An Adaptive Network Mobility Support Protocol in Hierarchical Mobile IPv6 Networks

Sangheon Pack, *Member, IEEE*, Taekyoung Kwon, Yanghee Choi, *Senior Member, IEEE*, and EunKyoung Paik

***Abstract*—The network mobility (NEMO) basic support protocol provides collective mobility for a group of nodes in vehicular area networks. Since the NEMO basic support protocol always performs the same operations regardless of a mobile network's characteristics, it cannot achieve the optimal performance. We propose an adaptive NEMO support protocol based on Hierarchical Mobile IPv6. The proposed protocol jointly optimizes binding update traffic and tunneling overhead by employing the adaptive binding update strategy depending on the session-to-mobility ratio (SMR). Specifically, both the mobile router (MR) and visiting mobile nodes (VMNs) configure two care-of-addresses: on-link care-of address (LCoA) and regional care-of address (RCoA). If the SMR is lower than a pre-defined threshold, the MR and VMNs respectively perform RCoA and LCoA binding update procedures to their HAs. Otherwise, LCoA and RCoA binding update procedures are conducted by the MR and VMNs, respectively. Via analytical models, we evaluate the performance of the adaptive NEMO support protocol against other NEMO support protocols, and derive the optimal SMR threshold. Numerical results demonstrate that the adaptive NEMO support protocol is a valuable solution for promising NEMO applications.**

***Index Terms*—Network mobility, Hierarchical Mobile IPv6, adaptive binding update, session-to-mobility ratio, performance analysis.**

I. Introduction

In wireless/mobile networks, users freely change their points of attachment as they move around. In such environments, mobility management is a key technology for maintaining ongoing sessions while moving and for locating the users' current locations to deliver data correctly. In current cellular networks for voice telephony services, many schemes have been proposed to provide efficient mobility management. However, next-generation wireless/mobile networks will be based on the IP technology and hence they will have different characteristics from the existing cellular networks. Therefore, the design of an IP-based mobility management scheme has become a crucial issue [1].

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With the advance of wireless/mobile technologies (e.g., 2.5G/3G, IEEE 802.11/16/20), the demand for Internet access while moving on vehicles such as trains, buses, and ships is constantly increasing [2], [3]. The problem of supporting these mobile Internet services is referred to as that of *network mobility (NEMO) support*. To address the NEMO support problem, the Internet Engineering Task Force (IETF) has established the NEMO working group (WG) [4] and the NEMO WG has standardized an IP layer mobility support protocol called *NEMO basic support* [5].

According to the NEMO terminology [6], a mobile network (NEMO) is defined as a network whose point of attachment to the Internet changes due to mobility. A NEMO consists of mobile routers (MRs) and mobile network nodes (MNNs). The MR within a NEMO is in charge of mobility management and each MR originally belongs to its home network where it is assigned a home address (HoA). An MR can be identified and reached by its HoA. If the MR visits a foreign network, it configures a care-of address (CoA) on its egress link for packet routing. By using the HoA and CoA, a dilemma that the MR's IP address should be changed for packet routing whereas the address should be kept for continuous services can be addressed. At the same time, the MR broadcasts a mobile network prefix (MNP), which is an IPv6 prefix delegated to the MR, toward its ingress link. The MR's CoA and MNP are registered to the home agent (HA) according to the NEMO basic support protocol [5].

However, an inherent limitation of the NEMO basic support protocol is inefficient packet routing, i.e., packets originating from or destined for a correspondent node (CN) are always forwarded through the MR's HA. This problem is exacerbated if several NEMOs are nested [7], [8]. A NEMO is called to be nested when a NEMO (sub-NEMO) is attached to a larger NEMO (parent-NEMO). For a nested NEMO, the packets are forwarded through all the HAs of MRs in the NEMO involved. This is because each MR in the nested NEMO configures a CoA from the MNP of its parent MR (i.e., the MR of the root-NEMO). Actually, the CoA is not topologically meaningful since the parent MR is also away from its home network. Hence, packets addressed to the CoA of the nested MR are delivered through the HAs of its ancestor MRs. Consequently, this inefficient routing incurs tunneling overhead due to multiple tunnelings.

The NEMO basic support protocol can reduce the binding update traffic; however, it can be achieved at the expense of tunneling overhead. So far, a number of schemes have been proposed in the literature to improve the performance of the NEMO basic support protocol (see [8] for survey). Most of them focus on route optimization [9], [10], [11], multihoming [12], prefix delegation [13], and security issues [14]. However, none of them addresses the problem of balancing the binding update traffic and tunneling overhead in an adaptive manner. Adaptability is important to support network mobility in heterogeneous wireless networks where different types of MNs and applications exist. This is the key question that we seek to address.

We extend the NEMO basic support protocol so that it can dynamically adapt to the NEMO's situation in terms of factors such as mobility and traffic patterns. The proposed adaptive NEMO support protocol is based on Hierarchical Mobile IPv6 (HMIPv6) [15], which enhances Mobile IPv6 (MIPv6) by introducing a local HA called mobility anchor point (MAP). Unlike the previous scheme [10] based on HMIPv6, our adaptive NEMO support protocol employs adaptive binding update procedures that jointly consider the mobility and session activity of a NEMO, and reduce either binding update traffic for a high mobility or packet tunneling overhead for a high session activity.

The major contributions of this paper are summarized as follows: (1) by employing adaptive binding update procedures depending on the NEMO's characteristics, our adaptive NEMO support protocol shows a better performance than the NEMO basic support protocol, especially when the mobility of the NEMO is high; (2) the adaptive NEMO support protocol considers the session activity as well as mobility. By jointly taking into account these two factors, it can achieve truly adaptive performance optimization in all-IP networks; (3) our NEMO support protocol requires only minor modifications to the existing protocols, i.e., NEMO basic support protocol and HMIPv6; and (4) we develop analytical models to evaluate the performance of relevant network mobility solutions. To the best of our knowledge, no analytical studies are reported in the literature. In addition, we derive the optimal threshold for adaptive binding updates.

The remainder of this paper is organized as follows. In Section II, the NEMO basic support protocol and HMIPv6 are introduced. Section III describes the adaptive NEMO support protocol in HMIPv6 networks. In Sections IV and V, analytical models and numerical results are presented, respectively. Section VI concludes this paper.

II. BACKGROUND

A. NEMO Basic Support Protocol

The basic NEMO support protocol provides collective Internet connectivity to MNNs via the MR and specifies two kinds of MNNs: local fixed node (LFN) and visiting mobile node (VMN). The LFN is a fixed node that belongs to a NEMO and is unable to change its point of attachment while maintaining ongoing sessions. On the other hand, the VMN is a mobile node (MN) or MR assigned to a home link, which does not belong to a NEMO and is able to change its point of attachment while maintaining ongoing sessions. In the NEMO basic support protocol, the MR performs several functions on behalf of the MNNs, both LFNs and VMNs. The MR informs its HA of the CoA and MNP. The MNP is used by the MR's HA to intercept packets destined for an MNN within the NEMO. These packets are then tunneled to the MR, which in turn decapsulates the packets and forwards them to the MNN. Unlike Mobile IPv6 [16], packets originated from an MNN are also tunneled via the MR's HA. In the sequel, the MR's HA decapsulates the packets from the MNN and forwards them to the CN.

As regards binding update, the MR registers the CoA with its HA, while the LFNs within the NEMO do not perform separate binding update procedures. This binding update procedure reduces the binding update traffic caused by handoffs significantly. On the other hand, a VMN performs a binding update procedure to its HA when it first attaches to the MR and configures a CoA on the ingress link.

