Cost Analysis of NEMO Protocol Entities

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Abstract

To support IP-mobility of networks in motion, IETF proposed Network Mobility (NEMO) protocol that uses various signaling messages to ensure connectivity of the mobile nodes with the Internet and to maintain security of ongoing sessions by protecting the binding updates. As the next-generation wireless / mobile network is supposed to be a unified network based on all-IP technology, compounded by the fact that the number of mobile nodes requiring mobility support has increased significantly, the cost analysis of mobility protocols and the underlying mobility management entities have become essential to avoid their performance degradation. However, there has been no comprehensive cost analysis of mobility protocol entities that considers all possible costs. In this paper, we have developed analytical models to estimate total costs of key mobility management entities of NEMO. We have presented numerical results to demonstrate the impact of network size, mobility rate, traffic rate and data volume on these costs. Our results show that a significant amount of resources (bandwidth, processing power, transmission power) are required by the mobility entities for transmission, processing of various signaling messages, as well as searching location database. Our cost analysis will thus help network engineers in estimating actual resource requirements for the key entities of the network in future design while optimizing network performance.

Index Terms

NEMO, mathematical modeling, cost analysis, mobility management entities, computer networks.

I. Introduction

To ensure continuous Internet connectivity of networks in motion, IETF proposed NEtwork MObility Basic Support Protocol (NEMO BSP) [1] which is an extension of IETF host-mobility protocol, Mobile IPv6 [2]. NEMO BSP requires different mobility agents to exchange various signaling messages to maintain continuous connectivity and security of ongoing sessions between mobile nodes and Internet nodes.

In a mobile computing environment, a number of *network parameters* (such as, network size, mobility rate, traffic rate) influence the cost arising from mobility protocols. These cost include costs related to query messages, updating Home Agents about the change of location of the mobile entity, sending updates to hosts with ongoing communication, and processing and lookup costs by various mobility agents. As the next-generation wireless/mobile network will be a unified network based on all-IP technology, and the number of mobile nodes requiring mobility support has increased significantly, the cost analysis of mobility protocols as well as the underlying *mobility management entities* (e.g., home agents, mobile router, etc.) have become essential to avoid performance degradation of the mobility protocol.

There has been earlier attempts for signaling cost analysis ([3]–[6]) of mobility protocols. Xie et al. [3] performed cost analysis of Mobile IP to minimize the signaling cost while introducing a novel regional location management scheme. Fu et al. [4] analyzed the signaling costs of SIGMA [7] and HMIPv6. Makaya et al. [6] presented an analytical model for the performance and cost analysis of IPv6-based mobility protocols. Reaz et al. [5] performed the signaling cost analysis of SINEMO [8]. However, these analysis did not consider all possible costs (e.g. costs for sending query message by CN, securing location updates, obtaining IP address by MH, etc.) and they did not compute the signaling costs on various mobility entities.

The main *differences* of this work are that we have considered all possible costs required for mobility management and have computed total costs on various mobility management entities of NEMO. *The authors are not aware of any such work.*

The *objective* of this work is to analyze the total cost (including data delivery cost) of various mobility entities of NEMO basic protocol and figure out how those costs are affected by various network parameters, such as network size, mobility rate, traffic rate, and data volume.

The *contributions* of this work are: (i) developing mathematical models to estimate total costs of various mobility management entities of NEMO: home agent for mobile router, home agent for mobile host, mobile router, and complete network and (ii) analyzing the impact of network size, mobility rate, traffic rate, and data volume on these costs.

The analytical cost model developed in this paper covers all possible costs required for mobility management and will help in estimating the actual resources (bandwidth, processing power, transmission power) required by key entities of the network in order to maintain continuous connectivity with remote Internet hosts and securing the ongoing session.

The rest of the paper is organized as follows. In Section II, NEMO architecture and BSP are briefly explained. In Section III, analytical cost models of various entities of NEMO are presented. Section IV analyzes the results. Finally, Section V has the concluding remarks.

II. Network Mobility

In this section, we explain briefly NEMO architecture and NEMO BSP. This will aid in understanding the cost analysis of NEMO in Section III.

A. NEMO Architecture

Fig. 1 shows the architecture of a Mobile Network (MN). Mobile Router (MR) act as gateways for the nodes inside the MN, each of the nodes are called a Mobile Network Node (MNN). Different types of MNNs are: Local Fixed Nodes (LFN) that do not move with respect to MN, Local Mobile Nodes (LMN) that usually reside in MN and can move to other networks, and Visiting Mobile Nodes (VMN) that get attached to the MN from another network. LMNs and VMNs are MIPv6 capable, and we refer them as *mobile nodes*. The MR attaches to the Internet through Access Routers (ARs). An MN is usually connected to a network called the home network where an MR is registered with a router called the Home Agent (HA). The HA is notified the location of the MR, and re-directs packets, sent by the Correspondent Node (CN) to MNNs.

