IEEE Wireless Communications and Networking Conference (WCNC), Budapest, 2009

NERON: A Route Optimization Scheme for Nested Mobile Networks

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***Abstract*—To manage the mobility of mobile networks, IETF has proposed MIPv6 based Network Mobility (NEMO) Basic Support protocol. However the NEMO protocol has severe performance limitations and does not specify the route optimization method for mobile networks and does not take into account the operational and functional complexities involving nested mobile networks. The Next Generation Network (NGN) however warrants and demands optimized protocol operation capabilities in terms of supporting nested mobile networks that would meet the stringent quality of service requirements imposed by NGN.**

This paper presents NERON: NEst Route Optimization for NEMO, an efficient and scalable approach that aims at enabling nodes behind nested mobile networks to use optimized communication paths with zero tunneling overhead and end-to-end delay, irrespective of the depth of the nest, with minimum changes to the base MIPv6 protocol and without introducing any new network entities. The performance results are validated using an accurate simulation model.

***Index Terms*—NEMO, Network Mobility, Nested Mobility, MIPv6, Route Optimization, Mobility Management.**

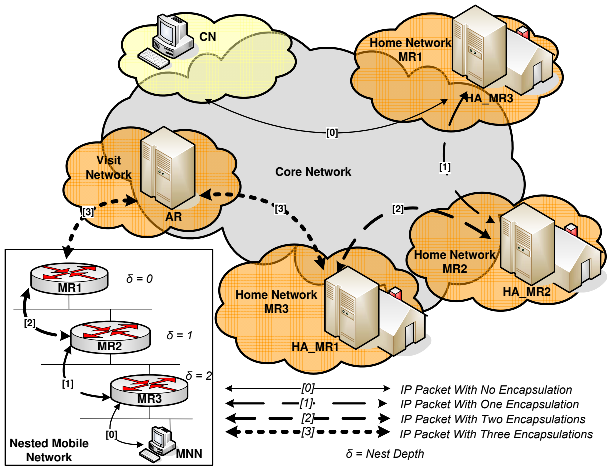


Fig. 1. Pinball Routing Problem in NEMO Without Route Optimization

I. Introduction

A. Background

The NGN is envisaged to be all-IP based and consisting of heterogeneous wireless access technologies providing ubiquitous and seamless communication to mobile entities over the Internet under the concept of Always Best Connected (ABC) [1] irrespective of their location. In the context of NGN, the mobile entities are not restricted to single mobile nodes but also encompasses mobile networks, such as fast moving buses, cars, trains, aeroplanes and ships. Inside these transport entities there are multiple network nodes (routers, switches and hosts) that interconnect creating a Vehicular Area Network (VAN) or a Personal Area Network (PAN) that may require access to the Internet while such a Mobile Network is changing its point of attachment to the Internet as it moves about. To manage and support the mobility of a Mobile Network, Internet Engineering Task Force (IETF) has proposed a NEMO Basic Support Protocol (NBSP) [2] which is an extension of the base MIPv6 protocol [3], a protocol designed to support the mobility of single host.

According to NBSP specification [2], a mobile network consists of several Mobile Network Nodes (MNN) attached to a Mobile Router's (MR) *ingress interface* whereas the MR connects the mobile network to the Internet via its *egress interface*. The MNNs of a mobile network are unaware of the mobility of the mobile network.