Figure 1 illustrates the operation of the NEMO basic support protocol. Initially, when an MR is attached to its home network (at the bottom right of Figure 1), the MR configures its HoA (i.e., HoA_MR) by concatenating its home network prefix (i.e., 3000:300:1000:100::/64) and its network interface ID (i.e., MAC address in the eui64 format). At the same time, LFNs have IP addresses which prefixes are based on the MNP of the MR's ingress link (i.e., 3000:300:1000:200::/64). When the MR moves to a foreign network (at the bottom left of Figure 1), the MR configures a CoA (i.e., CoA_MR) of the egress link (i.e., 3000:100:1000:1000::/64). Then, the MR sends a Binding Update (BU) message that contains its new CoA and MNP to its HA. If packets destined for LFNs arrive at the home network, the MR's HA intercepts them and tunnels them to the MR's current location.

When a VMN connects to an MR, the VMN configures its CoA (i.e., CoA_VMN) based on the MR's MNP. In Figure 1, the configured CoA is 3000:300:1000:200::VMN_{EUI} where VMN_{EUI} is the network interface ID of the VMN. After completing the address configuration, the VMN sends a BU message to its HA. For upcoming movements, the VMN does not need to update its location if the VMN is still in the same NEMO because the VMN's CoA is based on the MNP. If a CN sends packets to the VMN's HoA, they are intercepted by the VMN's HA (at the top left of Figure 1) and then tunneled to the VMN's CoA. As the VMN's CoA is derived from the MR's MNP, the packets are routed to the MR's home network and intercepted by the MR's HA. Since the binding cache of the MR's HA maintains a binding between the MR's MNP and MR's CoA, the MR's HA is able to forward the packets to the VMN through the MR.

B. Hierarchical Mobile IPv6

Mobile IPv6 [16] is a host mobility support protocol in IPv6 networks, where each MN can be identified by its HoA, regardless of its current point of attachment to the Internet. When a MN moves to a foreign network, the MN can be reached by its CoA that provides information about the MN's current location. Data packets destined to the MN are transparently routed to its CoA. In addition, the CN can send data packets to the MN directly by maintaining the binding information between the MN's HoA and the MN's CoA.

Hierarchical Mobile IPv6 (HMIPv6) enhances Mobile IPv6 by introducing the MAP. HMIPv6 minimizes the amount of

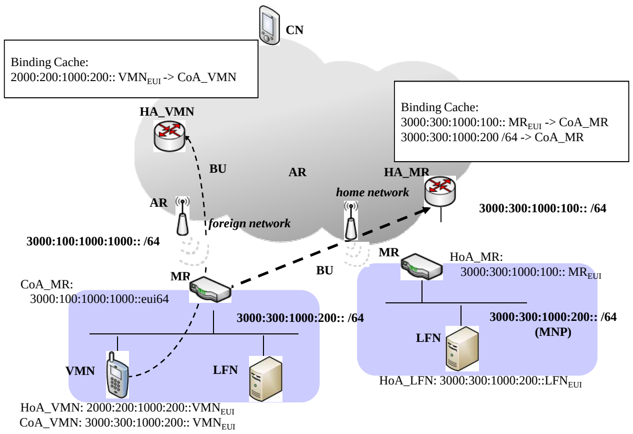


Fig. 1. The operation of the NEMO basic support protocol.

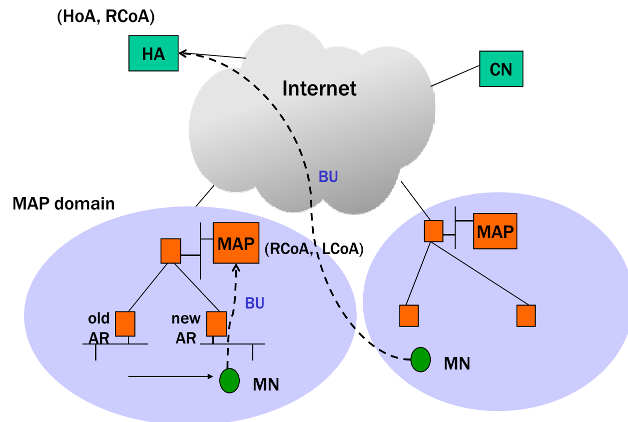


Fig. 2. The basic operation of HMIPv6 networks.

Mobile IPv6 signaling traffic outside the MAP domain and reduces the handoff latency. In HMIPv6 networks, an MN configures two CoAs: regional care-of address (RCoA) and on-link care-of address (LCoA). The RCoA is an address on the MAP's subnet. An MN configures an RCoA when it receives a Router Advertisement (RA) message with the MAP option containing MAP information. The LCoA is an on-link CoA assigned to the MN's interface based on the prefix information advertised by an access router (AR). If an MN hands off between ARs and changes its current address (i.e., LCoA) within the same MAP domain, it needs to register the new LCoA only with the MAP. The RCoA is not changed as long as the MN stays within the same MAP domain. Hence, the RCoA binding update with the HA and CNs makes the MN's mobility transparent to the CNs with which it is communicating.

Figure 2 illustrates the basic HMIPv6 operations. After address configuration, the MN sends a local BU message to the MAP. This local BU message includes the MN's RCoA in the Home Address Option field and its LCoA is used as the Source Address field. The BU message binds the MN's RCoA to LCoA. The MAP then performs a duplicate address detection (DAD) procedure for the MN's RCoA and returns a Binding Acknowledgement (BACK) message to the MN. This BACK message either confirms that the binding update was successful or contains an appropriate fault code. After registering with the MAP, the MN must register its new RCoA with its HA by sending a BU message containing its RCoA and HoA. The HoA is recorded in the Home Address Option field, while the RCoA is included in the Source Address field. The MN also sends BU messages specifying the binding information between the HoA and RCoA to its current CNs to achieve route optimization.

Once the MN has successfully registered with the MAP, a bi-directional tunnel is established between them. All packets sent by the MN are tunneled to the MAP. The outer header contains the MN's LCoA in the Source Address field and the MAP's address in the Destination Address field. The inner header contains the MN's RCoA in the Source Address field and the CN's address in the Destination Address field. In the opposite direction, packets addressed to the MN's RCoA are intercepted by the MAP and tunneled to the MN's LCoA.

III. Adaptive NEMO Support Protocol

Throughout this paper, we assume a NEMO topology where an MR has only LFNs and VMNs in its subnet because it is likely to be the most popular scenario in NEMO environments. In this section, we first describe how to configure addresses in the adaptive NEMO support protocol. After that, the HA and MAP binding update procedures are mentioned.

A. Address Configuration

The adaptive NEMO support protocol is based on the HMIPv6 protocol. The MR and VMNs in a NEMO need to configure their CoAs to operate in a HMIPv6 network. The MR configures its LCoA and RCoA by means of an RA message with the MAP option. At the same time, the MR relays the MAP option toward its subnet, which allows VMNs to configure RCoAs that are valid in the MAP domain[1]. The VMNs also configure their LCoAs and RCoAs based on the MR's advertisement message that contains the MNP and the MAP option, respectively. In short, both the MR and VMNs configure RCoAs and LCoAs when the NEMO enters a foreign network. Note that the VMN's LCoA is derived from the MNP, so that packet delivery to the VMN follows the NEMO basic support protocol if the VMN's LCoA is registered at the VMN's HA.

In the NEMO basic support protocol, the MR creates a binding between the MNP and its CoA at its HA. On the other hand, in the adaptive NEMO support protocol, the MR can register either its LCoA or RCoA with its HA depending on the characteristics of the NEMO. Using the NEMO basic support protocol, the VMN registers its HoA and CoA with its HA; but this results in an inefficient routing path in which multiple MRs' HAs have to be traversed. This is referred to as a *pinball routing problem* [7]. If the VMN registers its RCoA with its HA, the pinball routing problem can be eliminated

[1] In the adaptive NEMO support protocol, since LFNs do not perform binding update procedures as specified in the NEMO basic support protocol, they do not have to configure neither RCoAs nor LCoAs.