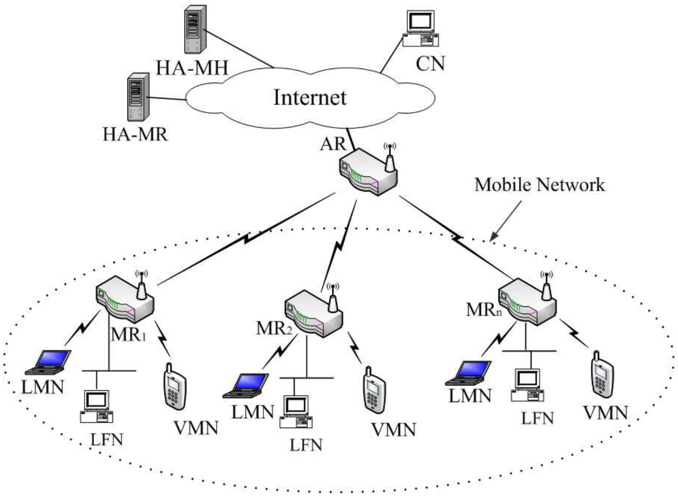


Fig. 1. NEMO Architecture

B. NEMO BSP

In NEMO BSP [1], the MR ensures connectivity of all hosts inside the MN when the MR changes its point of attachment to the Internet while moving from a home network to a foreign network. An MR has its unique IP address and one or more MN Prefixes (MNP) that it advertises to the hosts attached to it. MR establishes a bidirectional tunnel with the HA of Mobile Hosts (HA-MH) to pass all the traffic between its MHs and the CNs. When MR changes its point of attachment, it acquires a new care-of-address from the visited foreign network. It then sends a Binding Update (BU) to its HA which creates a cache entry, binding MRs home address with its care-of-address, and creates a bidirectional tunnel between HA and MR. When a CN sends a packet to a host, the packet is routed to the HA of the corresponding MR (HA-MR). HA-MR looks at its cache entry and forwards the packet to the MR using the bidirectional tunnel. Finally, MR receives the packet, decapsulates it, and forwards it to the host inside the MN.

III. Cost Analysis

We compute below the mobility management cost on NEMO's key entities, such as, Home Agent for Mobile Router (HA-MR), Home Agent for Mobile Host (HA-MH), Mobile Router (MR) and the complete network.

A. Notations

The notations that are used the cost analysis are listed below.

N_r Number of mobile routers in the mobile network,

N_f Number of LFNs in the mobile network,

N_l Number of LMNs in the mobile network,

N_v Number of VMNs in the mobile network,

N_{mnn} Total MNNs in the mobile network, that is, $N_{mnn} = N_f + N_l + N_v$,

N_m	Total mobile nodes in the mobile network, that is, $N_m = N_l + N_v$,
N_c	Average number of CNs communicating with the nodes inside the mobile network,
δ_L	Per hop transmission cost for Location Update (LU) message,
δ_B	Per hop transmission cost for Binding Update (BU) message,
δ_Q	Per hop transmission cost for query 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,
δ_{TH}	Transmission cost for extra IP header used in tunneling,
γ_t	processing cost for tunneled packet,
γ_r	processing cost at MR,
σ	Proportionality constant (for transmission cost) of wireless link over wired link,
ψ	Linear coefficient for lookup cost,
T_r	Subnet residence time,
λ_s	Average session arrival rate,
h_p	average number of hops between Internet to arbitrary CN, HA or AR,
h_{in}	average number of hops in the Internet,
ω_l	Ratio of number of LMNs to the total MNNs in the MN,
ω_f	Ratio of number of LFNs to the total MNNs in the MN,
ω_v	Ratio of number of VMNs to the total MNNs in the MN,,
κ	Maximum transmission unit,
α	Average session size.

B. *Assumptions*

Following are the assumptions of the model:

- All the MRs have the same HA which is HA-MR.
- HA-MR is the HA for LFNs and LMNs of the mobile network under consideration.
- HA-MH has been considered to be HA of all the VMNs of the mobile network under consideration. That is, HA-MH serves as the location manager of N_f mobile hosts.
- Session arrival rate for each mobile host is equal.
- The data (file) size in each session is equal.
- Each CN has, on the average, one ongoing session with a MNN.
- Binary search is used to search location database.

C. HA-MR

In NEMO, the HA-MR keeps the location database of the mobile network. In fact, the location information of MR, LFNs and LMNs are kept in the HA-MR whereas that of VMNs are kept in corresponding HAs since they belong to some other networks. The main tasks of HA-MR are processing 1) query messages from CNs, 2) LU messages from MRs, 3) RR test messages, 4) BU messages to CNs, and 5) data delivery cost.

