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An Efficient Fast Handoff and Route Optimization Protocol for the Nested Mobile Networks

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Abstract

For fast handoff protocol to succeed in nested NEMO, acquisition of new care-of-address, and exchange of signaling packets for handoff must be done with minimum delay. New care-of-address can be obtained using anticipation but signaling packets must also pass through minimum number of tunnels. These challenges creates far more complex scenario than a simple NEMO and node mobility. In this paper, we propose Fast Handoff with End-to-end Route Optimization (FHE2ERO) protocol for nested mobility that meets these requirements. FHE2ERO improves previous work on route optimization by combining the handoff and route optimization process and performing L2 and the L3 handoff in parallel, thereby, significantly reducing the number of signaling packets and hence the handoff delay. Numerical analysis shows that FHE2ERO reduces both handoff delay and packet loss duration and achieves zero packet loss during successful anticipation.

Keywords: fast handoff, route optimization, mobile networks, NEMO, PMIPv6

1. Introduction

When a group of mobile devices move as a single unit and change their point of attachment to the Internet also as a single unit, then this type of movement is typically referred as *Network Mobility (NEMO)* [1] and, the network of such nodes is called a *mobile* *network*, where, the nodes in the mobile network are called *mobile network nodes (MNNs)*. Example of mobile networks includes a PAN or a LAN, deployed in a public transport, say bus, where the nodes of the PAN or the LAN, performs handoff when the bus moves from one place to another. The IETF has standardized *NEMO Basic Support Protocol* [1] *(NBSP)* to provide Internet connectivity to a mobile network. According to NBSP, a specialized router, called *mobile router (MR)*, manages the mobility of the entire mobile network and performs handoff on behalf of the MNNs. The MR uses *router advertisements (RAs)* for detecting handoff, obtains a valid care-of-address (*CoA*) from visited network, and then performs binding update (*BU*) with its *home agent (HA)*. Successful completion of BU process establishes a bi-directional tunnel between the MR and it's HA (we will now refer HA of MR as *HA_MR* for convenience). A mobile network can also be visited by another mobile network, and the MR of the visiting network comes under the administrative domain of the MR of the visited network. This leads to *nested-NEMO* scenario, i.e., multilevel hierarchy of MRs. The root of the hierarchy, called *top-level MR (TLMR)*, is attached directly to Internet through an *access router (AR)*. Fig. 1 illustrates a nested-NEMO scenario of 3 levels, where TLMR1 (at level 1) is connected to AR1, the *Intermediate Mobile Router (IMR)* IMR2 (at level 2) is connected to TLMR1, and MR2 (at level 3) is connected to IMR2. So TLMR1 is the default gateway of IMR2, and IMR2 is the default gateway of MR2.

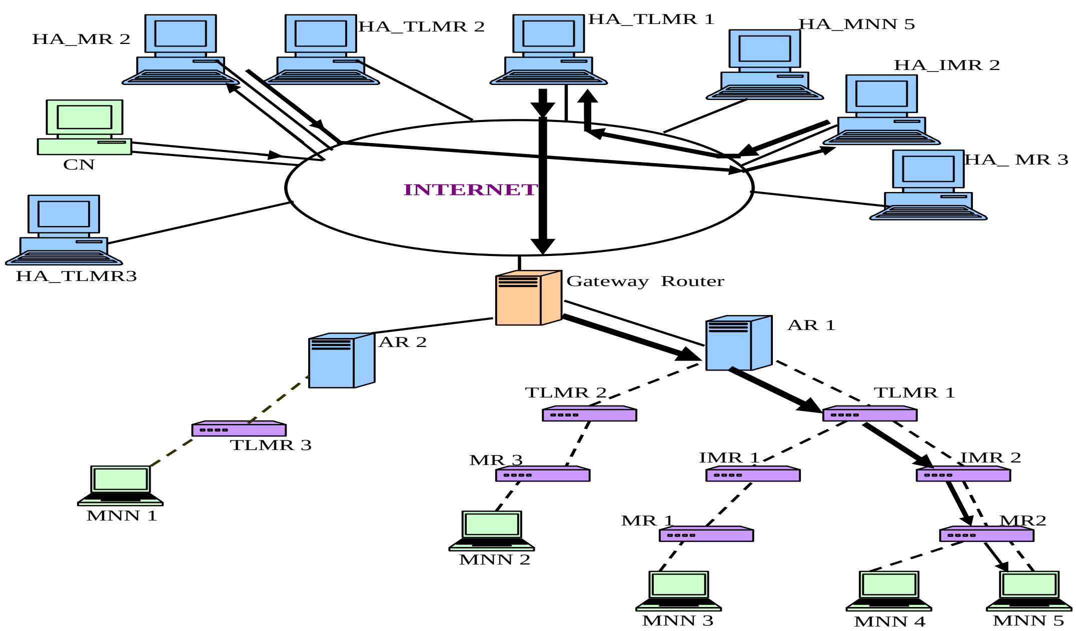

Figure 1. Nested-NEMO scenario. Dotted lines indicate wireless connections

Application of NBSP to nested-NEMO scenario leads to packet delivery through nested tunnels [1]. For example, in Fig. 1, the packet delivery from correspondent node *(CN)* to MNN5 takes place through the path[1]: CN→HA_MR2→HA_IMR2→HA_TLMR1→Gateway-Router→AR1→TLMR1→IMR2→MR2→MNN5. Moreover, the delivery of packets between the nodes in the nested-NEMO (called *intra-NEMO routing* [2] [3]), say, between MNN5 and MNN4 in Fig.1, will also take place through nested tunnels in the Internet. This

[1] MNN5 uses MIPv6 and it has completed the Return Routability Procedure with the CN [4].

mechanism increases packet delivery delay for both data and signaling packets which results in high handoff delay, leading to high packet loss. This issue becomes worse as the nesting level increases, adding more tunnels along the path of packet delivery. To reduce the packet delivery delay in both NEMO and intra-NEMO routing, *End-to-End Route Optimization protocol (E2ERO)* [4] uses route optimization technique that limits the number of tunnels between a CN and an MNN to 1. According to E2ERO, MR first performs a local BU with TLMR, and then sends BU packet to it's HA containing the CoA of TLMR (*CoA_TLMR*). This leads to a binding between MR's home address (*HoA_MR*) and CoA_TLMR. Hence the packets from CN to MNN5 in Fig. 1 are routed though the path: CN→HA_MR2→Gateway Router→AR1→TLMR1→IMR2→MR2→MNN5. However, the route optimization process takes place after link-layer (*L2*) handoff and receipt of RA, i.e., the L2 and L3 handoff are performed sequentially. The sequential execution of L2 and L3 handoff leads to high handoff delay and packet loss. To reduce packet loss during the handoff this paper proposes *Fast Handoff with End-to-end Route Optimization protocol (FHE2ERO)*. FHE2ERO improves E2ERO by adding two important features: fast handoff and route optimization process using lesser number of signaling packets, and performing L3 and L2 handoff in parallel. For fast handoff, FHE2ERO uses infrastructure network for anticipation and completing the handoff process, and achieves zero packet loss during successful anticipation. Numerical analysis shows that the FHE2ERO outperforms E2ERO in terms of handoff delay and packet loss duration, where the gains are in order of 100ms and 90% respectively.

Rest of the paper is organized as follows. In section 2, we briefly discuss the related fast handoff and route optimization protocols and analyze their merits and demerits. In section 3, we describe the working principles of FHE2ERO. Then we analyze and compare of the protocol with E2ERO in section 4. We then conclude the paper with possible fields where FHE2ERO protocol can be applied.

2. Related Works

Many NEMO protocols have been proposed in the literature that either aim for reducing the handoff delay using fast-handoff techniques, or, reducing packet delivery delay using route optimization techniques. In the following sub-sections, we briefly describe the fast handoff and route optimization protocols proposed for nested-NEMO, and point out their advantages and limitations.