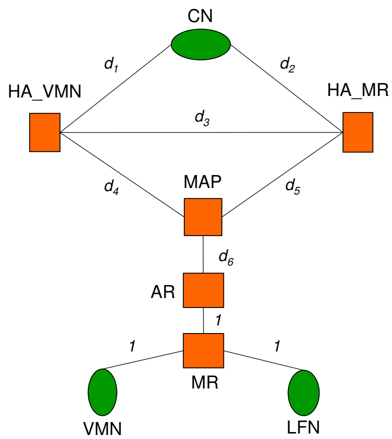


Fig. 3. The network topology: HA_VMN and HA_MR represent the HAs of the VMN and MR, respectively.

because the packets can be routed from the VMN's HA to the MAP without transiting via the MRs' HAs. However, the RCoA binding update induces more binding update traffic than the LCoA binding update. To strike a better balance between the efficient packet routing and the binding update traffic reduction, the VMN also employs the adaptive binding update strategy depending on the NEMO's characteristics. More details of the adaptive binding update procedure will be provided in the next sub-sections.

B. Binding Update to the HA

The NEMO basic support protocol does not consider binding updates to CNs. There are two reasons for this. First, performing binding update procedures to CNs brings about security concerns. Even though a return routability (RR) procedure has been adopted in Mobile IPv6, it cannot eliminate the security problems perfectly [17]. Second, binding updates with the MNP to CNs would require significant modifications to the CNs. Third, binding updates to CNs may lead to a binding update explosion problem. For these reasons, the NEMO basic support protocol specifies only the HA binding update, and we have adopted the same compromise.

Figure 3 shows the reference network topology for the adaptive NEMO support protocol, which combines the NEMO basic support protocol and HMIPv6. The adaptive NEMO support protocol considers the NEMO's handoff frequency[2] as well as the session activity. To consider these two factors jointly, we define a *session-to-mobility ratio (SMR)* as the ratio of the session arrival rate to the handoff rate. The SMR is similar to the call-to-mobility ratio (CMR), which is widely used for performance evaluation in cellular networks [18], [19]. The SMR can be measured as follows. At first, the initial SMR is set to a default value (i.e., 1.0). As a NEMO moves around, the SMR is updated continuously. That is , the SMR can be obtained by dividing the total number of session arrivals into the number of handoffs. To avoid oscillation of the estimated SMR, an exponentially weighted moving average (EWMA) scheme can be employed [20]. If the SMR is high, the session activity is a more important factor than the mobility rate, and thus we aim to reduce the packet tunneling overhead rather than the binding update traffic. Conversely, if the SMR is low, the handoff rate is dominant and it will be better to seek to reduce the binding update traffic [21], [22]. This trade-off is a central idea behind our adaptive NEMO support protocol.

We will now illustrate binding update procedures for an MR and a VMN. Figure 4 shows the adaptive binding update procedure of the MR. Let δ_1 be the pre-defined SMR threshold for the MR's adaptive binding update procedure. If the SMR of the MR is lower than δ_1, the MR performs a binding update procedure with its RCoA to its HA (see Figure 4(a)). Then, packets sent by a CN are now routed to the LFN through the MR's HA and MAP. Since the RCoA is not changed within a MAP domain, the binding update traffic can be reduced when the RCoA binding update is used. On the other hand, if the MR's SMR is equal to or higher than δ_1, the MR sends a BU message with its LCoA to its HA (see Figure 4(b)). Packets can then be delivered to the LFN without any MAP processing. Therefore, the LCoA binding update is efficient to reduce the tunneling overhead. The HA binding update procedure conducted by the MR is summarized as follows:

$$\begin{cases} \text{if}(SMR < \delta_1), & \text{RCoA binding update;} \\ \text{else if}(SMR \geq \delta_1), & \text{LCoA binding update.} \end{cases}$$

Since selecting the optimal SMR threshold is a critical issue, we derive the optimal threshold via an analytical approach, which will be described in Section V-A.

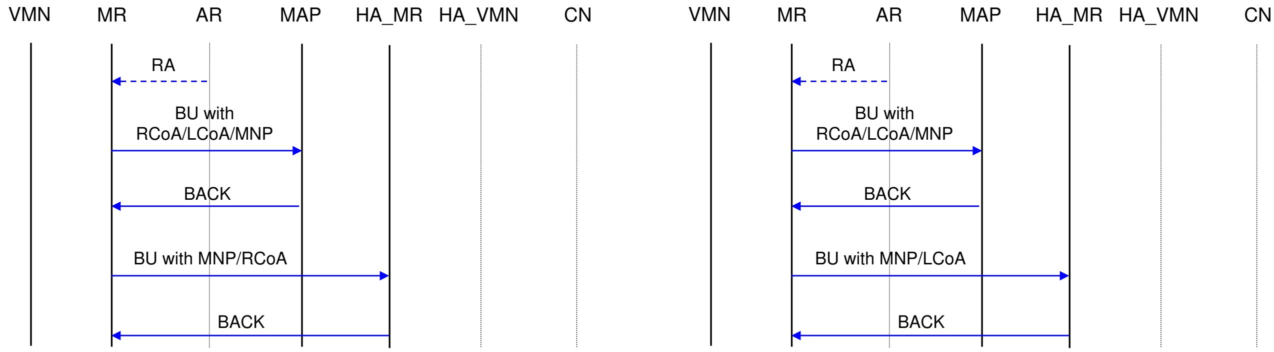
Let us now explain the VMN's adaptive binding update procedure, which is illustrated in Figure 5. As mentioned before, a VMN configures two CoAs. The RCoA is configured using the MAP option relayed by the MR, whereas the LCoA is based on the MNP notified by the MR. Since the MNP is not changed while the NEMO is moving, the LCoA requires only one binding update to the VMN's HA, which helps to reduce binding update traffic (see Figure 5(a)). Regarding packet delivery, if the LCoA binding update procedure is performed, the packets arriving at the VMN's HA are tunneled to the MR's HA because the VMN's LCoA is derived from the MR's MNP. Then, the packets need to be tunneled again to the MAP or AR, depending on the MR's binding update. Hence, this approach results in high tunneling overhead because a tunneling header occupies 40 bytes.

On the other hand, performing a binding update procedure with the VMN's RCoA mitigates packet tunneling overhead (see Figure 5(b)). This is because no tunneling is required to reach the MR's HA when the RCoA is registered at the VMN's HA. However, since the RCoA is changed when the NEMO visits a new MAP domain, the RCoA binding update requires more frequent registrations to the VMN's HA than the LCoA binding update. Therefore, we define another SMR threshold, δ_2, for the adaptive binding update of the VMN. Detailed binding update procedures are as follows:

$$\begin{cases} \text{if}(SMR < \delta_2), & \text{LCoA binding update;} \\ \text{else if}(SMR \geq \delta_2), & \text{RCoA binding update.} \end{cases}$$

The optimal SMR threshold for the VMN's binding update is also obtained by an analytical approach. This adaptive binding

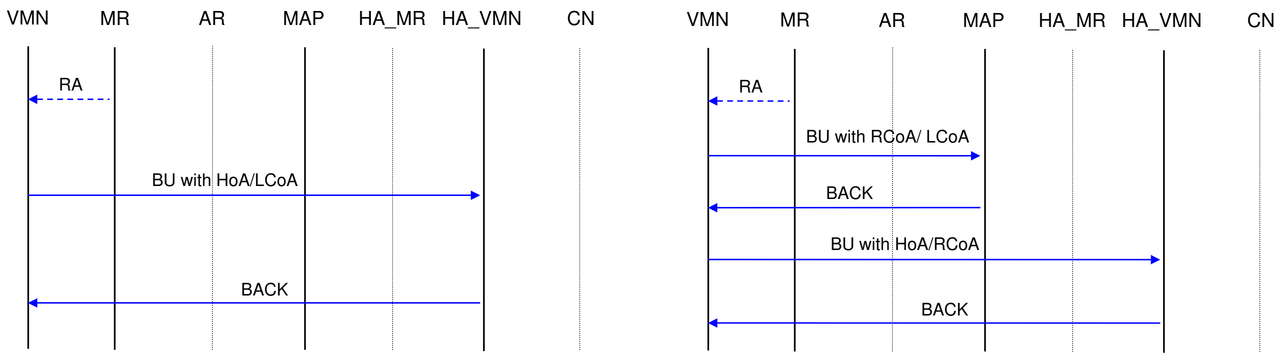
[2]Note that since the MR and MNNs belong to a single NEMO, they have the same degree of handoff frequency.