1) Query message: The fraction of CNs that communicate with either with a LMN or a LFN are $(\omega_l + \omega_f)N_c$. These CNs send query message to the HA-MR at the beginning of every session. This requires a lookup at the HA-MR which is proportional to the logarithm of the number of entries in the lookup table. As the HA-MR contains location information for all the MRs, LFNs and LMNs (see the assumption above), the lookup cost at HA-MR is $\Psi^{LK}_{HA-MR} = \psi \log_2(N_r + N_f + N_l)$. In addition, transmission cost is incurred for query-reply messages at the HA-MR. Hence, the cost relating to query messages at HA-MR are given by the following equation:

$$\Lambda^{QR}_{HA-MR} = (\omega_l + \omega_f)N_c\lambda_s\Big[2\delta_Q + \Psi^{LK}_{HA-MR}\Big] \tag{1}$$

2) Location update messages: When the mobile network crosses subnets, MR sends LU message to the HA-MR and the location database is modified by the HA-MR which sends back acknowledgement to LU message. This happens in every T_r seconds. In addition, MRs and mobile nodes send periodic refreshing updates to the HA-MR so that the entries are not removed from the the location database after the binding lifetime. Let the lifetime of the entries in the location database be T_e. Therefore, $\lfloor \frac{T_r}{T_e} \rfloor$ refreshing updates will be sent to HA-MR within the time T_r. Thus, the frequency of sending periodic refreshing updates are $\eta_r = \lfloor \frac{T_r}{T_e} \rfloor / T_r$, and total frequency of sending LU and refreshing LU is $\eta_t = \Big(1 + \lfloor \frac{T_r}{T_e} \rfloor\Big)/T_r$,

Each LU and corresponding Acknowledgement messages exchanged with HA-MR incurs transmission and processing cost. The LU messages from LMNs goes through one level of encapsulation which cost additional transmission cost of δ_{TH} and a processing cost of γ_t. whereas the LU messages from the MR goes without encapsulation. In both cases, a lookup cost of Ψ^{LK}_{HA-MR} is required. So the cost related to the LU and refreshing LU messages can be computed as follows:

$$\Lambda^{LU}_{HA-MR} = \eta_t N_r\Big[2\delta_L + \Psi^{LK}_{HA-MR}\Big] + \eta_r N_l\Big[2(\delta_L + \delta_{TH} + \gamma_t) + \Psi^{LK}_{HA-MR}\Big] \tag{2}$$

3) Return routability messages: NEMO employs RR test before sending BU to the HA similar to the mechanism employed in route optimization of MIPv6 [2]. Before each BU message, RR messages are exchanged among the MR, HA and CN. The HA-MR receives the Home Test Init (HoTI) message sent by the MR and forwards it to the CN. HA-MR also receives the Home Test (HoT) message from the CN and sends it back to MR. This happens for every T_r seconds. The HA-MR receives these RR messages for all CNs that are communicating with LMN. Therefore, the cost on HA-MR for RR messages are as follows:

$$\Lambda^{RR}_{HA-MR} = N_l\left(\frac{N_c}{N_{mnn}}\right)\frac{4\delta_{RR}}{T_r} \tag{3}$$

4) Binding updates to CNs: To continue ongoing sessions with the CNs, LMNs inside the mobile network sends refreshing Binding Updates (BU) to the CNs by tunneling through the HA-MR. The HA-MR has to lookup the table, tunnel and transmit those BUs. Hence, cost incurred on HA-MR due these BUs are given by,

$$\Lambda_{HA-MR}^{BU} = 2\omega_l N_c \eta_r \Big[\delta_B + \delta_{TH} + \gamma_t + \Psi_{HA-MR}^{LK}\Big] \tag{4}$$

5) Data delivery cost: In every session, the first data packet is sent through the HA and all other packets are transmitted through direct path to the MR [2]. This is also true for VMNs. Data packets (first one of each session) are routed though the HA-MR. This costs transmission cost data and ACK packets, extra IP-header processing and transmission cost as well as lookup cost. Therefore, the data delivery cost on the HA-MR is given by,

$$\Lambda_{HA-MR}^{DD} = N_c \lambda_s \left[\delta_{DT} + \delta_{DA} + 2\Big(\delta_{TH} + \gamma_t + \Psi_{HA-MR}^{LK}\Big)\right] \tag{5}$$

6) Total cost: Thus, the total cost of the HA-MR can be obtained by adding Eqns. (1), (2), (3) (4), and (5):

$$\Lambda_{HA-MR} = \Lambda_{HA-MR}^{QR} + \Lambda_{HA-MR}^{LU} + +\Lambda_{HA-MR}^{RR} + \Lambda_{HA-MR}^{BU} + \Lambda_{HA-MR}^{DD} \tag{6}$$

D. HA-MH

The HA-MH serves as the location manager of the VMNs of the mobile network. The main tasks of the HA-MH are 1) processing the query message sent by the CNs, 2) processing the LU messages, 3) RR messages of the VMNs, and 4) data delivery cost.