When a mobile network is at its home network, it is identified and reachable via its Home Address (HoA), which is auto-configured [4] or assigned [5] on the MR's egress interface based on the Home Agent's (HA) advertised address prefix on the home link. The prefix advertised on the MR's ingress interface inside the mobile network is called a Mobile Network Prefix (MNP), which is delegated from the subnet owned by the HA, and the MNNs configure their addresses with the advertised MNP. When the Mobile Network is away from its home network, the MR configures a Care-of-Address (CoA) on its egress interface according to the prefix advertised by the Access Router (AR) of the visit network whereas the address of the MR's ingress interfaces, and hence those of the MNNs remains unchanged. The MR will register its CoA with its HA through an exchange of Binding Update (BU) and Binding Acknowledgment (BA) message pair, and the HA will in turn create a binding between the MR's CoA and its respective MNP(s) with the MR's HoA, all conveyed by the BU message, in a locally maintained cache called Binding Cache (BC). After a successful binding, a bi-directional tunnel is created between the HA and the MR. A packet addressed to a MNN is first routed to its HA, which will intercept the packet and tunnel it to the CoA of the MR, which in turn will decapsulate the outer header of the packet and forward it to the MNN. In the reverse direction the MR will encapsulate the packet originating from the MNN and tunnels it to the HA, which in turn will decapsulate the outer header of the packet and forward it to the destination based on Internet routing mechanism.

B. Problem Statement

As stated earlier, NSBP introduces severe performance limitation in terms of sub-optimal communication paths for packets of the MNN as it has to traverse, in both directions, the MR's HA via a bidirectional tunnel established between the MR and its corresponding HA. This problem gets compounded when other MRs (and hence mobile networks) attach behind another MR (or mobile network) in a hierarchical fashion forming a larger mobile network. In such a cluster of mobile networks a MR that has connectivity to an AR is called a root-MR (rMR) and the MR behind the rMR is called a nest-MR (nMR), and such a topology is termed as "nest topology" and the network is called nested mobile network [7].

Although NBSP does not prevent the formation of such a nested architecture but, in the absence of any RO mechanism, when a Correspondent Node (CN) communicates with a MNN located behind a nMR_{δ} (where δ is the depth of the nest and rMR, which acts as a gateway to the nested mobile network, is considered at depth δ=0), the packets of the MNN will traverse over (δ+1) HAs (i.e., through the HAs of all the upper level mobile networks present in the nest chain) thereby undergoing (δ+1) encapsulations/decapsulations in both directions. Clearly as δ increases, packets destined for the MNN in a nested mobile network will undergo more and more inefficient routing. Such a routing of packets over multiple tunnels is called *pinball routing* [8] and depicted in figure 1 illustrating a nested mobile network with δ=2 (i.e., nest depth 3).

As depicted in figure 1, the data from the CN destined to a MNN will first be routed to MR3's HA (HA_MR3). The BC in HA_MR3 will indicate that MR3 is nested behind MR2 (as nMR_2) and hence the data gets tunneled to MR2's HA (HA_MR2). Similarly the BC in HA_MR2 will indicate MR2 to be nested behind rMR (as nMR_1) and so the data once again gets encapsulated and re-routed to rMR's HA (HA_MR1) which will tunnel it successfully to rMR. Till it reaches rMR, the original data gets encapsulated 3 times (i.e., $\delta+1$ times). The MR's in the nest chain will then successively decapsulate the data till it reaches the MNN. All in all each level of the nest hierarchy will add 40 bytes of an IPv6 header and hence increase the overall packet overhead, and increasing the header to payload ratio as per equation 1.

$$Ratio = \frac{(\delta+1)*40+Hext}{(\delta+1)*40+Hext+Payload} \tag{1}$$

where *Hext* is the total size of the IPv6 extension headers.

This ratio gets pronounced for packets with smaller payloads, such as VoIP payloads of 50 bytes as defined in [9].

The pinball routing process will limit the overall performance and give rise to various performance issues which are detailed in [6]. For instance packets undergoing pinball routing will take longer routes leading to increased delay and making the packets more susceptible to link failures. This will also impose additional infrastructural load adversely impacting real time applications and video streaming services. Since packets will have to undergo successive encapsulations/decapsulations; it will incur increased packet overhead thereby increasing the processing delay and reducing the overall bandwidth efficiency. The increased packet size will also increase the probability of packet fragmentation leading towards non-negligible packet loss and/or delay.