(a) $SMR < \delta_1$: RCoA binding update

(b) $SMR \geq \delta_1$: LCoA binding update

Fig. 4. Binding update flow of the MR.



(a) $SMR < \delta_2$: LCoA binding update

(b) $SMR \geq \delta_2$: RCoA binding update

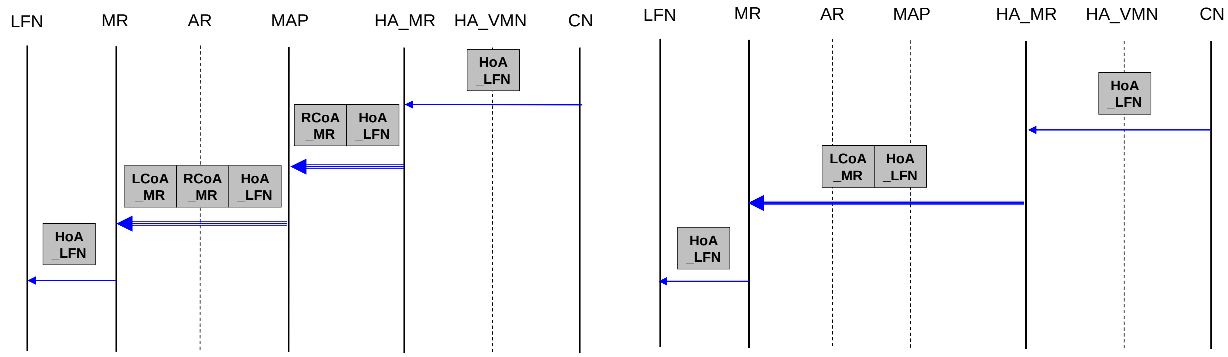
Fig. 5. Binding update flow of the VMN.

update affects the packet delivery procedure and it will be described in Section III-D.

C. Binding Update to the MAP

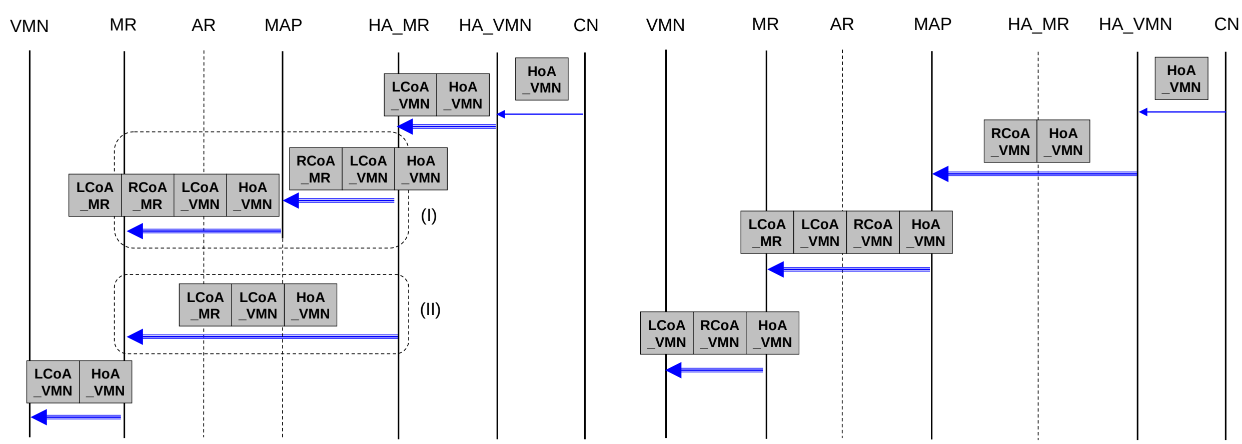
The MAP should maintain binding information between the RCoA and LCoA, so that the MR and VMN are required to perform binding update procedures to the MAP with their RCoAs and LCoAs. In the adaptive NEMO support protocol, the MR always performs the MAP binding update procedure regardless of the HA binding update (see Figure 4), whereas the VMN performs the MAP binding update procedure only when the RCoA binding update to its HA is triggered (see Figure 5(b)). Typically, the MAP binding update is not necessary when the MR informs its HA of the LCoA. However, in the adaptive NEMO support protocol, the MR should perform the MAP binding update procedure to help the VMN's packet delivery even though the LCoA is used for the MR's HA binding update.

As mentioned above, the VMN's LCoA is configured based on the MNP and the MAP maintains binding information for the VMN's RCoA and LCoA. When the MAP receives packets from the CN via the VMN's HA, it will add an outer header where the destination address is the VMN's LCoA. Since the VMN's LCoA is configured using the MR's MNP, all packets are redirected to the MR's HA. This routing path is quite inefficient. To overcome this problem, the MAP compares the destination address (i.e., the VMN's LCoA) in the outer header with the MNP before it sends the packets to the MR's HA. If the destination address is derived from the MNP, the MAP adds an additional header where the destination address is the MR's LCoA (see Figure 7(b)). As a result, the MAP has now added two IP tunneling headers. To support this functionality, the MAP BU message from the MR needs to contain the MNP, which requires the extension of the BU message [10]. Also, the MAP should manage the MNP information. Having made this arrangement, packets destined for a VMN can be routed more efficiently.



(a) $SMR < \delta_1$ (b) $SMR \geq \delta_1$

Fig. 6. Packet delivery to the LFN.



(a) $SMR < \delta_2$ (b) $SMR \geq \delta_2$

Fig. 7. Packet delivery to the VMN.

D. Packet Delivery Procedure

In the adaptive NEMO support protocol, packet delivery is dependent on the adaptive binding update procedure. The delivery procedures for a packet destined to an LFN are shown in Figure 6, in which only destination addresses are depicted. If the SMR is lower than δ_1, an MR updates the binding information (MNP, RCoA) to the HA. Otherwise, the MR updates the binding information (MNP, LCoA) to the HA. In the former case, packets from a CN are routed to the MR after visiting the MR's HA and MAP; in the latter case, packets are directly tunneled to the MR from the MR's HA without processing at the MAP. Figure 6 compares these two packet delivery procedures. In general, the packet delivery cost is proportional to the number of tunnelings and hop distance in the packet delivery path [22]. Hence, reducing the number of tunnelings at the HA or MAP will reduce the packet delivery cost.

As explained already, the VMN performs different adaptive binding update procedures from the MR. Hence, the packet delivery procedure for the VMN is also different from that for the LFN (see Figure 7). The delivery procedure is dependent on the relationship between the SMR and δ_2. If the SMR is less than δ_2, the VMN's LCoA is registered with its HA and then packets intercepted by the VMN's HA will be tunneled to the MR's HA. Whether the MR's HA tunnels the packets to the MAP or MR is determined by the MR's adaptive binding update strategy (see (I) and (II) in Figure 7(a)). If the SMR is equal to or higher than δ_2, the RCoA is updated to the VMN's HA. Then, packets from a CN are tunneled at the MAP as well as the VMN's HA (see Figure 7(b)).