2.1. Fast Handoff NEMO Protocols

In [5], the authors proposed fast handoff protocol for NEMO that anticipates handoff using L2-trigger. On receiving L2-trigger, the MR initiates the handoff process by sending fast binding update (FBU) [6] to HA_MR. Then the rest of the handoff process is performed between HA _MR and the new IMR (or, AR in case the nesting level is one) as in FMIPv6 [6]. By the duration of signaling packet exchange between the HA_MR and the new IMR, the MR completes the L2 handoff. By starting the L3 handoff with the event of sending FBU and performing the L2 handoff involving the L2 entities only, the protocol achieves parallel handoff between L2 and L3 layers. However, during the binding update process, the HoA_MR is mapped with the CoA_MR. This results routing of signaling packets through the nested tunnels involving HA of higher level MRs (or IMRs). The mechanism delays the formation of tunnel between the MR and HA_MR and contributes to high rate of increase in handoff delay with nesting level. This also leads to high amount of packet loss.

In [7], the authors proposed to merge L2 and L3 handoff processes for MR by sending the L3 handoff packets in the re-association frames of L2 handoff. The MR performs handoff process with the HA_MR as in NBSP after the L2 handoff is completed. The entire handoff process results mapping of HoA_MR to CoA_MR. Sending of some of the L3 handoff packets along with the L2 handoff frames poses an advantage by reducing the delay in obtaining CoA and thus reduces handoff delay to some extent; however, the process does not avoid the nested tunnels in the path from MR to HA_MR, which overweighs the advantage of the protocol as the nesting level becomes more than one. This eventually results high handoff delay and packet loss.

In MM-NEMO [8], authors have proposed to extend FHHMIPv6 [9], where the AR assumes the role of mobility anchoring point (MAP) [10]. As soon as the MR receives L2 trigger, MR sends RtSolPr [6] to the AR. The rest of the handoff follows the predictive mode of FMIPv6 and results binding between HoA_MR with the CoA_MR at HA_MR. Thus, like the previous schemes, the protocol suffer due to formation of nested tunnels when nesting level becomes more than one. Moreover, the protocol reduces to NBSP when the anticipation is not successful leading to significant increase in packet loss.

From the above discussion we conclude that the fast handoff protocols no longer remains fast as nesting level increases.

2.2. Route Optimizing NEMO Protocols

E2ERO assumes tree topology of nested-NEMO, and addresses the packet delivery delay and intra-NEMO routing. Each MR maintains two caches. The *first cache* contains binding information of all the MRs under its administrative domain; for instance, in Fig. 1, the cache of TLMR1 will contain the information of IMR1, IMR2, MR1 and MR2. The entries in the cache are a 3-tuple: <HoA_MR, CoA_MR, NEMO prefix of MR>. The *second cache* maintains information of CNs that are communicating with the sub-level MNNs. Also each MR, including TLMR, advertises CoA_TLMR in its domain. On receiving RA from higher level MR, i.e., IMR, the MR obtains a CoA and performs *local binding update (LBU)* with the TLMR. Then the MR performs BU with the HA_MR. This BU packet contains the CoA_TLMR. The BU process results binding between HoA_MR and CoA_TLMR at the HA_MR. Thus, the HA_MR uses the CoA_TLMR as the tunnel end-point. Thus, in Fig. 1, a tunnel is established between HA_MR2 and TLMR1. So the packets will be delivered to TLMR directly and, the packets from TLMR1 to MNN5 (Fig. 1) are delivered using source route created using the first cache [11]. This achieves route optimization. The first cache is also used to create source-route to a destination within the mobile network, thus achieving intra-NEMO route optimization [2]. The second cache (cache of CNs) is used to notify CNs about the CoA_TLMR, which although limits the number of tunnels between CNs and MNN to one, results in binding update storm [12].

Like E2ERO, ROTIO [13] assumes tree topology of nested-NEMO and, addresses route optimization and intra-NEMO route optimization. Each MR maintains two caches: first cache maintains information of the MRs in its domain, and the second cache contains CoAs of higher level MRs. The information in the first cache is maintained as a 3-tuple: <HoA_MR, CoA_MR, source-route to MR>. The MR configures its CoA from RA which contains HoA_TLMR and CoA_TLMR. Then the MR performs LBU with TLMR. After successful LBU, the MR performs BU with the HA_MR, and sends the HoA_TLMR to the HA_MR. This mechanism creates a binding between HoA_MR and HoA_TLMR, resulting a bi-directional tunnel between HA_MR and HA_TLMR. For example, in Fig. 1, the successful binding update by MR2 results a tunnel from HA_MR2 to HA_TLMR1 and thus, the packet delivery from CN to MNN5 takes place through the path CN→HA_MR2→HA_TLMR1→TLMR1→IMR2→MR2→MNN5.

Table 1. Abbreviations

Abbreviation	Meaning
RA	Router advertisement
CPoA	Change in Point of Attachment packet
IM/AR	Higher Level IMR or AR for an MR (Example: in Fig. 1, IMR2 is higher level MR for MR2, and AR1 is higher level AR for TLMR1)
NM/AR	New MR or AR under which MR can move
PM/AR	Previous MR or previous AR
HA_MR	HA of MR
HoA_MR	Home Address of MR
CoA_MR	CoA of MR
BU	Binding Update packet
BAck	Binding Acknowledgement packet
PBU	Proxy Binding Update [16] packet
LPBU	Local PBU packet
PBAck	Proxy Binding Acknowledgement [16] packet
LPBAck	Local PBAck packet
NCoA	New CoA, i.e., CoA that is valid under NM/AR
UNA	Unsolicited Neighbor Advertisement [6] packet

In [14], the authors proposed to use two additional entities: correspondent router (*CR*) and optimization-capable local fixed nodes (*OLFN*). The CR is responsible for route optimization for a group of CNs, whereas, OLFN is responsible for prioritization of sessions by discovering appropriate CR for the sessions. This scheme increases complexity of route optimization for two reasons: first, the deployment and discovery of appropriate CR for a CN, and the second is deciding priority of the sessions using OLFN. These facts make the protocol deployment very costly.

Common advantage of the discussed route-optimization protocols is that the number of tunnels between CN and MNN (CN and MNN5 in Fig. 1) is always constant (for example, it is 1 in case of E2ERO and 2 in case of ROTIO). This indirectly reduces rate of increase in handoff delay with increase in nesting level, since signaling packets now follow optimized route between MR and HA_MR. Common disadvantages are late movement detection and delay in duplicate address detection (DAD) [15].

From the discussion of the NEMO protocols, we observe that both fast handoff and route optimization NEMO protocols cannot meet demand for seamless Internet connectivity: the fast handoff protocols reduces delay in acquiring CoA but does not avoid tunnels, whereas, the route optimization protocols avoids tunnels but increases delay in acquiring CoA. This paradoxical scenario calls for a NEMO protocol that should satisfy two fundamental objectives: first, fast handoff and route optimization at any level of a nested-NEMO, and the second, zero packet loss in case of successful anticipation. In the next section we propose FHE2ERO that meets these two objectives by improving E2ERO. We preferred to improve E2ERO because E2ERO limits the number of tunnels between MNN and CN to one.

3. Proposed Protocol: FHE2ERO

In this section, we describe the working principles of FHE2ERO. Since FHE2ERO improves E2ERO, it inherits two advantages of the protocol: route optimization and intra-NEMO route optimization. The disadvantage of E2ERO, that is, late movement detection is eliminated by adding by adding fast handoff feature to FHE2ERO. In addition to these, as we shall describe, FHE2ERO also reduce the signaling cost in its route optimization process. The abbreviations used to describe FHE2ERO are given in Table I[2].