C. Related Work and Motivation

For any serious contender for a RO solution it must support nested architectures with reduced tunneling, signaling and infrastructural overhead to directly impact the reduction of the packets' overall Round Trip Delay (RTD). RFC 4889 [8] gives a comprehensive outline of the RO solution possibilities for nested Mobile Networks. Several RO solutions for Mobile Networks have been proposed attempting to address the problems and issues highlighted in [6].

However each mechanism has some drawback which can be categorized in the following five categories;

1) No support for nested architectures
2) Introduction of additional network entity
3) Increased signaling overhead
4) No support for legacy MNNs (i.e., non-MIPv6 nodes)
5) Exchange of packets over tunnels

For example Multiple Mobile Router Management system [10] falls under the first category whereas Optimized Route Cache (ORC) management protocol [11] falls under the second category. OptiNets+ [12] falls under category 3 and 4 whereas Prefix Delegation (PD) [14] comes under category 4. Multiple Router Tunneling Protocol (MRTP) [15] and a proposal by Kang et al [16] suggests a bi-directional tunnel to be maintained between the HA and the MR and also does not demonstrate the support for dynamic tunneling thereby making them fall under category 1 and 5. Another proposal by J. Na et al [17] comes under category 2 and 5. Recursive Binding Update (RBU) [18] is a simple proposal based on MIPv6 and falls under category 3 as it incurs higher signaling cost, which is proportional to the degree of nesting, and recording longer convergence time making it unsuitable for deeper nested topologies and does not support non-MIPv6 MNNs.

Amongst the more recent proposals are MANET for NEMO (MANEMO) [19], MIPv6 Route Optimization for NEMO (MIRON) [21] [22] and Optimized NEMO (ONEMO) [24]. The MANEMO RO solution employs a special routing header called a Reverse Routing Header (RRH) [20], which is a variant of IPv4 Loose Source and Record Route (LSRR) adapted for IPv6. It always uses a bi-directional tunnel between the rMR and the nMR of the MNN and hence does not always offers a 100% optimised route for the packets and hence falls under category 5.

MIRON [21] on the other hand uses the MIPv6 prescribed *Return Routability (RR)* procedure [3] for RO but it marginally improves upon NEMO RO in that it avoids only the *last tunnel* corresponding to a nMR and as such is not suitable for handling nest topologies. The authors of MIRON have however proposed in [22] an approach for handling nesting but that is achieved by supplementing the original MIRON proposal with third party protocols such as PANA protocol [23] and DHCPv6 [5] adding complexity to Visit MN (VMN) and MR and complicating the whole NEMO protocol and NEMO network infrastructure.

ONEMO [24] approach adds infrastructural as well as functional complexities by specifying additional entities namely *Correspondent Router (CR)* and *Binding Proxy Agents*. It is accompanied by additional CR Discovery mechanism and a complicated non-MIPv6 compliant binding mechanism. After RO is achieved, traffic between CN and MNN is exchanged via a bi-directional tunnel established between CR and rMR.

In our opinion the best solution is one that utilizes the native MIPv6 [3] and IPv6 Neighbor Discovery protocol [25] constructs with minimum changes/modifications. It should not introduce any new network infrastructure entities and/or does not require the support of any third party protocols. Based on the above consideration we present *NEst Route Optimization for NEMO (NERON)* which is a light weight and scalable RO scheme, the performance of which is independent of the nest depth and packets are exchanged with zero tunneling overhead. An Internet Draft [26] has also been submitted to the IETF detailing the protocol constructs and operation. In the subsequent sections, we present the details of the NERON protocol and analyse its performance over a realistically modeled simulation environment.

II. NERON Protocol Summary

The NERON protocol is composed of the following three essential steps;

1) Detection of nest formation.
2) Notification of routes within the mobile network domain.
3) Route optimization and Binding registration.