IV. Performance Analysis

In this section, we develop analytical models for binding update (BU) and packet delivery (PD) costs [21], [22], [23]. The BU and PD costs are the accumulative traffic loads due to exchanging BU/BACK messages and IP tunneling headers of data packets, respectively [24]. Therefore, the BU and PD costs are calculated by the product of message length and hop distance, and their units are $bytes * hops$. We model the BU and PD costs during an inter-session arrival time, which is defined as the time interval between the arrival of the first packet of a data session and the arrival of the first packet of the next data session [25], [26]. Then, the total cost C_T is formulated as

$$C_T(m,n) = C_{BU}(n) + C_{PD}(m,n), \tag{1}$$

where m and n are the numbers of LFNs and VMNs in a NEMO, respectively. Note that since LFNs do not perform any binding update registrations, the binding update cost does not consider the number of LFNs, m.

A. System Model

For performance analysis, we have the following assumptions without loss of generality.

- The inter-session arrival time follows an exponential distribution with rate λ_I.
- The AR subnet residence time of a NEMO follows a general distribution with mean $1/\mu_S$, and its probability density function (pdf) is $f_S(t)$. $F_S(t)$ and $f_S^*(s)$ denote the cumulative distribution function and Laplace transform of $f_S(t)$, respectively.
- The MAP domain residence time of a NEMO follows a general distribution with mean $1/\mu_D$, which pdf is $f_D(t)$. $F_D(t)$ and $f_D^*(s)$ denote the cumulative distribution function and Laplace transform of $f_D(t)$, respectively.
- Based on the fluid flow model [25], μ_S and μ_D are given by
$$\mu_S = \frac{vL_S}{\pi A_S} \quad \text{and} \quad \mu_D = \frac{vL_D}{\pi A_D} ,$$
where v is the average velocity of a NEMO and L_S and L_D denote the perimeters of an AR subnet and MAP domain, respectively. Also, A_S and A_D are the areas of an AR subnet and MAP domain, respectively. If we assume that a MAP domain consists of N subnets, then $\mu_D = \mu_S/\sqrt{N}$ [27].
- We consider only incoming sessions to MNNs and the session arrival rate (or the amount of traffic) for each MNN is independent and identically distributed (*i.i.d.*).
- We assume that the binding update refresh interval is sufficiently long and thus the cost for the refreshment is not considered. Also, we focus on the binding update cost incurred by handoffs and therefore initial binding update costs are not considered.
- Let t_I and t_S be the random variables for inter-session arrival time and AR subnet residence time, respectively. Then, the SMR random variable r is given by t_S/t_I and its mean is λ_I/μ_S. The SMR cumulative distribution function is derived as [28]:
$$\Pr(r < \delta) = \Pr(t_S/t_I < \delta) = f_S^*(s)|_{s=\lambda_I/\delta} .$$
- Let N_S and N_D be the numbers of subnet crossings and domain crossings during an inter-session arrival time. Then, $\Pr(N_S = i) = \alpha(i)$ and $\Pr(N_D = j) = \beta(j)$ are derived as follows [29]:
$$\alpha(i) = \begin{cases} 1 - \frac{1}{\rho_S}\left[1 - f_S^*(\lambda_I)\right] & i = 0 \\ \frac{1}{\rho_S}\left[1 - f_S^*(\lambda_I)\right]^2 \left[f_S^*(\lambda_I)\right]^{i-1} & i > 0 \end{cases}$$
$$\beta(j) = \begin{cases} 1 - \frac{1}{\rho_D}\left[1 - f_D^*(\lambda_I)\right] & j = 0 \\ \frac{1}{\rho_D}\left[1 - f_D^*(\lambda_I)\right]^2 \left[f_D^*(\lambda_I)\right]^{j-1} & j > 0 \end{cases} ,$$
where $\rho_S = \lambda_I/\mu_S$ and $\rho_D = \lambda_I/\mu_D$.
- The per-hop transmission costs for a BU/BACK pair and a tunneling header are a and b, respectively. Our analytical model accounts for transmission costs incurred by additional IP tunneling headers, not including the original packet. In general, transmission over a wireless link is more expensive than that over a wired link [22]. To allow for this, we define a weight factor, ω, for the wireless link. We would now consider the transmission cost of an IP tunneling header (with size b) over a 1-hop wired link to be $1 \cdot b$, for instance, and the transmission cost of the same header over a wireless link would be $\omega \cdot 1 \cdot b$.

Let $C_{BU}(n|i,j)$ be the BU cost when a NEMO experiences i AR subnet crossings and j MAP domain crossings during an inter-session arrival time. Then, the average BU cost can be computed from
$$C_{BU}(n) = \sum_j \sum_i C_{BU}(n|i,j) \cdot \alpha(i) \cdot \beta(j) .$$
The NEMO basic support protocol have no concept of MAP. Therefore, the average BU cost is expressed as
$$C_{BU}(n) = \sum_i C_{BU}(n|i) \cdot \alpha(i) .$$

B. NEMO Basic Support Protocol

The cost model for the NEMO basic support protocol can be derived as follows. In the NEMO basic support protocol, the MR provides transparent mobility to LFNs and VMNs within a NEMO. Therefore, only one binding update message from the MR is generated when the NEMO hands off, and thus the BU cost is
$$C_{BU}^{Basic}(n|i) = i \cdot B_{HA}^{MR}, \tag{2}$$
where B_{HA}^{MR} is the HA binding update cost performed by the MR, which is equal to $(d_5 + d_6 + \omega) \cdot a$.

The NEMO basic support protocol is based on the tunneling between the MR and its HA. For an LFN, there is only one tunneling at the MR's HA. On the other hand, packets destined for a VMN should be tunneled at the MR's HA as well as the VMN's HA. Therefore, the VMN has a higher packet delivery cost than the LFN. Let C_{PD}^{LFN} and C_{PD}^{VMN} be the PD costs to the LFN and VMN, respectively, and they are respectively given by
$$C_{PD}^{LFN} = (d_5 + d_6 + \omega) \cdot b \tag{3}$$
and
$$C_{PD}^{VMN} = d_3 \cdot b + (d_5 + d_6 + \omega) \cdot 2b + \omega \cdot b. \tag{4}$$
Accordingly, the PD cost of a session with L packets in the NEMO basic support protocol is
$$C_{PD}^{Basic}(m,n) = L \cdot \left(\frac{m}{m+n} \cdot C_{PD}^{LFN} + \frac{n}{m+n} \cdot C_{PD}^{VMN} \right). \tag{5}$$

C. HMIPv6-based NEMO Support Protocol

In the HMIPv6-based NEMO support protocol [10], the concept of MAP is adopted and the MAP advertisement message is slightly modified. The key idea is to separate routings inside the NEMO and outside the NEMO. That is, an MR and VMN configure an RCoA and an LCoA. The MR performs both HA and MAP binding update procedures when an inter-MAP domain handoff occurs, whereas only a

MAP binding update procedure is performed for an intra-MAP domain handoff. On the other hand, for an inter-MAP domain handoff, a VMN also performs both HA and MAP binding update procedures. However, no BU message is sent by the VMN for an intra-MAP domain handoff. This is because the VMN's LCoA is configured from the MNP regardless of the location within the MAP domain. In other words, the VMN's LCoA is not changed even though an intra-MAP domain handoff occurs. Therefore, the BU cost of the HMIPv6-based protocol is

$$C_{BU}^{HMIPv6}(n|i,j) = j \cdot B_{HA}^{MR} + i \cdot B_{MAP}^{MR} + n \cdot j \cdot (B_{HA}^{VMN} + B_{MAP}^{VMN}), \tag{6}$$

where B_{MAP}^{MR} is equal to $(d_6 + \omega) \cdot a$.