3.1. Design Objectives

In addition to providing fast handoff, route optimization, and intra-NEMO route optimization, following are the design objectives behind FHE2ERO:

1. Reducing handoff delay and packet loss duration without adding any new network entities.
2. Reducing delay in route optimization process.
3. The protocol should require minimum software changes in the existing network entities.
4. Avoiding sequential processing of L2 and L3 handoff whenever possible.
5. Ensuring zero packet loss during successful anticipation and fast resuming of connection if anticipation is not successful.

3.2. Assumptions

1. MRs are organized in hierarchical structure (Fig. 1).
2. Every MR periodically announces its presence using RA in which it includes HoA_TLMR and CoA_TLMR [4].
3. Each MR maintains a cache of MRs under its domain. Each entry in the cache is a 3-tuple: <HoA_MR, CoA_MR, NEMO prefix of MR> [4].
4. Each AR and MR maintains a Boolean variable, ***W***, to specify their respective type. If W is 1 then the router is an MR, otherwise the router is an AR.

3.3. Protocol Description

FHE2ERO has two modes of operation: predictive mode and reactive mode. In *predictive mode*, infrastructure network perform handoff on behalf of the MR. More specifically, the MR anticipates handoff, notifies the event to the infrastructure network, and then the infrastructure network performs fast handoff and route optimization. The protocol operates in *reactive mode*, when the MR detects new point of attachment to the Internet other than the anticipated IM/AR; the detection uses RA from IM/AR. In the reactive mode, the MR performs handoff and route optimization.

3.2.1. Predictive Mode of Operation

Fig. 2 gives a quick look of the fast handoff and route optimization operation of FHE2ERO in predictive mode. On receiving L2-trigger, the MR sends a CPoA containing HA_MR and HoA_MR to its default gateway, i.e. PM/AR, thereby, starting the fast handoff process. Then the PM/AR finds NM/AR under which the MR can move [17]. After predicting the NM/AR and then using the CPoA, the PM/AR creates an Address Request packet

[2] Some of the abbreviation has been repeated for ready reference.

containing the following information: <HoA_MR, HA_MR, CoA_TLMR>. The Address Request packet is then sent to the NM/AR.

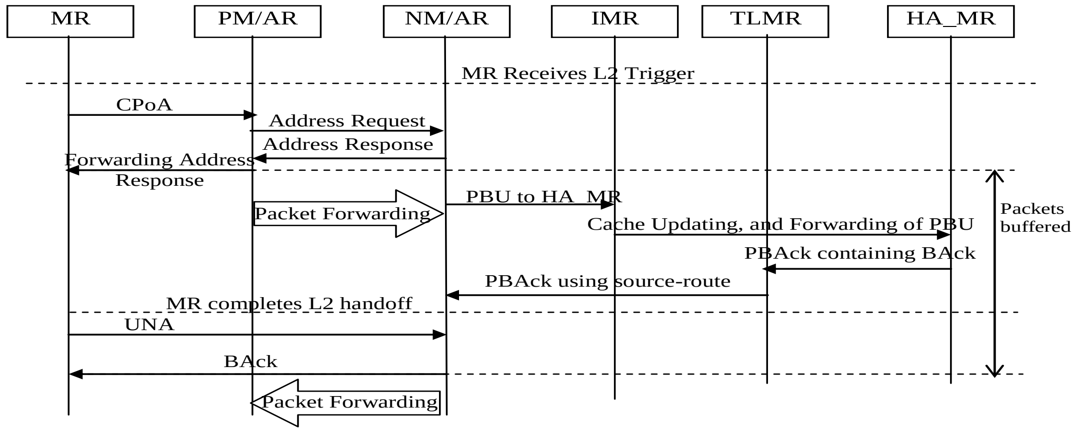

Figure 2. Predictive Mode Operation of FHE2ERO

On receiving the Address Request packet, the NM/AR does the following in sequential order:

1. An Address Response packet is sent to the PM/AR with appropriate status. The packet holds the NCoA if the status is a success. The field for NCoA is invalid if status is not a success and the next step is not executed.
2. Sends a PBU (if the movement is not within the same TLMR, i.e., in case of global handoff) to HA_MR with the following information: <HoA_MR, NCoA_MR, CoA_TLMR>. The CoA_TLMR is already known from RAs. A new bit 'W' (from reserved field of PBU) is set to the same value as the variable W (assumption 4 of section 3.2). This step separates L2 and L3 handoff for the MR.

After receiving the Address Response packet from NM/AR, the PM/AR checks the status of the packet. If the status indicates a success, then the PM/AR starts forwarding the packets to NM/AR, where the packets get buffered and delivered as soon as MR announces its presence using UNA. The status, along with the NCoA (if status is a success), is forwarded to the MR; this packet also includes L2 address of the NM/AR which is used by the MR to send UNA to NM/AR.

After receiving the PBU, every IMR (including TLMR) checks its cache to find out whether the information regarding the MR (for which PBU is sent) is present in its cache (assumption 3 of section 3.2). If the information is not present, then the following entry is added into the cache: <HoA_MR, CoA_MR, NEMO prefix of MR>. The PBU is then forwarded to higher IMR or AR. When the HA_MR receives the PBU, it adds an entry to its binding cache where the entry is a 4-tuple: <HoA_MR, CoA_MR, W, CoA_TLMR>. If W is 0 (assumption 4 of section 3.2), then the field corresponding to CoA_TLMR has no significance. The HA_MR then creates a BAck packet and encapsulates the packet in a PBAck packet. The PBAck packet has following information:

- The outer header has the same format as in PBAck, with an additional bit W, taken from the reserved field. W bit is copied from the PBU.
- The mobility option contains the CoA of NA/MR. If W bit is 0, then this field will not be interpreted by an AR.

The PBAck packet is then sent to CoA_TLMR, if W=1, or to the AR, in case W=0. Note that the PBAck is used to send BAck since the MR cannot use the assigned CoA (by PM/AR) until it receives the BAck from HA_MR.

When AR receives the PBAck, it checks the 'W' bit. If W bit is 0, and the MR has sent UNA to the AR, then the packet is decapsulated[3] and, the BAck is sent to the MR; if MR has not sent the UNA then the BAck is buffered at the AR and is delivered to the MR when it sends UNA. If the W bit set to 1, then the AR simply forwards the packet to the next hop. When the TLMR receives the PBAck, it modifies the header and adds a source-route (extended type-0 routing header [16]). The source-route is created using CoA of NA/MR and the cache of MRs maintained at the TLMR (assumption 3 of section 3.2) and using same algorithm as in E2ERO.

When the NM/AR receives the PBAck, it decapsulates the packet, and retrieves the BAck. If the MR has not sent the UNA, then the packet is buffered at the NM/AR, and is delivered to the MR as soon as it announces its arrival using UNA. However, if UNA is received from the MR, then the BAck is delivered immediately to the MR. When the MR receives the BAck, a bi-directional tunnel from CoA_TLMR to HA_MR is formed. Thus the number of tunnels between the MR and the HA_MR is always 1, irrespective of the nesting level.

3.2.2. Reactive Mode of Operation

The reactive mode operation of FHE2ERO is shown in Fig. 3. When the MR receives an RA with TLMR information, it checks with the default gateway to which it is trying to attach. If the source of RA is different from its expected IM/AR, then it obtains NCoA from the visited network, and then sends a BU packet to the HA_MR as in NBSP. The BU packet contains the CoA_TLMR. After receiving BU, each IMR checks it cache to find out whether there is an entry corresponding to the MR. If the entry does not exist, then an entry is added as described in the predictive mode, and the packet is forwarded to the higher level IMR. When the HA_MR receives the BU it creates a binding between CoA_TLMR, CoA_MR, and HoA_MR in its binding cache, and sends a BAck to the MR. When AR receives BAck, it forwards the packet to next hop, that is, the TLMR under which the MR is present. When the TLMR receives BAck, it extracts the CoA_MR and creates a source-route to the MR as in the predictive mode of operation. Then the packet is encapsulated and the source-route is added to the outer header. The packet then sent to the MR. When the MR receives BAck, it activates the NCoA as its present CoA. Since binding is formed between CoA_TLMR and HoA_MR, the number of tunnels between MR and the HA_MR in this mode is also one.