A. Nest Formation Detection

When a Visit Mobile Router (VMR) enters the domain of a Mobile Network it must be able to differentiate a MR from a infrastructure AR and must determine not only the address of the rMR's egress interface, as it serves as a gateway for the entire Mobile Network domain, but it should also compute its position inside the nest. The VMR will be able to distinguish a MR from an infrastructure AR based on the status of the newly defined *Mobile Router Flag (R-flag)* carried by the Router Advertisement (RA) message [3]. When set, the *R-flag* will indicate the AR is acting as a MR and such an RA must also carry the new 20-Byte *Mobile Network Gateway (MNG)* option (see figure 2) which conveys the rMR's egress interface address and also its depth in the nest indicated by the *Depth (D) field* (for rMR, *D = 0* by default). The VMR receiving this RA on its egress interface will process the *MNG* option and cache the rMR's egress interface address and the *incremented value* of the *D* field in a local cache called *Nest Gate Table (NGT)*. The *NGT* is a two-field cache that keeps the record of the address of the rMR's egress interface under the *"Mobile Network Gateway"* field and also its position in the nest under the *"Nest Position"* field.

A non-zero *"Nest Position"* value in the local *NGT* implies that the MR is nested as *nMR* behind another MR at a depth indicated by it. The nMR in turn must include the entries of its local *NGT* in the corresponding fields of the *MNG* option of the RA messages advertised periodically over its respective ingress interface(s). In other words the nMR will relay the assigned address of the rMR's egress interface to other nMRs deep inside the nest which in turn will relay it further deep inside the nest. All nMRs will likewise cache the rMR's address and an incremented value of the *D-Field* in their respective local *NGTs*. In this way all nMRs will not only *self-compute* their position in the nest but will also be informed of the rMR's egress interface address. The *Primary Flag (P-Flag)* in the MNG when set will indicate that the MR is attached to an infrastructure AR and hence eliminate a possible race condition that would normally ensue between a rMR and VMR.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |    Length     | Prefix Length |P|  D  |Reserve|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                   root Mobile Router CoA                      +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Fig. 2. The Mobile Network Gateway (MNG) Option for the RA Message

B. Route Notification

After the visit MR nests behind a rMR and updates its NGT, it will send an *Unsolicited Neighbor Advertisement (UNA)* message [25] with the *Override flag (O-flag)* set to 0 over its egress interface to next higher MR in the nest chain. This *UNA* will convey the nMR's egress interface's *link local address* and respective MNPs embedded in the newly defined *Route Notification Option (RNO)*, the format of which is depicted in figure 3. A MR upon receiving the *UNA* on one of its ingress interface will update its local routing table with the MNPs carried by the *UNA* and assign/specify the corresponding *Link Local Address (LLoA)* carried by the same UNA message as the next hop address to reach the listed MNPs. When the *Relay Flag (R-Flag)* of the *RNO* is set; it will indicate to the receiving MR to relay the MNP carried by that particular *RNO* to the next higher MR. The MR will thus send a new UNA, with its egress interface's LLoA, and appended with the *RNO* received from the lower nMR (with R-flag set). The receiving MR will again update its routing tables with the MNPs located deeper inside the nest and will relay it to the next higher MR as described above.

This relaying of the MNPs to the higher MRs and the updating of the local routing tables of the receiving MRs will continue till the rMR is reached. Since the rMR is at $\delta = 0$ (indicated in the *NGT*); it will not relay it further.