The packets destined for an LFN first visit the MR's HA and they are then tunneled to the MAP. The MAP re-tunnels the packets to the current location of the MR, i.e., the MR's LCoA. On the other hand, the packets destined for a VMN travel to the VMN's HA and MAP. At the MAP, two IP tunneling headers are added to the packets destined for the VMN to make the routing more efficient (see Section III-C). Consequently, the PD costs for the LFN and VMN are respectively given by

$$C_{PD}^{LFN} = d_5 \cdot b + (d_6 + \omega) \cdot 2b \tag{7}$$

and

$$C_{PD}^{VMN} = d_4 \cdot b + (d_6 + \omega) \cdot 3b + \omega \cdot 2b. \tag{8}$$

Finally, the PD cost for a session with L packets in the HMIPv6-based protocol is given by

$$C_{PD}^{HMIPv6}(m,n) = L \cdot \left(\frac{m}{m+n} \cdot C_{PD}^{LFN} + \frac{n}{m+n} \cdot C_{PD}^{VMN} \right). \tag{9}$$

D. Adaptive NEMO Support Protocol

The BU cost of the adaptive NEMO support protocol is dependent on the SMR. Let $C_{BU}^{MR}(i,j)$ and $C_{BU}^{VMN}(i,j)$ be the BU costs of the MR and VMN when there are i intra-MAP domain handoffs and j inter-MAP domain handoffs during an inter-session arrival time, respectively. In the adaptive protocol, if the MR's SMR is lower than δ_1, the RCoA is notified to the HA. Therefore, the MR performs the MAP binding update procedure for an intra-MAP domain handoff and the HA binding update for an inter-MAP domain handoff. Hence, the BU cost in this case is the same as that of the HMIPv6-based protocol. On the other hand, if the SMR is equal to or higher than δ_1, the LCoA is registered with the MR's HA. As mentioned in Section III-C, even though the LCoA binding update procedure is performed, the MAP binding update procedure is also performed for an intra-MAP domain handoff by the MR. Therefore, $C_{BU}^{MR}(i,j)$ is given by

$$\begin{aligned} C_{BU}^{MR}(i,j) &= \Pr(r \geq \delta_1) \cdot i \cdot (B_{HA}^{MR} + B_{MAP}^{MR}) \\ &+ \Pr(r < \delta_1) \cdot (j \cdot B_{HA}^{MR} + i \cdot B_{MAP}^{MR}) \end{aligned} \tag{10}$$

In the adaptive NEMO support protocol, the VMN also chooses either the RCoA binding update or LCoA binding update depending on the SMR. However, the criteria for the choice is different. If the SMR is lower than δ_2, the LCoA binding update procedure is performed. As already described, the LCoA is derived from the MNP, so that it is not changed during movements. Consequently, when the LCoA binding update procedure is performed, the VMN's BU cost is simply zero in steady state. On the other hand, if the SMR is equal to or higher than δ_2, the VMN performs the RCoA binding update procedure to its HA for inter-MAP domain handoffs. Unlike to the MR's binding update, since the VMN's LCoA is not changed by movements, binding updates to the MAP are triggered only by inter-MAP domain handoffs. Accordingly, the VMN's BU cost is computed as

$$\begin{aligned} C_{BU}^{VMN} &= \Pr(r \geq \delta_2) \cdot j \cdot (B_{HA}^{VMN} + B_{MAP}^{VMN}) \\ &+ \Pr(r < \delta_2) \cdot 0, \end{aligned} \tag{11}$$

where B_{MAP}^{VMN} is equal to $(d_6 + 2\omega) \cdot a$. By Eqs. (10) and (11), the BU cost for a given number of handoffs is given by

$$C_{BU}^{Adaptive}(n|i,j) = C_{BU}^{MR}(i,j) + n \cdot C_{BU}^{VMN}(i,j). \tag{12}$$

Since the MR and VMN perform different binding update procedures depending on the SMR, the packet delivery paths are also different. Let $C_{PD}^{LFN\_RCoA}$ and $C_{PD}^{LFN\_LCoA}$ denote, respectively, the costs of delivering a packet from a CN to an LFN when RCoA and LCoA binding update procedures are performed by the MR. Based on the flow diagram shown in Figure 6, they are respectively calculated as

$$C_{PD}^{LFN\_RCoA} = d_5 \cdot b + (d_6 + \omega) \cdot 2b \tag{13}$$

and

$$C_{PD}^{LFN\_LCoA} = (d_5 + d_6 + \omega) \cdot b. \tag{14}$$

In a similar way to the LFN's cost, the packet delivery costs to a VMN when LCoA and RCoA binding update procedures are performed are respectively given by

$$\begin{aligned} C_{PD}^{VMN\_LCoA} &= d_3 \cdot b + \omega \cdot b \\ &+ \Pr(r < \delta_1) \cdot (d_5 \cdot 2b + (d_6 + \omega) \cdot 3b) \\ &+ \Pr(r \geq \delta_1) \cdot ((d_5 + d_6 + \omega) \cdot 2b) \end{aligned} \tag{15}$$

and

$$C_{PD}^{VMN\_RCoA} = d_4 \cdot b + (d_6 + \omega) \cdot 3b + \omega \cdot 2b. \tag{16}$$

By combining Eqs. (13), (14), (15), and (16), the PD costs for a packet destined for an LFN and VMN are respectively obtained from

$$C_{PD}^{LFN} = \Pr(r < \delta_1) \cdot C_{PD}^{LFN\_RCoA} + \Pr(r \geq \delta_1) \cdot C_{PD}^{LFN\_LCoA} \tag{17}$$

and

$$C_{PD}^{VMN} = \Pr(r < \delta_2) \cdot C_{PD}^{VMN\_LCoA} + \Pr(r \geq \delta_2) \cdot C_{PD}^{VMN\_RCoA}. \tag{18}$$

Consequently, the PD cost for a session with L packets in the adaptive NEMO support protocol is given by

$$C_{PD}^{Adaptive}(m,n) = L \cdot \left(\frac{m}{m+n} \cdot C_{PD}^{LFN} + \frac{n}{m+n} \cdot C_{PD}^{VMN} \right). \tag{19}$$

TABLE I
SYSTEM PARAMETER VALUES.

m	n	L	ω	N	d_1, d_2	d_3	d_4, d_5	d_6
5	5∼20	5∼20	10	49	5	8	10	3

V. NUMERICAL RESULTS

The lengths of BU and BACK messages in the NEMO basic support protocol are 72 bytes and 52 bytes, respectively[3]. In addition, an additional IP tunneling header requires 40 bytes. Therefore, a and b are set to 124 $bytes*hop$ and 40 $bytes*hop$, respectively. The hop distance values used in the analysis are listed in Table I. The weight factor for a wireless link is set to 10 [22].

The AR subnet residence time is assumed to follow a Gamma distribution with mean $1/\mu_S$ and variance V_S. Likewise, the MAP domain residence time also follows a Gamma distribution with mean $1/\mu_D$ and variance V_D. Therefore, the Laplace transforms of $f_S(t)$ and $f_D(t)$ are respectively given by

$$f_S^*(s) = \left(\frac{\mu_S\gamma}{s+\mu_S\gamma}\right)^\gamma, \qquad \gamma = \frac{1}{V_S\mu_S^2}$$

and

$$f_D^*(s) = \left(\frac{\mu_D\gamma}{s+\mu_D\gamma}\right)^\gamma, \qquad \gamma = \frac{1}{V_D\mu_D^2}.$$

Then, the SMR cumulative distribution function can be rewritten as

$$\Pr(r<\delta) = f_S^*(\frac{\lambda_I}{\delta}) = \left(\frac{\delta\mu_S\gamma}{\lambda_I+\delta\mu_S\gamma}\right)^\gamma.$$

Default variances, V_S and V_D, are assumed to be $1/\mu_S^2$ and $1/\mu_D^2$; however, the effect of different variances is explored in Section V-E.