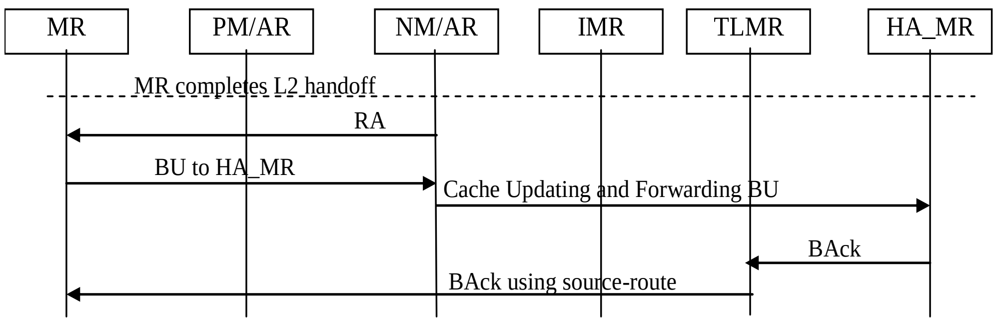

Figure 3. Reactive Mode Operation of FHE2ERO

[3] Note that in FHE2ERO, we need to decide which type of router (AR or MR) has sent the PBU. If AR has sent the PBU, then it can do so only if the arriving MR can move directly under it. In that case it does need to create a source route. However, if an IMR has sent the PBU then the TLMR should be source-routing the PBAck to the IMR.

3.2.3. Local Handoff

Local handoff occurs when the MR moves from one IMR to another IMR, both being within the domain of a TLMR. In predictive mode, NM/AR distinguishes between local and global handoff by matching the CoA_TLMR received from Address Request packet: if CoA_TLMR is same as the CoA_TLMR of the NM/AR, then the handoff is a local handoff. In this case, the IMR, under which the MR can move, sends a LPBU to the TLMR. LPBU is a modification of PBU with ***C bit*** set to 1. If C bit is set to 0, then the packet will be a PBU. Then the TLMR sends back an LPBAck. LPBAck is a modification of PBAck packet with C bit set to 1; if C is 0 then the packet is a PBAck.

In reactive mode, MR distinguishes between local and global handoff by looking into CoA_TLMR field of RA (assumption 2 of section 3.2). If CoA_TLMR field of the RA is same as the CoA_TLMR of the MR, then the handoff is a local handoff. In this case, local BU (LBU) and local BAck (LBAck) will be exchanged between the TLMR and the MR with C bit set to 1.

3.2.4. Route Optimization and Packet Delivery

Let us consider Fig. 1 to illustrate the packet delivery process of FHE2ERO. The packet sent by the CN to MNN5 is intercepted by HA_MR2. The HA_MR2 will refer to the binding cache for entry about MNN5. The longest prefix match algorithm is used to find the MR under which MNN5 is present. When such entry is found, the packet is encapsulated with destination address of the outer header set to CoA_TLMR, and CoA_MR is placed in type-2 routing header. When the TLMR receives the packet, it replaces the type-2 routing header by extended type-0 routing header, with source route to the MR. The source route, with CoA_MR as the last hop, is created as in E2ERO. The destination address is the next hop in the (nested) mobile network along the path to the MR. When the MR receives the packet, it extracts the inner packet and delivers the extracted packet to the MNN5. Thus, the number of tunnels from CN to MNN remains same as in E2ERO, i.e., 1.

3.2.5. Intra-NEMO Route Optimization

For intra-NEMO route optimization, an MR after receiving a packet, checks whether there is a source-route attached to the packet. If the source route is present then the MR updates the source-route and forwards the packet to the next hop. If source-route is not present, then the MR checks its cache whether the destination exist in its domain. If destination exists in the domain, then it creates a source-route to the destination as in E2ERO, adds the route to extended type-0 routing header, and attaches the header to the packet. Then the MR sends the packet to the next hop in the source-route.

4. Performance Analysis

We compare the performance of FHE2ERO with E2ERO in terms of handoff delay and packet loss duration during handoff. We first define the performance parameters, followed by the assumptions on network model and performance evaluation. The notations used for analysis are given in Table 2.

4.1. Definitions

1. ***Handoff Delay (h)***: The interval between the connection break-up at L2 to receiving BAck by the MR.
2. ***Packet Loss Duration (γ):*** Interval between the connection break-up at L2 to the completion of route optimization process.

Table 2. Notations used in Quantitative Analysis

Notation	Meaning
l	Nesting level
$h_{E2ERO-G}$, $h_{E2ERO-L}$	Global and local handoff delay for E2ERO
$h_{FHE2ERO-P-G}$, $h_{FHE2ERO-R-G}$	Global handoff delay for FHE2ERO in predictive and reactive mode respectively
$h_{FHE2ERO-P-L}$, $h_{FHE2ERO-R-L}$	Local handoff delay for FHE2ERO in predictive and reactive mode respectively
$\gamma_{E2ERO-G}$, $\gamma_{E2ERO-L}$	Global and local packet loss duration for E2ERO respectively
$\gamma_{FHE2ERO-P-G}$, $\gamma_{FHE2ERO-R-G}$	Global packet loss duration for FHE2ERO in predictive and reactive mode respectively
$\gamma_{FHE2ERO-P-L}$, $\gamma_{FHE2ERO-R-L}$	Local packet loss duration for FHE2ERO in predictive and reactive mode respectively

4.2. Assumptions on Network Model

1. The organization of MNNs, MRs, HAs and CNs is as shown in Fig. 1.
2. The MR under observation is at lowest level of nesting, level *l*.
3. The inter-MR communication delay (direct link between two MRs) is same in both directions and, is equal to the communication delay between AR and any TLMR under it.
4. The communication delay between HA of one MR to HA of another MR through Internet, is equal to the communication delay between CN and gateway router (or HA of MR). This delay is equal to the communication delay between gateway router and HA of any MR.

4.3. Parameters

The parameters used in numerical analysis are shown in Table 3. The values of the parameters are taken from [18] and [19].

Table 3. Parameters Used in Quantitative Analysis

Parameter	Meaning	Value
$T_{wireless}$	Inter-MR delay	6 ms
$T_{internet}$	Delay between gateway router and HA	1088 ms
T_{wired}	Delay between AR and gateway router	2 ms
T_{L2}	Delay in L2 handoff	50 ms
T_{DAD}	Delay in DAD	500 ms
T_{adv}	L3 advertisement interval	30ms

4.4. Analysis of Handoff Delay

4.4.1. Analysis of Global Handoff Delay

Global handoff occurs when the MR moves from one TLMR to another TLMR, one AR to a TLMR and vice versa, or, one AR to another AR. For E2ERO, $h_{E2ERO-G}$ includes T_{L2}, average of T_{adv} and $T_{wireless}$, T_{DAD}, (l-1) times $T_{wireless}$ (for sending a LBU to TLMR), (l-1) times $T_{wireless}$ (for getting LBAck), twice the l times $T_{wireless}$ + T_{wired}+ $T_{internet}$ (for exchanging BU and BAck between MR and HA_MR). Thus, the expression for $h_{E2ERO-G}$ is:

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$$h_{E2ERO-G} = T_{L2} + (\frac{T_{adv} + T_{wireless}}{2}) + T_{DAD} + 2\{(l-1)T_{wireless}\} + 2\{lT_{wireless} + T_{wired} + T_{internet}\} \quad (1)$$