C. Route Optimization and Binding Registration

In NERON, the MR of the MNN will perform home registration with its HA as specified in [2]. After successful home registration, the MR will perform MIPv6 specified RR procedure on behalf of the MNN as specified in [21]. After a successful RR procedure with the CN, the nMR, on behalf of the MNN, will send a BU carrying the rMR's address

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |  Length = 3   | Prefix Length |R|  Reserved   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Valid Lifetime                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                    Prefix (variable length)                   +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Fig. 3. Route Notification Option (RNO)

(accessed from its NGT) in the *Nest Gate (NG)* Option. *The format of this option is similar to the MIPv6's* Alternate Care of Address *Option [3] but with a different Type value*. It should be noted that the BU is triggered every time the entry in the NGT changes indicating a handover of the mobile network. The CN upon receiving the BU, will process it as specified in [21] and *additionally* it will extract the rMR's address carried in the *NG Option* and records it in the BC entry of the corresponding nMR. The CN will send a BA thus completing the RO and correspondent registration process and now the CN and MNN will exchange packets over optimized paths as shown in figure 4 and described below.

1) MNN Sending Packets to CN: When a MR receives a packet from its MNN destined to the CN, it will replace the source address of the IPv6 header with the CoA assigned to its egress interface and put the address of the MNN in the *Home Address Destination option* [3] (see figure 4). All the other nMRs on the path to the rMR will simply forward this packet until it reaches the rMR. The rMR will then forward the packet normally to the CN and hence the packet arrives at the CN with *no encapsulation* and via a direct optimized route bypassing the HAs.

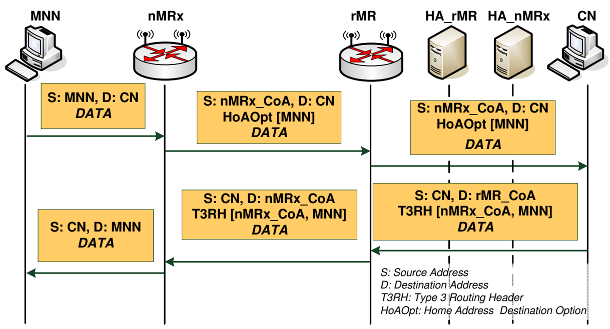


Fig. 4. Packet Flow between MNN and CN after NERON RO

2) CN Sending Packets to MNN: NERON extends the NEMO specified BC [2] with an additional *Nest Gate* field indicating the rMR's address behind which the corresponding MR is nested. When a CN wants to a send a packet to a nested MNN, it will first search its BC for a valid cached entry for the packet's destination address. If the packet's destination address is found listed in the BC, the CN will then check if a Nest Gate exists for the destination. If a Nest Gate address is present in the BC, the CN knows that the MNN resides inside a nested mobile network and composes the packet as follows;

- The source address field in the IPv6 header is set to the CN address.
- The destination address field in the IPv6 header is set to the Nest Gate address found in the BC entry.
- The CoA of the nMR found in the BC entry corresponding to the MNN's destination prefix, and the MNN destination address are contained in the newly defined Type 3 Routing Header (T3RH) address vector. The format of the T3RH is shown in figure 5 and it gets processed only by the destination router.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Next Header  |Hdr Ext Len = 4|Routing Type=3 |Segment Left=1 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Reserved                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                  nested MR Care of Address                    +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                  Mobile Network Node Address                  +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Fig. 5. NERON's Type 3 Routing Header (T3RH) Format

When receiving the packet with a T3RH, the rMR replaces the destination address with the nMR's CoA found in the T3RH address vector. Since inside the nest routes have already been exchanged between the MRs as part of the route notification process, the rMR, and the subsequent MRs nested behind the rMR, will route the packet to the destination nMR using standard routing algorithm. The destined nMR will then replace the packet's destination address with the address of the MNN carried inside the T3RH address vector and the packet eventually gets delivered to the MNN without any tunneling over head. This process is depicted in figure 4.

III. Simulation Experiments

In this section we present the results of the simulation experiments comparing and analyzing the performance of the proposed NERON mechanism to that of the IETF's NEMO protocol [2] and MIRON protocol [21] in terms of their effect on the packets' Round Trip Delay (RTD) when the MNN is communicating with the CN over the Internet using the ICMPv6 ping packets sent at an interval of 300ms. NBSP is used as a reference to demonstrate the inefficiencies that data packets undergo in the absence of RO, whereas the version of MIRON specified in [21] is chosen because it uses the MIPv6 specified Return Routability procedure for RO and has a partial support for nesting, an approach adopted by NERON but with an overall enhanced ability to support any-level of nesting without adding new complexities. All three protocols are modeled in our mobility management simulation framework [27] developed in OMNeT++ [28] and using realistic message structures and timer implementations.