1) Query message: The fraction of CNs that communicate with the VMN are $\omega_v N_c$ and they send query message to the HA-MH at the beginning of every session. This incurs transmission and lookup cost for HA-MH. Thus, cost on HA-MH for query messages is

$$\Lambda_{HA-MH}^{QR} = \omega_v N_c \lambda_s \Big[2\delta_Q + \psi \log_2 N_v\Big] \tag{7}$$

2) Location update messages: Each VMN sends LU message after each handoff and periodic refreshing updates to the HA-MH which incurs transmission, and lookup cost. Thus the cost on HA-MH is

$$\Lambda_{HA-MH}^{LU} = N_v \eta_t \Big(2(\delta_L + \delta_{TH} + \gamma_t) + \psi \log_2 N_v\Big) \tag{8}$$

3) Return routability messages: Each VMN sends RR messages involving the HA-MH which costs the following:

$$\Lambda_{HA-MH}^{RR} = N_v \left(\frac{N_c}{N_{mnn}}\right) \frac{4\delta_{RR}}{T_r} \tag{9}$$

4) Data delivery cost: The first data packet from the CN travel through the HA-MH, and then through the HA-MR to reach the VMN. This requires transmission, extra IP-header processing and lookup cost at HA-MH. Therefore, the data delivery cost on the HA-MH is given by

$$\Lambda_{HA-MH}^{DD} = \omega_v N_c \lambda_s \left[\delta_{DT} + \delta_{DA} + 2\Big(\delta_{TH} + \gamma_t + \psi \log_2 N_v\Big)\right] \tag{10}$$

5) Total cost: Thus, the total cost of the HA-MR can be obtained by adding Eqns. (7), (8), (9), and (10):

$$\Lambda_{HA-MH} = \Lambda_{HA-MH}^{QR} + \Lambda_{HA-MH}^{LU} + \Lambda_{HA-MH}^{RR} + \Lambda_{HA-MH}^{DD} \quad (11)$$

E. Mobile Router

In NEMO, the main tasks of each MR are 1)IP address and prefix acquisition, 2) sending LU messages to HA-MR, 3) sending binding updates to the CNs, 4)processing RR messages, and 5) processing data (ACK) packets to and from MNNs,

1) Acquiring IP address and prefixes: MRs acquire IP address from access router in the foreign network during each handoff by exchanging DHCPv6 request-reply messages through the wireless media.

$$\Lambda_{MR}^{DHCP} = \frac{2\sigma\delta_{DH}}{T_r} \quad (12)$$

2) Location updates: After each handoff, each MR sends a LU message to the HA-MR. In addtion, periodic refreshing updates are also sent by the MRs and the mobile nodes through MR. Thus the cost on each MR due to LU messages is,

$$\Lambda_{MR}^{LU} = 2\sigma\eta_t\delta_L + 2\eta_r\left(\frac{N_m}{N_r}\right)\Big(\sigma(\delta_L + \delta_{TH}) + \gamma_t\Big) \quad (13)$$

3) Binding updates to CNs: Mobile nodes send periodic refreshing BUs to the CNs through the MR updating the current address to continue ongoing sessions. Number of CNs that communicates with the mobile nodes are $N_c(\omega_l + \omega_v)$. This requires transmission of BU message through the wireless media with extra IP-header (encapsulation), and processing cost due to tunneling. Thus the cost on each MR for these BU messages are

$$\Lambda_{MR}^{BU} = 2\eta_r\left(\frac{N_c}{N_r}\right)(\omega_l + \omega_v)\Big(\sigma(\delta_B + \delta_{TH}) + \gamma_t\Big) \quad (14)$$

a) MH's local registration Mmssages: Every subnet crossing by the MH (in every T_l sec from a MR region) triggers a local registration message to be sent to the MR. This involves transmission cost over the wireless link and processing cost at MR.

$$\Lambda_{MR}^{LR} = \frac{N_m}{N_r} \times \frac{2\sigma\delta_R + \gamma_r}{T_l} \quad (15)$$

4) Return routability messages: To ensure that the ongoing session is not hijacked by some malicious agent, before sending binding updates to the HA-MR, it is essential to perform RR test to verify that the node can actually respond to packets sent to a given CoA [2]. Thus the MR will have to process and transmit RR messages on behalf of the mobile nodes under its domain.

$$\Lambda_{MR}^{RR} = \frac{4\sigma(N_m/N_r)\delta_{RR}}{T_r} \quad (16)$$

5) Data delivery cost: In each session between the CN and MNN, an average of $\lceil\frac{\alpha}{\kappa}\rceil$ data packets are sent from the CN to MNN or vice versa. The successful reception of each data packet is confirmed by a corresponding ACK packet from the receiver. As each MR manages the ongoing communication of N_c/N_r sessions, total data / ACK packet arrival rate to the MR is $\lambda_p = (N_c/N_r)\lambda_s\lceil\frac{\alpha}{\kappa}\rceil$. Data packet delivery incurs transmission cost through the wireless media (with extra IP-header), and processing cost for the MR. Therefore, the data delivery cost at each MR is given by,

$$\Lambda_{MR}^{DD} = \lambda_p\Big(\sigma(\delta_{DT} + \delta_{DA} + \delta_{TH}) + \gamma_t\Big) \tag{17}$$

6) Total cost: Therefore, total cost of each MR can be obtained by adding Eqns. (12), (13), (14), (16), and (17),

$$\Lambda_{MR} = \Lambda_{MR}^{DHCP} + \Lambda_{MR}^{LU} + \Lambda_{MR}^{BU} + \Lambda_{MR}^{LR} + \Lambda_{MR}^{RR} + \Lambda_{MR}^{DD} \tag{18}$$

F. Complete Network

In order to compute the signaling load on the network as a whole, we consider all the resources (such as, bandwidth, processing power, etc.) consumed in all network entities. The cost of the network due to the operation of NEMO BSP include query messages exchanged between HA and CN, local registration of MHs, RR messages, location update messages, binding updates to CNs, and data delivery to CN.