Simplifying,

$$h_{E2ERO-G} = (\frac{8l-3}{2})T_{wireless} + 2T_{internet} + 2T_{wired} + T_{L2} + T_{DAD} + \frac{T_{adv}}{2} \quad (2)$$

For FHE2ERO, $h_{FHE2ERO-P-G}$ includes $T_{wireless}$ (for sending CPoA), $T_{wireless}$ or $2T_{wired}$ (for sending Address Request in wired or wireless link, for *l*=1 or *l*>1 respectively) [4], T_{DAD}, duration involving sending PBU, receiving PBAck, completing L2 handover and sending UNA, and, receiving BAck from NM/AR. The duration for exchanging PBU, PBAck, completing L2 handover and sending UNA will be maximum of two durations: delay in exchanging PBU and PBAck with HA and; delay in completing L2 handover and sending UNA to NM/AR (which is AR for *l*=1 and IMR for *l*>1). Thus,

$$h_{FHE2ERO-P-G} = \begin{cases} T_{wireless} + 2T_{wired} + T_{DAD} + Max\{2T_{wired} + 2T_{internet}, 2T_{wired} + T_{wireless} + T_{L2} + T_{wireless},\} + T_{wireless}; \quad (l=1) \\ T_{wireless} + T_{wireless} + T_{DAD} + Max[2\{(l-1)T_{wireless} + T_{wired} + T_{internet}\}, \{T_{wireless} + T_{wireless} + T_{L2} + T_{wireless}\}] + T_{wireless}; (l>1) \end{cases} \quad (3)$$

Rearranging we get,

$$h_{FHE2ERO-P-G} = \begin{cases} 2T_{wireless} + 2T_{wired} + Max\{2T_{wired} + 2T_{internet}, 2T_{wired} + 2T_{wireless} + T_{L2}\} + T_{DAD}; \ (l=1) \\ 3T_{wireless} + Max\{2(l-1)T_{wireless} + 2T_{internet} + 2T_{wired}, 3T_{wireless} + T_{L2}\} + T_{DAD}; \quad (l>1) \end{cases} \quad (4)$$

$h_{FHE2ERO-R-G}$ includes T_{L2}, $(T_{adv}+T_{net})/2$ (average delay in receiving RA), T_{DAD} and, delay in sending and receiving BU and BAck. Thus we have:

$$h_{FHE2ERO-R-G} = T_{L2} + (\frac{T_{adv} + T_{wireless}}{2}) + T_{DAD} + 2(lT_{wireless} + T_{wired} + T_{internet}) \quad (5)$$

Simplifying we get:

$$h_{FHE2ERO-R-G} = (\frac{4l+1}{2})T_{wireless} + 2T_{internet} + 2T_{wired} + T_{L2} + T_{DAD} + \frac{T_{adv}}{2} \quad (6)$$

Fig. 4 shows the comparison between global handoff delay experienced in E2ERO and FHE2ERO based on equation 1 to 3, and values from Table 3. From Fig. 4, it is clear that FHE2ERO performs much better than E2ERO even in reactive mode, and the performance gain increases as the nesting level increases. This happens because MR performs local binding update process with TLMR along with the global handoff process. Note that in Fig. 4, FHE2ERO in predictive mode has a greater slope from *l*=1 to *l*=2. This is because for *l*=1, Address Request and Address Response packets exchanged using wired link, whereas, for

[4] In Fig. 1, the packets between AR1 to AR2 pass through the Gateway Router.

l≥2, the same packets are exchanged using wireless link, where the delay is higher than the wired link ($T_{wireless}$>2T_{wired}).

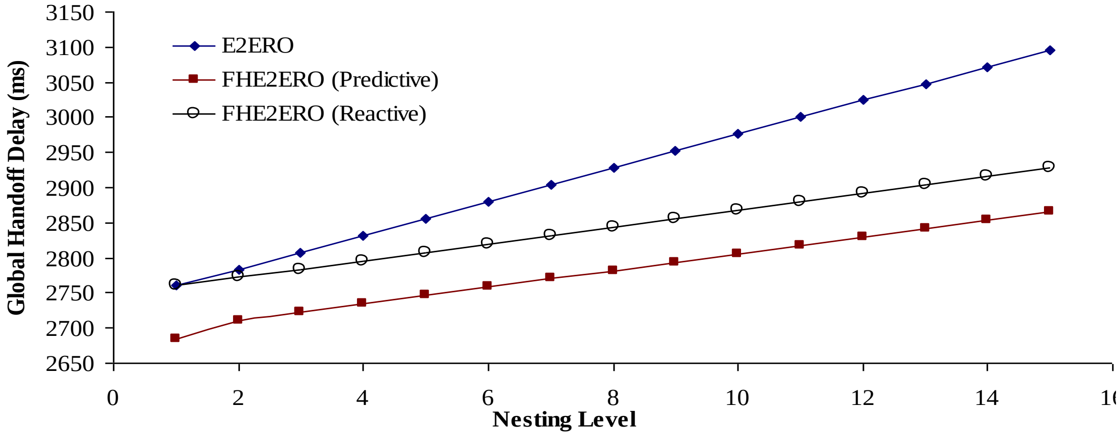

Figure 4. Comparison of Global Handoff Delay

4.4.2. Analysis of Local Handoff Delay

Local handoff takes place when MR moves within the domain of the TLMR. For *l*=1, the MR will be the TLMR. For *l*=2, the MR moves directly under a TLMR and hence no local handoff will take place. So, for both E2RO and FHE2ERO, local handoff is applicable for *l*>2, and the respective local handoff delays will not include the delay for performing binding update with HA. So, $h_{E2ERO\text{-}L}$ is obtained from $h_{E2ERO\text{-}G}$ by subtracting the delay in performing binding update with the HA, i.e., the term 2($lT_{wireless}$+T_{wired}+$T_{internet}$). Thus, we have:

$$h_{E2ERO-L} = (\frac{4l-3}{2})T_{wireless} + T_{L2} + T_{DAD} + \frac{T_{adv}}{2};\ (l>2) \tag{7}$$

Similarly for FHE2ERO, $h_{FHE2ERO\text{-}P\text{-}L}$ is obtained from $h_{FHE2ERO\text{-}G}$ (equation 2) by removing the term 2(T_{wired}+$T_{internet}$), replacing (*l*-1) by (*l*-2), and imposing the condition *l*>2. Thus, we have:

$$h_{FHE2ERO-P-L} = 3T_{wireless} + Max\{2(l-2)T_{wireless}, 3T_{wireless} + T_{L2}\} + T_{DAD};\quad (l>2) \tag{8}$$

In reactive mode, $h_{FHE2ERO\text{-}R\text{-}L}$ includes T_{L2}, average of 0 and (T_{adv}+$T_{wireless}$) (delay in receiving RA), T_{DAD}, and delay in exchanging LBU and LBAck. Thus we have:

$$h_{FHE2ERO-R-L} = T_{L2} + (\frac{T_{adv} + T_{wireless}}{2}) + T_{DAD} + 2(l-1)T_{wireless};\qquad (l>2) \tag{9}$$

Simplifying we get,

$$h_{FHE2ERO-R-L} = (\frac{4l-3}{2})T_{wireless} + T_{L2} + T_{DAD} + \frac{T_{adv}}{2};\ (l>2) \tag{10}$$

Based on equations 4 to 6, we draw the comparison graph as shown in Fig. 5. From Fig. 5, we see that the FHE2ERO in predictive mode performs much better than E2ERO. This happens due to anticipation of handoff using L2 trigger. We also see that till *l*=7, $h_{FHE2ERO\text{-}P\text{-}L}$ remains unchanged. This is because for *l*<8, the PBAck reaches IMR before the MR sends UNA to the NM/AR and hence in equation 5, 3$T_{wireless}$+T_{L2} > 2(*l*-2)$T_{wireless}$. FHE2ERO in reactive mode performs same as E2ERO since the MR performs BU with TLMR using equivalent sequence of packet exchange.