A. Simulation Environment

The reference simulation network environment is shown in figure 6 and the experiments are carried in a homogeneous

802.11b wireless environment using a free space propagation model at 2.4 GHz for a radio channel over a total coverage area of 800m x 800m. At the start of the simulation each MR (MR1, MR2 and MR3) is located at its home network and connected to the respective home agent (HA-MR1, HA-MR2 and HA-MR3 respectively). MR1 is the designated rMR whereas MR2 and MR3 will move into the HA_MR1 domain and connect and nest behind rMR after 180 seconds simulation time.

For $\delta = 0$, the mobile network consists of a single MR, i.e., rMR (MR1) with the MNN connected directly to it. For $\delta = 1$, the MR2 enters the domain of the mobile network and connects and nests behind the rMR (as nMR_2). Similarly for $\delta = 2$, the MR3 enters the domain of HA_MR1 (where MR2 is already nested behind rMR) and connects and nests behind nMR2 (as nMR_3). In all the three scenarios, the MNN is always connected behind the last MR in the nest and is communicating with the the CN across the Internet. This last scenario is depicted in figure 6.

In all three scenarios, the mobile network is moving along the path HA_MR1→ $AR1$ → $AR2$ →HA_MR2 undergoing three instances of handovers. The reference network (fig 6) is designed to represent a realistic environment by assigning different delays on the various inter-connecting links and is denoted by L_d. The L_d values (in msec) of the respective links are labeled in figure 6.

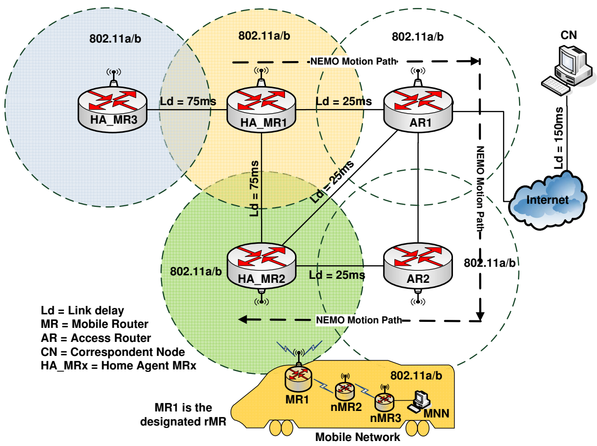


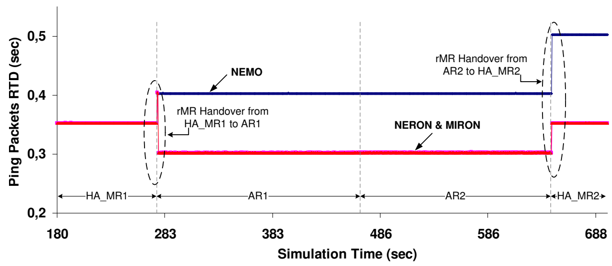
Fig. 6. Reference Simulation Test Environment

B. Results and Analysis

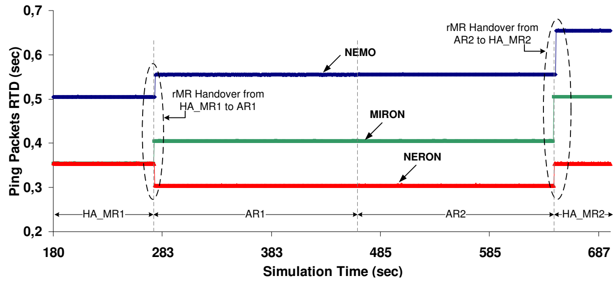
The simulation experiments are carried out by realizing three levels of nest depths (δ), i.e., for $\delta = 0$, $\delta = 1$ and $\delta = 2$ and the RTD of the Ping6 packets, communicating between the CN and MNN, incurred by each protocol is graphically depicted in figure 7 and tabulated in figure 8.