1) Query message: At the beginning of each session between a MNN and a CN, query messages are exchanged between CN and HA (HA-MR or HA-MH). As the session arrival rates for each MNN are assumed to be equal (λ_s), the transmission cost for all the query and reply messages towards the HA-MR or HA-MH is $2N_c(h_p+h_{in}+h_p)\delta_Q\lambda_s$. The searching cost in the HA-MR is $(\omega_l+\omega_f)N_c\psi\lambda_s\log_2(N_r+N_l+N_f)$ and that in HA-MH is $\omega_v N_c\psi\lambda_s\log_2 N_v$. Hence, the cost of the network for the query messages from the CNs is,

$$\Lambda_{Net}^{QR} = \lambda_s N_c\Bigg[2\delta_Q(2h_p + h_{in}) + \psi(\omega_l + \omega_f)\log_2(N_r + N_l + N_f) + \psi\omega_v\log_2 N_v\Bigg] \tag{19}$$

2) Local registration messages: Every subnet crossing by the MH (in every T_l sec) within a MR region, triggers a local registration message to be sent to the MR. This involves transmission cost in one wireless hop. In addition, processing cost is incurred at the MR for updating the local location database.

$$\Lambda_{Net}^{LR} = N_m\frac{2\sigma\delta_R + \gamma_l}{T_l} \tag{20}$$

3) Return routability messages: The RR messages are sent every T_r second by the MRs (on behalf of the MNNs) to HA (either HA-MR or HA-MH) which forwards them to CN. The HoTI message follow the path between MR and HA which consists of $(h_p + h_{in} + h_p)$ wired hops with one wireless hop (between the MR and the AR). The path between HA and CN contains $(h_p + h_{in} + h_p)$ wired hops. Similar cost is incurred for each HoT message. Each CoTI message is sent directly to CN from the MR which uses $(h_p + h_{in} + h_p)$ wired hops and one wireless hop. Therefore, cost on the network for RR messages are as follows:

$$\Lambda_{Net}^{RR} = \frac{N_c}{T_r} \times 2\delta_{rr}\Big((h_p + h_{in} + h_p + \sigma) + (h_p + h_{in} + h_p) + (h_p + h_{in} + h_p + \sigma)\Big) \tag{21}$$

4) Location updates: After each handoff, each MRs and LMNs send LU to the HA-MR and VMNs send LU to HA-MH informing the newly acquired IP address and prefixes. As the HA is $(h_p + h_{in} + h_p + 1)$ hops (including h_p wireless hop) away from the MR, each LU from MR (and corresponding Ack) message incurs a transmission cost of $\delta_L(h_p + h_{in} + h_p + \sigma)$, and a lookup cost of Ψ^{LK}_{HA-MR} at the HA-MR. The LU messages from LMNs (or VMNs) travels one more wireless hop than the MR with additional transmission cost for tunneling header and tunnel processing cost. Thus the cost of LU message on the network is given by,

$$\begin{aligned}\Lambda^{LU}_{Net} &= 2N_r\delta_L\eta_t(h_p + h_{in} + h_p + \sigma) + 2(N_l + N_v)\eta_r\Big((\delta_L + \delta_{TH})(h_p + h_{in} + h_p + 2\sigma) + \gamma_t\Big) \\ &\quad + (\eta_t N_r + \eta_r N_l)\Psi^{LK}_{HA-MR} + \eta_t N_v \psi \log_2 N_v\end{aligned} \tag{22}$$

5) Binding updates to CNs: To maintain continuous connectivity with the CNs that are communicating with the mobile nodes, binding updates informing the care-of-address are sent to the CNs. These BU messages goes through and $(h_p + h_{in} + h_p)$ wired hops and two wireless hop, on the average, to reach a CN. Thus cost required to send BU to CNs are given by,

$$\Lambda^{BU}_{Net} = 2N_c\eta_r(\omega_l + \omega_v)\Big[(h_p + h_{in} + h_p + 2\sigma)(\delta_B + \delta_{TH}) + \gamma_t\Big] \tag{23}$$

6) Data delivery cost: The first data packet in a session goes through the HA (with tunneling) whereas the rest of the packets, that is, $\left(\lceil\frac{\alpha}{\kappa}\rceil - 1\right)$ packets use direct route (without tunneling). The path between a MNN and the HA contains $(h_p + h_{in} + h_p)$ wired links and 2 wireless links whereas the path between HA and CN contains $(h_p + h_{in} + h_p)$ wired links. In addition, data packets incur table lookup in HA-MR and HA-MH. Thus, the costs related to data delivery and processing by the network are given by

$$\begin{aligned}\Lambda^{DD}_{Net} &= \lambda_s N_c\left[\Big((h_p + h_{in} + h_p + 2\sigma) + (2h_p + h_{in})\Big)(\delta_{DT} + \delta_{DA} + 2\delta_{TH}) + 2\gamma_t + 2\omega_v\psi\log_2 N_v + 2\Psi^{LK}_{HA-MR}\right] \\ &\quad + N_c\lambda_s\left(\left\lceil\frac{\alpha}{\kappa}\right\rceil - 1\right)\left[\Big((h_p + h_{in} + h_p + 2\sigma)\Big)(\delta_{DT} + \delta_{DA})\right]\end{aligned} \tag{24}$$