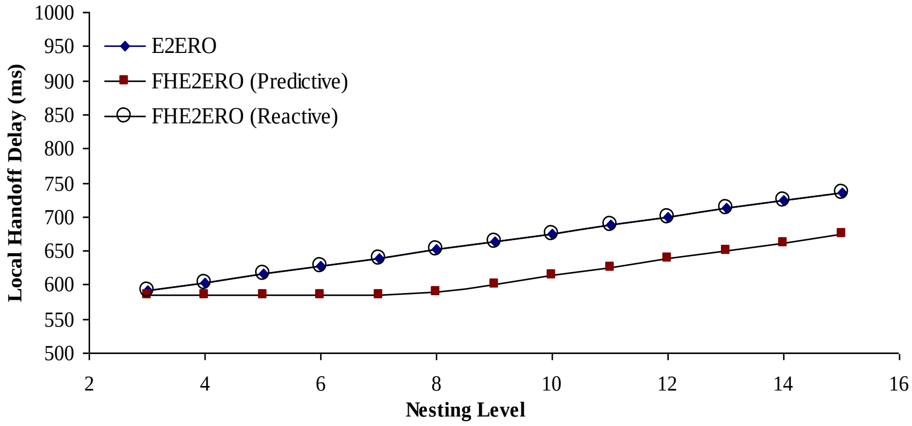

Figure 5. Comparison of Local Handoff Delay

4.5. Analysis of Packet Loss Duration

For E2ERO, $\gamma_{E2ERO\text{-}G}$ and $\gamma_{E2ERO\text{-}L}$ contain duration from start of L2 handoff, to the receipt of BU by HA_MR and LBU by TLMR respectively[5]. So, $\gamma_{E2ERO\text{-}G}$ and $\gamma_{E2ERO\text{-}L}$ can be obtained from $h_{E2ERO\text{-}G}$ and $h_{E2ERO\text{-}L}$ by subtracting ($lT_{wireless}+T_{wired}+T_{internet}$) and ($l$-1)$T_{wireless}$ respectively. Thus,

$$\gamma_{E2ERO-G}=(\frac{6l-3}{2})T_{wireless}+T_{internet}+T_{wired}+T_{L2}+T_{DAD}+\frac{T_{adv}}{2} \quad (11)$$

$$\gamma_{E2ERO-L}=(\frac{2l-1}{2})T_{wireless}+T_{L2}+T_{DAD}+\frac{T_{adv}}{2};(l>2) \quad (12)$$

For FHE2ERO in predictive mode, the packets are redirected to NM/AR and are buffered at the NM/AR. So, the expressions for $\gamma_{PROPOSED\text{-}P\text{-}G}$ and $\gamma_{PROPOSED\text{-}P\text{-}L}$ are:

$$\gamma_{FHE2ERO-P-G}=\gamma_{FHE2ERO-P-L}=0 \quad (13)$$

For reactive mode of FHE2ERO, packet loss occurs, and the duration is obtained by subtracting the delay in receiving BAck and LBAck (in case nesting level is greater than 1), i.e., the terms ($lT_{wired}+T_{wired}+T_{internet}$) from $h_{FHE2ERO\text{-}R\text{-}G}$ (for $\gamma_{FHE2ERO\text{-}R\text{-}G}$), and ($l$-1)$T_{wireless}$ from $h_{FHE2ERO\text{-}R\text{-}L}$ (for $\gamma_{FHE2ERO\text{-}R\text{-}L}$). Thus we have,

$$\gamma_{FHE2ERO-R-G}=(\frac{2l+1}{2})T_{wireless}+T_{internet}+T_{wired}+T_{L2}+T_{DAD}+\frac{T_{adv}}{2} \quad (14)$$

$$\gamma_{FHE2ERO-R-L}=(\frac{2l-1}{2})T_{wireless}+T_{L2}+T_{DAD}+\frac{T_{adv}}{2};(l>2) \quad (15)$$

Based on equation 7, 9 and 10, and Table 3, we draw the comparison graph (Fig. 6). From Fig. 6, we see that there is no packet loss for FHE2ERO in predictive mode. This is because the redirected packets are buffered at NM/AR. However, packet loss occurs in reactive mode but the duration is still less than that of E2ERO. This is due to the fact that in

[5] The packet will be redirected by HA_MR and TLMR as soon as it receives BU and LBU respectively.

the case of FHE2ERO, the local binding update with TLMR and the global binding update with HA of MR are performed simultaneously.

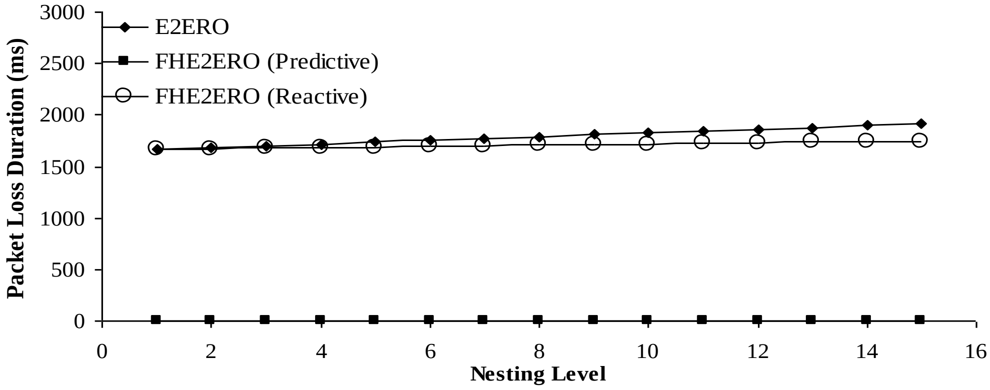

Figure 6. Comparison of Packet Loss in Global Handoff

Based on equations 8, 9 and 11, the comparison graph is drawn as in Fig. 7. Fig. 7 shows the benefit of using FHE2ERO in predictive mode. However, the reactive mode operation shows the same performance as E2ERO. This is because FHE2ERO and E2ERO use equivalent sequence of packet exchange to perform their respective local handoffs.

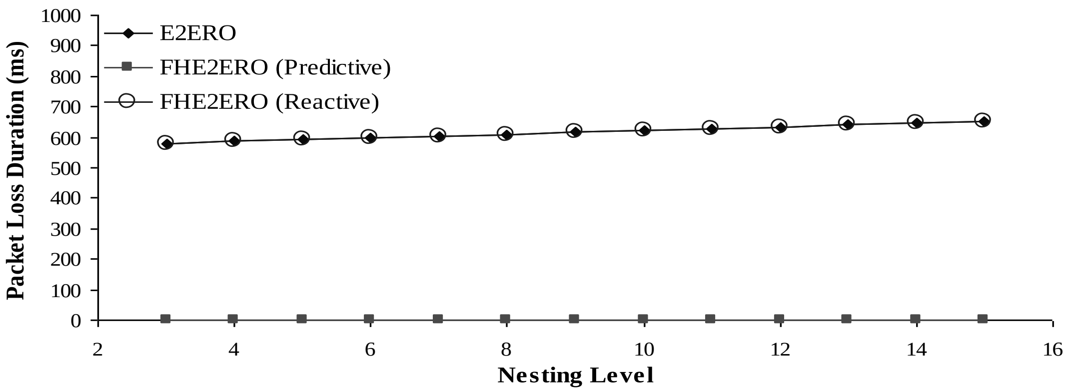

Figure 7. Comparison of Packet Loss in Local Handoff

5. Conclusion

We have proposed FHE2ERO protocol for nested-NEMO that also supports intra-NEMO route optimization. Performance analysis in terms of handoff delay and packet loss duration show significant improvement in both the parameters. Since the handoff delay and packet loss duration is low in FHE2ERO, the MR can provide seamless or fast resuming of data service, thus providing higher throughput. We also see that the local handoff delay for FHE2ERO remains same till nesting level 7. This makes FHE2RO an attractive solution for loss sensitive applications like disaster relief, telemedicine over IP, etc and, in the scenarios where vehicle's trajectory can be predicted with high success rate. To implement our solution, the MR, AR, and HA need to be upgraded to interpret incoming and outgoing modified mobility headers.