A. Optimal SMR Threshold

In this subsection, we derive the optimal SMR thresholds, δ_1^* and δ_2^*, for the adaptive NEMO support protocol. We need to find δ_1^* first because δ_2^* is dependent on it. Since the explicit derivation of the optimal threshold is quite complex, we obtain the optimal threshold as follows. In the adaptive NEMO support protocol, the MR chooses either LCoA binding update or RCoA binding update depending on the SMR. Then, the total costs for LCoA and RCoA binding updates by the MR can be represented by $C_{MR}^{LCoA}(r)$ and $C_{MR}^{RCoA}(r)$, respectively, where r is the SMR. Let ϕ be the SMR value where $C_{MR}^{LCoA}(r)$ and $C_{MR}^{RCoA}(r)$ are equivalent. Then, the adaptive NEMO support protocol chooses RCoA binding update when the SMR is less than ϕ because RCoA binding update can minimize the total cost; otherwise, LCoA binding update is chosen. Therefore, it can be concluded that ϕ is the optimal SMR threshold for the MR's binding update. ϕ can be found by a binary search algorithm in Algorithm 1, where a sufficiently small value of ϵ (e.g., 10^{-3}) is used. By a similar approach, the optimal SMR threshold for the VMN binding update, δ_2^*, can be derived from Algorithm 2.

[3]Since IPsec is applied to all relevant protocols, the effect of the IPsec header size is not considered in our analysis.

Algorithm 1 Determination of δ_1^*: $Left = 10^{-3}$ and $Right = 10^3$

$Left \leftarrow MIN$;
$Right \leftarrow MAX$;
$r \leftarrow (Left + Right)/2$;
while $TRUE$ **do**
  if $\left|C_{MR}^{RCoA}(r) - C_{MR}^{LCoA}(r)\right| < \varepsilon$ **then**
    $\delta_1^* \leftarrow r$;
    return ;
  else
    if $C_{MR}^{RCoA}(r) < C_{MR}^{LCoA}(r)$ **then**
      $Left \leftarrow r$;
      $r \leftarrow (Left + Right)/2$;
    else
      $Right \leftarrow r$;
      $r \leftarrow (Left + Right)/2$;
    end if
  end if
end while

Algorithm 2 Determination of δ_2^*: $Left = 10^{-3}$ and $Right = 10^3$

$Left \leftarrow 0$;
$Right \leftarrow 1$;
$r \leftarrow (Left + Right)/2$;
while $TRUE$ **do**
  if $\left|C_{VMN}^{RCoA}(\delta_1^*, r) - C_{VMN}^{LCoA}(r)\right| < \varepsilon$ **then**
    $\delta_2^* \leftarrow r$;
    return ;
  else
    if $C_{VMN}^{RCoA}(\delta_1^*, r) < C_{VMN}^{LCoA}(r)$ **then**
      $Left \leftarrow r$;
      $r \leftarrow (Left + Right)/2$;
    else
      $Right \leftarrow r$;
      $r \leftarrow (Left + Right)/2$;
    end if
  end if
end while

Table II shows the optimal SMR thresholds for different session lengths L. It can be shown that the optimal SMR threshold δ_1^* decreases with the increase in L. This is because, for a large L, the packet delivery cost dominates the binding update cost and thus it is better for the MR to use the LCoA binding update more frequently by reducing the SMR threshold. On the other hand, the VMN performs the RCoA binding update procedure when the packet delivery cost is a main contributor to the total cost compared with the binding update cost. Consequently, as L increases, δ_2^* also decreases to reduce the packet delivery cost by employing the RCoA binding update more frequently. In terms of γ, it can be seen that the effect of γ is more apparent in δ_2^* than in δ_1^*. This indicates that more accurate mobility estimation schemes are required to find suitable SMR thresholds for the VMN binding update. In addition, the effect of γ is more clear when L is small, i.e., the packet delivery cost is not dominant.

TABLE II
OPTIMAL SMR THRESHOLD.

L	δ_1^*			δ_2^*		
	$\gamma = 1$	$\gamma = 10$	$\gamma = 100$	$\gamma = 1$	$\gamma = 10$	$\gamma = 100$
10	0.4701	0.4702	0.4703	0.4250	0.4456	0.4482
20	0.2351	0.2351	0.2351	0.1650	0.1652	0.1652
30	0.1464	0.1464	0.1464	0.1060	0.1060	0.1060
40	0.1175	0.1175	0.1175	0.0787	0.0787	0.0787
50	0.0940	0.0940	0.0940	0.0626	0.0626	0.0626

B. Effect of SMR

For the purpose of comparison, we define the relative total cost gain to the NEMO basic support protocol as follows:

$$G = \frac{\text{Total cost of the NEMO basic support protocol}}{\text{Total cost of X}},$$

where X is either HMIPv6-based protocol or adaptive NEMO support protocol. If G of a protocol is larger than 1.0, it indicates that the corresponding protocol outperforms the NEMO basic support protocol. As shown in Figure 8, G of the HMIPv6-based protocol increases with ρ_S. However, the HMIPv6-based protocol has a higher total cost than the NEMO basic support protocol over the entire ρ_S range, i.e., G is always smaller than 1.0.

Compared with the NEMO basic support protocol, the adaptive NEMO support protocol can reduce the total cost by 6-25% when ρ_S is low, while it shows a comparable total cost to the NEMO basic support protocol for a high ρ_S. In short, the adaptive NEMO support protocol reduces the total cost incurred in the NEMO basic support protocol when the mobility is high. In addition, G of the adaptive NEMO support protocol is not severely degraded as ρ_S increases. This result reveals that the effect of additional MAP tunnelings in the adaptive NEMO support protocol is not noticeable, even though the session activity is dominant. When we consider that one of the most promising NEMO applications is a vehicular network with high mobility [30], it is more preferable to reduce the total cost when the mobility is high. Consequently, we believe that the adaptive NEMO support protocol is more appreciated in real NEMO applications.

Our analytical model is based on the average session length. However, since the session length can be variable, the analytical model may not be accurate. Therefore, we validate the analytical model via simulations. In the simulation, the session arrival process follows an exponential distribution, and the subnet and MAP domain residence times are assumed to be Gamma distributions. In addition, the session length (in units of $Kbytes$) process follows a Lognormal distribution with mean $10Kbytes$ and variance $625Kbytes$ [31]. Since the fixed packet size is assumed (i.e., $1Kbytes$), the average session length in units of packets is 10 and the variance is 625. The simulation results are plotted in Figure 8. Simulation results for the HMIPv6-based protocol match analytical results very well. On the other hand, when ρ_S is high, small discrepancies between analytical and simulation results are observed in the adaptive NEMO support protocol. This is because high variance in the session length has a significant effect on the total cost when ρ_S is high. However, the overall simulation results are consistent with the analytical results, and it indicates that our analytical model is sufficiently accurate and the adaptive NEMO support protocol is a viable solution in realistic environments.