7) Total cost of the network: Therefore, the total cost of the complete network due to NEMO protocol can be obtained by adding Eqns. (19), (20), (21), (22), (23), and (24),

$$\Lambda_{Net} = \Lambda^{QR}_{Net} + \Lambda^{LR}_{Net} + \Lambda^{RR}_{Net} + \Lambda^{LU}_{Net} + \Lambda^{BU}_{Net} + \Lambda^{DD}_{Net} \tag{25}$$

G. Efficiency

Efficiency of a mobility protocol is defined as the ratio of data delivery cost (when an optimal route is used) to the total cost (that includes signaling and data delivery costs) required for the mobility protocol. In NEMO BSP, the data packets are sent through the HA even though it is not the optimal route. The cost to send data from CN to MH in the optimal route can be obtained as follows:

$$\Lambda^{DD} = N_c\lambda_s\left\lceil\frac{\alpha}{\kappa}\right\rceil\Big((h_p + h_{in} + h_p + 2\sigma)\Big)\delta_{DT} \tag{26}$$

Therefore, efficiency of NEMO BSP can be obtained using the following equation:

$$\zeta^N = \frac{\Lambda^{DD}}{\Lambda_{Net}} \tag{27}$$

IV. Results

In this section, we present numerical results to demonstrate the impact of network size, mobility rate, traffic rate and data volume on the total cost of various mobility management entities. The values for the system parameters have been taken from the previous works [5], [9]: δ_L = 0.6, δ_B = 0.6, δ_Q = 0.6, δ_{DH} = 1.4, δ_{RR} = 0.6, δ_{DT} = 5.72, δ_{DA} = 0.60, δ_{TH} = 0.40, σ = 10, λ_s = 0.01, γ_t = 10, $N_c = N_{mnn}$, h_{in}= 5, h_p= 1, T_r = 70s, T_e = 60s, ψ = 0.3, α = 10Kb, and κ = 576b, N_r = 20, N_f = 70, N_l = 100, N_v = 100; N_m = 200;

A. HA-MR

In Fig. 2(a), the total cost of the HA-MR is shown for varying number of mobile hosts and different subnet residence times. Here we have used equal number of LMNs and VMNs, that is, $N_v = N_l = \frac{1}{2}N_m$. and the values used for N_f and N_r are 100 and 20, respectively. It is found that total cost of HA-MR increases for higher number of mobile hosts and higher residence times. For NEMO, when the subnet residence time increases the refreshing binding cost increases although the cost related to handoff reduces due to less handoff frequency. Other costs, such as, query and data delivery cost remains unchanged. The net result is increase of total cost. It can be noted that refreshing BU is dependent on the values of T_r and T_e. For T_e = 60 sec and T_r = 50 sec, there will be no need of refreshing BU, whereas for T_r = 100 and T_r = 150, the number of times RBU sent by mobile hosts (while residing in a subnet) are 1 and 2, respectively.

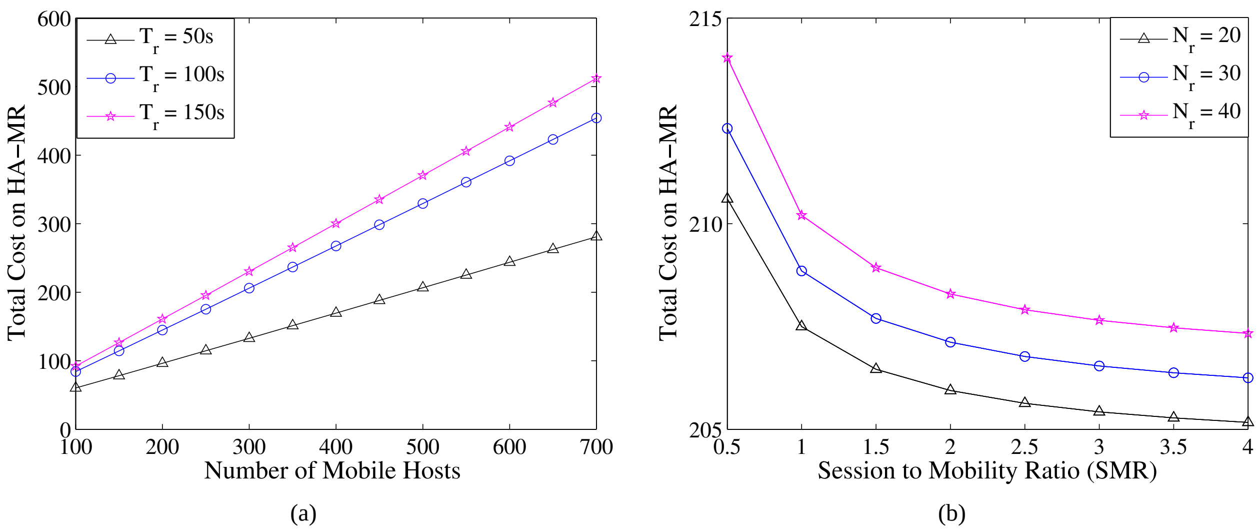


Fig. 2. (a) Impact of number of mobile hosts on the total cost on the HA-MR for different subnet residence times and (b) Impact of SMR on the total cost of the HA-MR for different number of MRs.