As a future work, we will look into to the total buffer requirements for the vehicles under an AR/MR, and check whether the cost of maintaining the buffer is surpassed by the benefits of reducing handoff delay and packet loss duration. Moreover, we will verify the analytical results with simulation and experiments. The algorithm outlined in Appendix 1 can be used for future implementation.

References

[1] Devarapalli. V, Wakikawa. R., Petrescu. A., Thubert. P., "Network Mobility (NEMO) Basic Support Protocol", IETF RFC 3963, January, 2005.

[2] Ernst. T., "Network Mobility Support Goals and Requirements", IETF RFC 4886, July, 2007.

[3] Ng C., Zhao F., Watari M., Thubert P., "Network Mobility Route Optimization Solution Space Analysis", IETF RFC 4889, July 2007.

[4] Kuo G.S., Ji. K., "Novel Hierarchical Network Mobility Support Protocol with Bidirectional End-to-end Route Optimization Solution for Nested Mobile Networks", IEEE Globecom, 2006. http://dx.doi.org/10.1109/GLOCOM.2006.340

[5] Zhong L., Liu F., Wang X., Ji Y., "Fast Handover Scheme for Supporting Network Mobility in IEEE 802.16e BWA System", WiCom 2007. http://dx.doi.org/10.1109/WICOM.2007.441

[6] Koodli R. Ed., "Mobile IPv6 Fast Handovers", IETF RFC 5568, July 2009.

[7] Jung W.J., Ki H.J., Lee T.J., Choo H., Chung M.Y., "Cross-Layer Design for Reducing Handoff Latency in Mobile Network", LNCS 4706, Part II, pp216-225, ICCSA 2007. http://dx.doi.org/10.1007/978-3-540-74477-1_22

[8] Islam. S., Abdalla. A.H., Othman O. Khalifa, M.K.H., Mahmud O., Saeed R.A., "Macro Mobility Scheme in NEMO to Support Seamless Handoff", ICCCE 2012. http://dx.doi.org/10.1109/ICCCE.2012.6271186

[9] Wen W.C., Ping. W., "Improved Fast Handover Scheme for Hierarchical Mobile IPv6 Network Mobility", *Wireless Personal Communication*, 2009.

[10] Soliman H., Castellucci C., ElMarki K., Bellier L., "Hierarchical Mobile IPv6 (HMIPv6) Mobility Management", IETF RFC 5380, October 2008.

[11] Thubert P., Molteni M., "IPv6 Reverse Routing Header and its Application to Mobile Networks", IETF Draft, August 2007. Available from: http://tools.ietf.org/html/draft-thubert-nemo-reverse-routing-header-07

[12] Ferng. H.W., Laksmono. T., "Route Optimization Using the Distributed Binding Update for Nested Mobile Networks", *Wireless Communication and Mobile Computing*, 2012. http://dx.doi.org/10.1002/wcm.2323.

[13] Cho. H, Kwon. T, Choi. Y, "Route Optimization Using Tree Information Option for Nested Mobile Networks", *IEEE JSAC*, vol. 24, issue 9, pp 1717-1724, September 2006. http://dx.doi.org/10.1109/JSAC.2006.875110

[14] Kong R., Feng J., Gao R., Zhou H., "A New Route Optimization Scheme for Network Mobility: Combining ORC Protocol with RRH and Using Quota Mechanism", *Journal of*

Communications and Networks, vol. 14, no. 1, February 2012. http://dx.doi.org/10.1109/JCN.2012.6184554

[15] Moore N., "Optimistic Duplicate Address Detection (DAD) for IPv6", IETF RFC 4429, April, 2006.

[16] Gundavelli. S, ed., Leung. K., Devarapalli. V., Chowdhury. K., Patil. B., "Proxy Mobile IPv6", IETF RFC 5213, August 2008.

[17] Mao Shan, Worrall S., Nebot E., "Probabilistic Long-Term Vehicle Motion Prediction and Tracking in Large Environments", IEEE Transactions on Intelligent Transportation Systems, vol. 14, issue 2, pp 539-552, June 2013. http://dx.doi.org/10.1109/TITS.2012.2224657

[18] Makaya C., Pierre S., "An Analytical Framework for Performance Evaluation of IPv6-Based Mobility Management Protocols", *IEEE Transactions on Wireless Communications*, vol. 7, no. 3, March 2008. http://dx.doi.org/10.1109/TWC.2008.060725

[19] Perkins C., ed., Johnson D., Arkko J., "Mobility Support in IPv6", IETF RFC 6275, July 2011.

Appendix 1

The working procedures of network entities, i.e., MR, AR and HA_MR that can be used for implementation in simulations and experiments are given below.

1. Steps followed by an MR

1. If the received message is an L2 trigger, then:
    1.1. Send a CPoA packet to the default gateway (PM/AR) with the following information-
        1. Sender's address as CoA of this MR.
        2. Receiver's address as PM/AR.
        3. IP address of HA_MR.
        4. HoA_MR of this MR.

2. If the received packet is a CPoA packet then:
    2.1. Predict the NM/AR for the MR.
    2.2. Create an Address Request packet with the following information-
        1. Sender's address as PM/AR.
        2. Receiver's address as NM/AR.
        3. HoA_MR.
        4. IP address of HA_MR.
        5. CoA_TLMR of this MR. [This will be used for deciding whether the handoff is a Local or global handoff].
    2.3. Send the Address Request packet.

3. If the received packet is an Address Request packet then:
    3.1. If the credentials are valid then:
        3.1.1. Formulate NCoA for MR (NCoA_MR).
        3.1.2. Send an Address Response packet to source address of Address Request packet containing the following information-
            1. Destination address of the packet is same as the source address of Address Request packet.
            2. Source address as CoA of this MR.
            3. Status field indicating success.
            4. CoA_MR obtained from the Address Request packet.
            5. NCoA_MR.
        3.1.3. If the CoA_TLMR of Address Request is same as CoA_TLMR of this MR then send LPBU with the following information-
            1. NCoA_MR.
            2. HoA_MR.
            3. CoA_TLMR.
            4. W bit to 1 [Signifying that LPBU is sent from an MR].
            5. C bit to 1 [Signifying that this message is send for local binding update].
        3.1.4. Else: send a PBU to HA_MR with the following information-
            1. HoA_MR
            2. NCoA_MR
            3. CoA_TLMR [Obtained from RA]
            4. W bit set to 1 [The router is an MR].
            5. C bit set to 0 [signifying that this message is sent for global binding

Update].

3.2. If the credentials are not valid then send an Address Response packet with the following information-

1. Destination address is same as that of source address of Address Request Packet.
2. Source address as the CoA of this MR.
3. Status field set to a value indicating failure.

4. If the received packet is an Address Response packet then:
   4.1. Set the destination address to CoA_MR (obtained from Address Response packet),
   4.2. Add L2 information of NM/AR.
   4.3. Forward the Address Response packet.
   4.4. If the status of Address Response packet indicates success then-
      4.4.1. Start forwarding packets to the NM/AR.

5. If the received packet is a forwarded Address Response then:
   5.1. If the status indicates a success then, save the NCoA.
   5.2. Else: try again.

6. If the received packet is a PBU packet then:
   6.1. Check whether there exists a cache entry of the MR (for which PBU is sent). If such entry does not exist then add a 3-tuple <HoA_MR, CoA_MR, NEMO prefix of MR> to its cache.
   6.2. Forward the PBU.