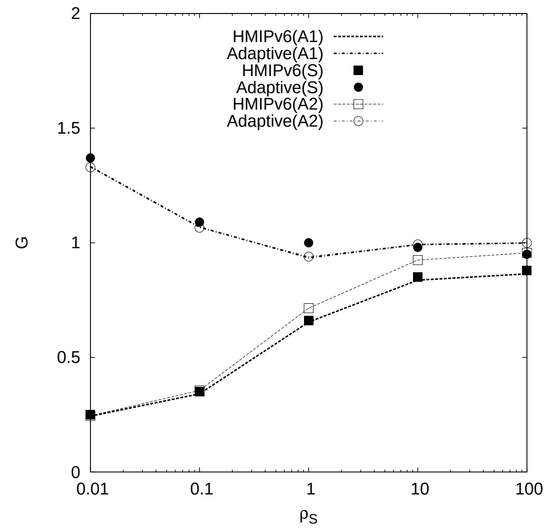


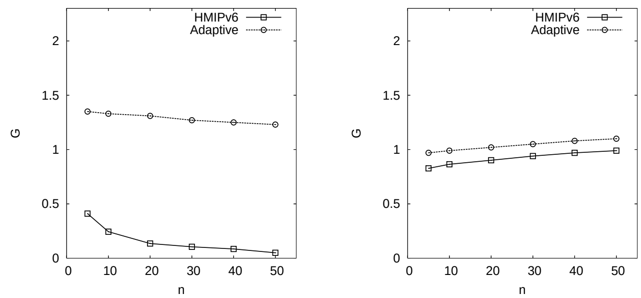
Fig. 8. G vs. ρ_S (A1: Analysis ($d_3 = 8$), A2: Analysis ($d_3 = 16$), S: Simulation ($d_3 = 8$), $n = 10$, $L = 10$).

The network topology also affects the performance. Especially, the distance between the MR's HA and VMN's HA (i.e., d_3 in Figure 3) is important because it influences the packet delivery cost in the NEMO basic support protocol. Figure 8 also illustrates the effect of d_3. As d_3 increases, the total cost gain of the HMIPv6-based protocol increases. This is because the HMIPv6-based protocol is not affected by the increased d_3, while the total cost of the NEMO basic support protocol increases significantly with the increase in d_3. On the other hand, the adaptive NEMO support protocol exhibits almost the same total cost gain regardless of d_3. It implies that the adaptive NEMO support protocol is a robust solution, which can be used for different network topologies.

From the results on the total cost, it can be inferred that the adaptive NEMO support protocol can reduce the handoff latency adaptively. Let us take an example of an MR's binding update. When the SMR is low, the reduction of handoff latency originated from HMIPv6 can be obtained by choosing the RCoA binding update. On the contrary, if the SMR is high, a longer handoff latency is expected because the LCoA binding update is employed. However, if the SMR is high, the handoff frequency is low and hence the increased handoff latency has no significant effect on the average handoff latency [28]. Consequently, the adaptive NEMO protocol can achieve the reduced handoff latency comprehensively.

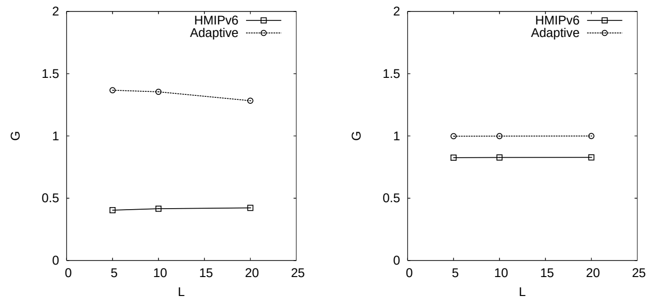
C. Effect of Number of VMNs

For NEMO service providers, it is important to support a large number of VMNs while keeping signaling traffic manageable. Figure 9 shows the total cost gain as the number of VMNs, n, increases. When ρ_S is low (e.g., 0.01), the performance of the adaptive NEMO support protocol is excellent compared with other protocols. Specifically, the adaptive NEMO support protocol can reduce the total cost of the



(a) ρ_S=0.01 (b) ρ_S = 100

Fig. 9. G vs. n ($L = 10$).



(a) ρ_S=0.01 (b) ρ_S = 100

Fig. 10. G vs. L ($n = 10$).

NEMO basic support protocol by 24-25%, regardless of the number of VMNs. This makes the adaptive NEMO support protocol the best choice for a large size NEMO if ρ_S is low. On the other hand, when ρ_S is high (e.g., 100), the adaptive NEMO support protocol exhibits comparable total cost to the NEMO basic support protocol. However, since NEMO services are likely to be more popular in highly mobile environments [30], as already mentioned, the performance with a low ρ_S is more important.

D. Effect of Session Length

Figure 10 shows the total cost gains for different average session lengths, L. When ρ_S is 0.01, the gain of the HMIPv6-based protocol is smaller than 1.0 for all L. On the other hand, even though G of the adaptive NEMO protocol slightly decreases with the increase of L, G remains over 1.0 for all L. When ρ_S is 100, the adaptive NEMO protocol still outperforms the HMIPv6-based protocol. From Figure 10, it should be noted that G of the adaptive NEMO support protocol is rarely affected by L. In short, the adaptive NEMO support protocol can provide a consistent performance over a wide range of session lengths, and it is highly desirable in mobile networks with heterogeneous traffic patterns.

E. Effect of Variance

To discover the effect of variance, we vary the values of V_S and V_D by 1, 10, and 100 times the square of the mean residence time (i.e., $V_S = 1/\mu_S^2, 10/\mu_S^2, 100/\mu_S^2$ and $V_D = 1/\mu_D^2, 10/\mu_D^2, 100/\mu_D^2$). Table III summarizes the differences among $C(1)$, $C(10)$, and $C(100)$, where $C(A)$ is the total cost when $V_S = A/\mu_S^2$.

TABLE III
EFFECT OF VARIANCE ($n = 10$, $L = 10$, $Diff_1 = C(10) - C(1)$, $Diff_2 = C(100) - C(1)$).

ρ_S	Basic		HMIPv6		Adaptive	
	$Diff_1$	$Diff_2$	$Diff_1$	$Diff_2$	$Diff_1$	$Diff_2$
0.01	217	239	249	274	128	141

As the variance increases, a longer residence time is expected. A longer residence time incurs more subnet/domain crossings, which is why a longer variance results in a higher total cost. As shown in Table III, the HMIPv6-based protocol is the most sensitive to the variance, whereas the adaptive NEMO support protocol is the least sensitive to the variance. This is because the adaptive NEMO support protocol utilizes a MAP function (as the HMIPv6-based protocol) and performs only a single binding update procedure by the MR on behalf of LFNs (as the NEMO basic support protocol). Consequently, the adaptive NEMO support protocol is least affected by the change of variances and hence we expect that it can operate well in highly diverse mobile environments.

VI. CONCLUSION

We have proposed an adaptive NEMO support protocol that makes use of HMIPv6 and NEMO basic support protocol. The adaptive NEMO support protocol employs the adaptive binding update strategy depending on the SMR that is a key factor characterizing a mobile network. The rationale behind the adaptive binding update is to reduce the number of binding updates when the SMR is low (i.e., handoffs happen more frequently than session arrivals); on the other hand, the number of tunnelings is reduced when the SMR is high (i.e., session activity dominates mobility). We have developed analytical models to evaluate NEMO support protocols, and verified the analytical results by simulations. Extensive numerical results demonstrate that the adaptive NEMO support protocol achieves a significant performance improvement for a low SMR and shows a comparable performance with the NEMO basic support protocol when the SMR is high. Moreover, it can be seen that the adaptive NEMO support protocol is scalable and works well in diverse mobile environments. Therefore, we expect that the adaptive NEMO support protocol would be valuable in vehicular networks that will be promising NEMO applications. As further research, how to reduce implementation overhead due to SMR measurement and how to address security issues in the adaptive NEMO support protocol should be investigated.

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