In Fig. 2(b), the total cost of the HA-MR is shown as a function of Session to Mobility Ratio (SMR) which is defined as $\lambda_s \times T_r$. We keep λ_s constant while varying the value of T_r between 50 to 400 sec. Increase of SMR value implies higher subnet residence times of the mobile network, producing less signaling relating to location updates and refreshing binding updates. In addition, the presence of higher number of MRs results in more LUs, thus increasing the total cost of HA-MR.

B. HA-MH

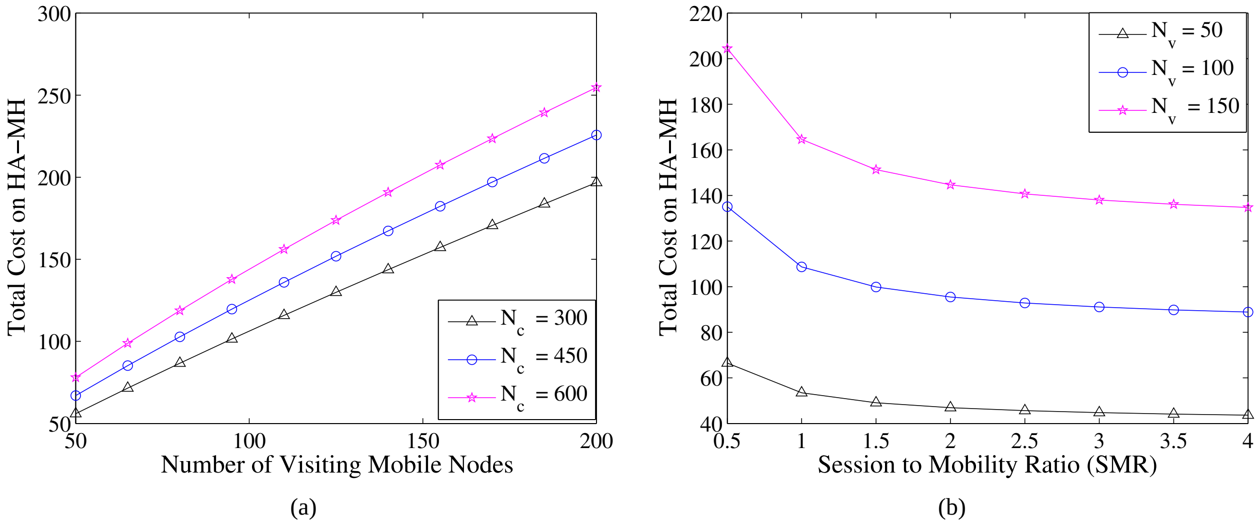


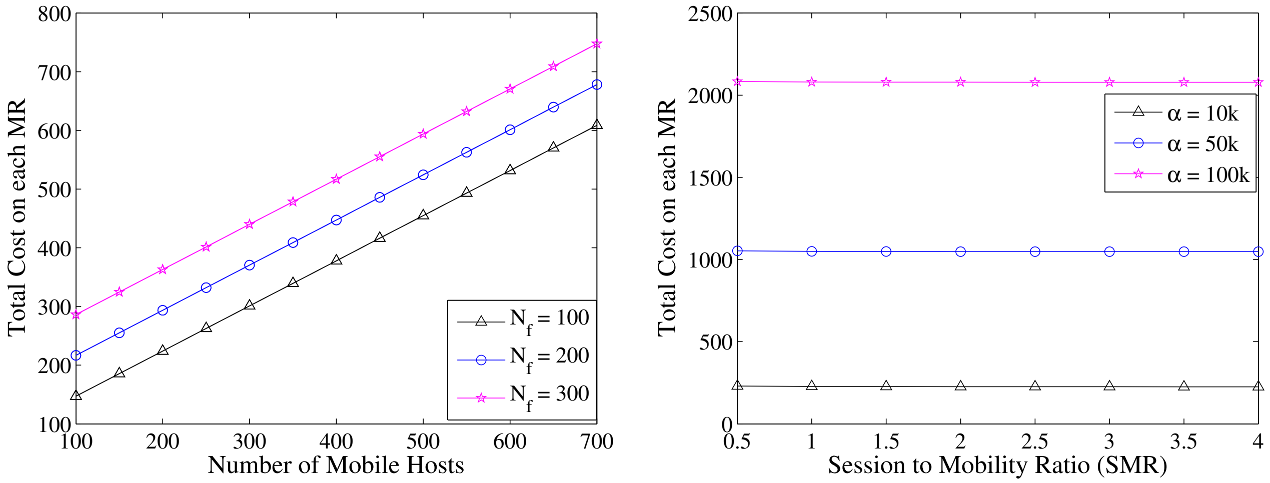
Fig. 3. (a) Impact of number of VMNs on the total cost of the HA-MH for different number of CNs, (b) Impact of SMR on the total cost of the HA-MH for different number of VMNs.

