each MAG for different number of CNs.

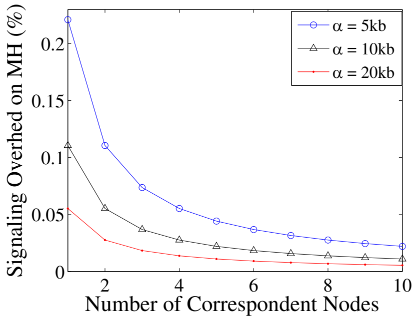

Fig. 8. Signaling overhead on the MH vs. number of CNs.

Fig. 7 shows the impact of session lengths on the efficiency of each MAG. Efficiency increases for larger sessions as net data delivery through the MAG increases. In addition, higher number of CNs also results in more data traffic to the CNs, resulting in improved efficiency.

C. MH

The percentage of signaling overhead on each MH is shown in Fig. 8. The only signaling responsibility of MH (other than data transmission cost) is to establish Shim6 context with the LMA after its registration with it. Results show that the overhead is very small ($< 0.25\%$) for the MH; the higher the session length is, the lower the percentage overhead is, having more payload traffic compared to signaling traffic.

VI. CONCLUSION

In this paper, we have proposed a novel seamless mobility solution for network-based mobility management that requires least involvement of the low-power mobile devices. We have developed analytical model to derive the total overhead on the mobility management entities of the proposed scheme. Results show interesting relationships among various network parameters, such as, network size, mobility rate, traffic rate. Our proposed scheme can guide design engineers to improve the handoff performance of network-based mobility protocols that have received significant attention with the convergence of next generation all-IP networks.

REFERENCES

[1] C. Perkins, D. Johnson, and J. Arkko, “Mobility support in IPv6,” IETF RFC 6275, Jul 2011.

[2] S. Gundavelli and K. L. et al., “Proxy Mobile IPv6,” IETF RFC 5213, August 2008.

[3] M. S. Rahman and M. Atiquzzaman, “SEMO6 - A multihoming-based seamless mobility management framework,” in *IEEE MILCOM*, San Diego, CA, Nov 17-19, 2008.

[4] M. S. Rahman, M. Atiquzzaman, W. Ivancic, and W. Eddy, “Performance Comparison between MIPv6 and SEMO6,” in *IEEE GLOBECOM*, Miami, FL, Dec 6-10, 2010.

[5] G. Iapichino and C. Bonnet, “Host identity protocol and proxy mobile IPv6: A secure global and localized mobility management scheme for multihomed mobile nodes,” in *IEEE GLOBECOM*, Honolulu, HI, Nov 30- Dec 4, 2009.

[6] J.-H. Lee, Y.-H. Han, S. Gundavelli, and T.-M. Chung, “A comparative performance analysis on Hierarchical Mobile IPv6 and Proxy Mobile IPv6,” *Journal of Telecommunication Systems*, vol. 41, no. 4, pp. 279–292, Aug. 2009.

[7] M. S. Kim, S. K. Lee, D. Cypher, and N. Golmie, “Fast handover latency analysis in Proxy Mobile IPv6,” in *IEEE Global Telecommunications Conference*, Miami, FL, Dec 6-10 2010.

[8] G. Iapichino and C. Bonnet, “Experimental evaluation of Proxy Mobile IPv6: An implementation perspective,” in *IEEE WCNC*, Sydney, Australia, April 18-21 2010.

[9] A. Shahriar, M. S. Hossain, and M. Atiquzzaman, “A cost analysis framework for NEMO prefix delegation-based schemes,” *IEEE Transactions on Mobile Computing*, vol. 11, no. 2, pp. 1192–1206, Jul 2012.

[10] M. S. Hossain, M. Atiquzzaman, and W. Ivancic, “Cost analysis of mobility management entities of SINEMO,” in *IEEE ICC*, Kyoto, Japan, Jun 5-9, 2011.

[11] E. Nordmark and M. Bagnulo, “Shim6: Level 3 multihoming shim protocol for IPv6,” IETF RFC 5533, Jun 2009.