7. If the received packet is a PBAck packet then:
   7.1. If this MR is a TLMR then:
      7.1.1. Find the MR to which the PBack is to be sent.
      7.1.2. Add a type-0 reverse routing header that has the source-route to the MR.
      7.1.3. Send the packet to next hop MR.
   7.2. If this MR is not a TLMR then update the type-0 reverse routing header and forward the packet.
   7.3. If this MR is the last hop for the source-route then:
      7.3.1. De-capsulate the packet and extract the inner packet.
      7.3.2. Check if UNA corresponding to the destination MR of the inner packet has arrived or not. If UNA has arrived then send the inner packet immediately. Else, buffer the inner packet.

8. If the received packet is a LPBU packet but not its destination then:
   8.1. If this MR is not the destination of the LPBU then:
      8.1.1. Check whether there exists a cache entry of the MR (for which LPBU is sent). If such entry does not exist then add a 3-tuple <HoA_MR, COA_MR, NEMO prefix> to its cache and forward the LPBU.
   8.2. If this MR is the destination of the LPBU then:
      8.2.1. Check the credentials.
      8.2.2. If the credentials are valid then send LPBAck to proxying MR after attaching a source-route to the proxying MR.

9. If the received packet is a LPBAck packet then:
    9.1. If this MR is not at the last of the source-route then update the source-route and forward to next hop.
    9.2. If this MR is the last hop of the source-route then:
        9.2.1. Check if UNA has arrived from the MR for which it is proxying.
            9.2.1.1. If UNA has arrived, then extract the packet and send the packet to the MR immediately.
            9.2.1.2. Else buffer the packet.

10. If the received packet is LBU packet then:
    10.1. If this MR is not the destination of the LBU then:
        10.1.1. Check whether there exists a cache entry of the MR (for which LBU is sent). If such entry does not exist then add a 3-tuple <HoA_MR, CoA_MR, NEMO Prefix> to its cache and forward the LBU.
    10.2. If this MR is the destination of the LBU the:
        10.2.1. Check the credentials.
        10.2.2. If the credentials are valid then send LBAck to the MR after attaching the source-route to the MR.

11. If the received packet is LBAck packet then:
    11.1. If this MR is not the last hop of the source-rote the update the source-route and forward to next hop.
    11.2. If this MR is the last hop of the packet then:
        11.2.1. Take action according to the status of LBAck.

12. If the received packet is a data packet.
    12.1. If the packet has destination address as this MR and the inner packet has destination address that lies under this MR, then add a source-route to inner packet and send to the next hop.
    12.2. If the packet has destination address that lies under this MR then add a source route to the packet and send to the next hop.
    12.3. If the destination address is not under this MR then forward the packet.
    12.4. If the received packet has a destination address for which binding update process is not completed [case for the packets that needs to be buffered], then-
        12.4.1. Allocate the buffer if it is not allocated previously.
        12.4.2. Buffer the packet.

13. If the received packet is UNA packet, then:
    13.1. Check whether the PBAck has arrived for the MR.
    13.2. If the packet has arrived then:
        13.2.1. Send the BAck to the MR. Also start forwarding the packets that have been buffered till now.

14. If the received packet is an RA packet, then:
    14.1. Check whether the RA's source address as the same prefix to which this MR is associated to or trying to associate.
    14.2. If the prefix of the advertisement is different from the prefix of the router to which it has associated to then:
        14.2.1. Check whether the CoA_TLMR from the root-MR option is the same as

CoA_TLMR of this MR.

14.2.1.2. If they are same then send an LBU with the following information-
1. NCoA.
2. CoA_TLMR.
3. NEMO Prefix of MR.
4. C bit to 1.

14.2.1.3. If the CoA_TLMRs are different then:
14.2.1.3.1 Formulate NCoA using DAD.
14.2.1.3.2. Send a BU packet with the following information
1. NCoA.
2. CoA_TLMR.
3. NEMO Prefix of MR.

15. If the received packet is a BU packet then:
15.1. Check the cache entry for existing entry corresponding to source address.
15.2. If such entry does not exist then add the 3-tuple <HoA_MR, CoA_MR, NEMO Prefix of MR> to the cache.
15.3. Forward the BU packet.

16. If the received packet is a BAck packet then:
16.1. If this MR is TLMR then:
16.1.1. Check the destination address of type 2 routing header.
16.1.2. Create a source route (extended type-0) to the MR using the cache and add the same to the packet and send to the next hop.
16.2. If this MR is an IMR then:
16.2.1. Update the source-route.
16.2.2. Send the packet to next hop.
16.3. If this MR is the last hop of the packet then check the status of the BAck's fields.
16.3.1. If status indicates a success then:
16.3.2. Set the NCoA as CoA.
16.3.2. Else, try again as specified in NBSP.

2. Steps followed by an AR

1. If the received packet is a CPoA packet then:
1.1. Predict the NM/AR for the MR.
1.1. Send an Address Request packet to the NM/AR with the following information:
1. Source address as address of this AR
2. HoA_MR.
3. HA_MR.

2. If the received packet is an Address Request packet then:
2.1. If the credentials are valid then:
2.1.1. Formulate NCoA_MR.
2.1.2. Create an Address Response packet containing the NCoA and send it to the source address of the Address Request.
2.1.3. Create a PBU for the MR with the following information.
1. HoA_MR.
2. NCoA_MR

3. CoA_TLMR set to 0.
4. W bit set to 0 [signifying that AR is doing proxy binding update].

2.2. If the credentials are invalid then send appropriate invalid status in Address Response packet.

3. If the received packet is an Address Response packet then:
   3.1. If the status indicate a success then
      3.1.1. Forward the status and NCoA to MR.
      3.1.2. Start forwarding packets to NAR
   3.2. If the status message does not indicate a success then forward the status to MR.

4. If the received packet is a PBU then forward the message.

5. If the received packet is PBAck then:
   5.1. If W bit is 1 then forward the packet.
   5.2. If W bit is 0 then:
      5.2.1. Extract the inner packet.
      5.2.2. Check whether the corresponding MR has sent UNA or not. If the UNA has arrived then send the inner packet to MR immediately. Else buffer the packet.

6. If the received packet is a data packet then send the packet to the destination.

3. Steps followed by an HA_MR

1. If the received packet is a PBU packet then:
   1.1. If the W bit is 1 then:
      1.1.1. Check the credentials of PBU.
      1.1.2. If credentials are valid then:
         1.1.2.1. Update the binding update cache with the following information (HoA_MR, CoA_MR, W, CoA_TLMR). If W is 0 then CoA_TLMR will not be considered.
         1.1.2.2. Create BAck for the MR.

         1.1.2.3. Encapsulate the BAck into PBAck with the following information.
            1. CoA_NMR in a mobility header of new type.
            2. Set W to 1.
         1.1.2.4. Send the PBAck to appropriate destination.
   1.2. If W bit is 0 then:
      1.2.1. If the credentials are valid then:
         1.2.1.1. Create a BAck for MR
         1.2.1.2. Encapsulate the BAck into a PBAck packet with the blank information in the mobility header with W bit set to 0.
         1.2.1.3. Send the PBU to destination.

2. If the received packet is a BU packet then:
   2.1. If the credentials are valid then:
      2.1.1. Create a BAck as in NBSP.
      2.1.2. Send the packet to appropriate destination.

3. If the received packet is a data packet then:
   3.1. Check the destination MR under which the destination address can reside.
   3.2. If the corresponding entry of the MR has W bit as 0 then the data is encapsulated with CoA_MR as destination address and the packet is sent.
   3.3. If the corresponding entry of the MR has W bit as 1 then the data packet is encapsulated with CoA-TLMR as destination address and the packet is sent.