Fig. 3(a) shows the impact of number of VMNs on the total cost of HA-MH. We have varied total number of CNs communicating with the MNNs for this graph. As number of VMNs increases in the mobile network, data packets are sent through the HA-MH along with higher number of LU and RR messages. In addition, higher number of CNs implies in higher query messages exchanged between HA-MH and CN, thus producing higher cost for HA-MH.

Fig. 3(b) shows the impact of SMR on the total cost of the HA-MH for different number of VMNs. Total cost decreases with higher SMR values (that is, when mobility rate of MN is low). The changes of total cost is very small as the total cost is dominated by the data delivery cost which is independent of subnet residence time.

C. MR

In Fig. 4(a), the total cost of each MR is shown for varying number of mobile hosts and LFNs. Increase in LFNs results in constant shifting of the total cost graph due to the increase in query message cost and data delivery cost. In Fig. 4(b), the impact of SMR on the total cost of each MR is shown for varying session lengths. Higher session length causes more data packets to be routed through each MR, resulting in higher cost. The total cost is found to be invariant of SMR due to the dominance of data delivery cost.

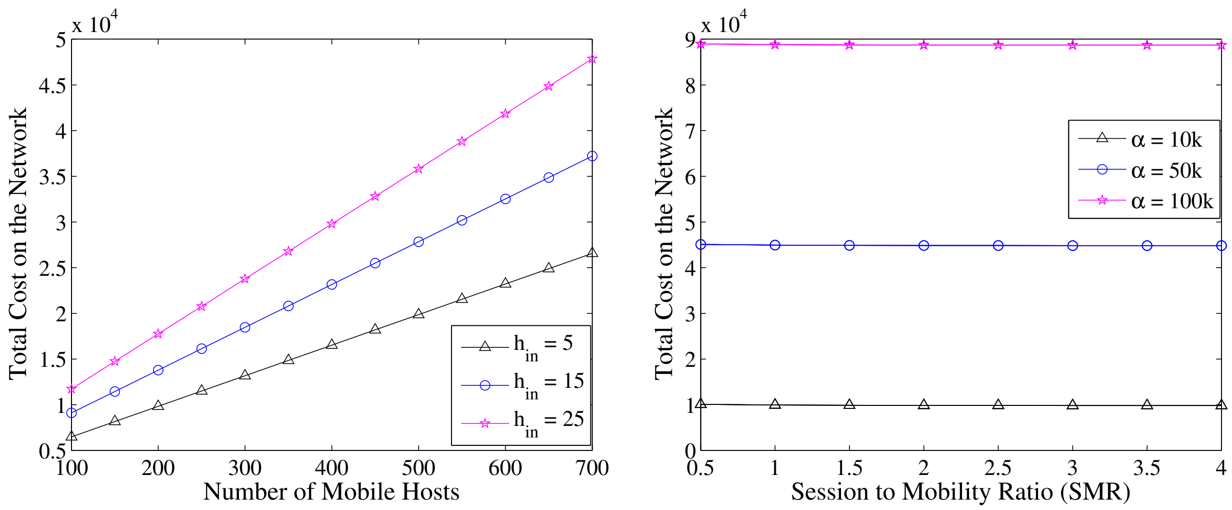


(a) (b)

Fig. 4. (a) Impact of number of mobile hosts on the total cost of each MR for different number of LFNs, (b) Impact of SMR on the total cost of each MR for different session lengths.

D. Complete Network

Fig. 5(a), the total cost of the complete network is shown as function of number of mobile hosts. We have used equal number of LMN and VMNs for this graph. Increased number of mobile hosts sends higher number of location updates, binding updates; in addition, query for the mobile hosts are also increased for higher number of mobile hosts in the MN. The total cost is also shown for different number of hops in the Internet (such as, h_{in} = 5, 15 and 25). The slope of the total cost graph rises for higher values of h_{in} since its value of influences all the costs of the network.



(a) (b)

Fig. 5. (a) Impact of number of mobile hosts on the total cost of the network for different number of hops in Internet, (b) Impact of SMR on the total cost of the network for different session lengths.

In Fig. 5(b), total cost of the network is shown as a function of SMR for different session length. It is found that the total cost does not vary much (around 1%) with respect to SMR. This implies that data delivery cost (through optimized and unoptimized route) dominates the total cost.

V. CONCLUSION

In this paper, we have developed a mathematical model to estimate the total cost of various mobility management entities of NEMO BSP considering all possible costs that influence their operation. We have presented numerical results to show the impact of network size, mobility rate, and traffic rate on those mobility entities. It is found that total cost on various entities increases for smaller session length as there is more signaling traffic compared to data traffic. In addition, the cost on various entities does not vary much with respect to session to mobility ratio due to the dominance of data delivery cost over signaling costs. The cost analysis presented in this paper will help network engineers in estimating actual resource requirements for the key entities of the network in future design while optimizing network performance.

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