As seen from the figure 8, NBSP incurs the maximum delay and the RTD increases with the increase in the nest depth because NBSP does not support RO and thus the packets have to traverse each HA of the nested MRs and the rMR *atleast* once and sometimes twice depending on the topology and the distance of the mobile network from its home network. For example for $\delta = 3$ and when the mobile network is at HA_MR2, the packets in NBSP will traverse the *CN→AR1→HA_MR1→HA_MR3→HA_MR1→HA_MR2→HA_MR1→HA_MR2* path in one direction and *HA_MR2→HA_MR1→HA_MR3→HA_MR1→HA_MR2→HA_MR1→AR1→CN* path incurring a total RTD of 1100 msec. It is noted that HA_MR1 is traversed 3 times while HA_MR2 is traversed 2 times adding to the overall RTD. This is because NBSP does not support RO.

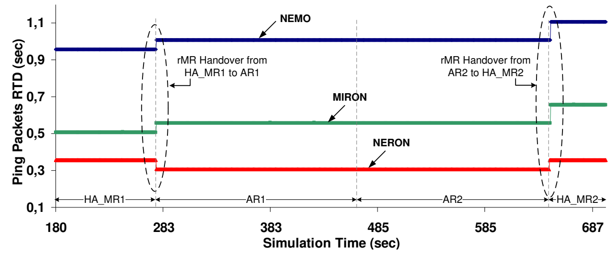
In contrast the RO mechanism of MIRON only skips the HA pertaining to the last MR in the nest. For instance, for $\delta = 2$, when the mobile network is at location HA_MR2, the packets in MIRON will traverse the path CN→AR1→HA_MR2→HA_MR1→HA_MR2 in one direction and HA_MR2→HA_MR1→HA_MR2→AR1→CN in the other direction skipping HA_MR3 (HA of nMR3, the last MR in the nest) and incurring a total RTD of 650 msec, but the superior RO mechanism of NERON incurs a constant minimum RTD of 350 ms for the same situation independent of the depth of the nest as it ensures that the packets traverse optimum low cost path. Figure 8 also tabulates the average RTD incurred by the three protocols and it is evident that NERON not only incurs minimum RTD but its performance is constant independent of the nest depth δ.



(a) Round Trip Packet Delay With Nest Depth 0



(b) Round Trip Packet Delay With Nest Depth 1



(c) Round Trip Packet Delay With Nest Depth 2

Fig. 7. RTT Delay Comparison of NEMO, MIRON and NERON

Protocol	Nest Depth (δ)	Mobile Network Location			Average RTD (ms)
		HA_MR1	AR1 & AR2*	HA_MR2	
		RTD (ms)	RTD (ms)	RTD (ms)	
NBSP	0	350	400	500	403.55
	1	500	550	650	555.82
	2	925	1000	1100	1008.57
MIRON	0	350	300	350	316.56
	1	350	400	500	405.54
	2	500	595	650	558.0
NERON	0	350	300	350	316.538
	1	350	300	350	318.239
	2	350	300	350	320.13

**AR1 & AR2 are neighbors and hence the link delay (L_d) is negligible*

Fig. 8. Comparison of NERON with NBSP and MIRON In Terms of Round Trip Delay (RTD)

IV. Conclusions and Future Work

In this paper we have proposed a new RO solution called NERON that solves the pin-ball routing problem in the context of nested Mobile Networks. NERON uses the MIPv6's Return Routability process for creating bindings with a CN, enabling the exchange of data packets between MNN and CN over optimum paths, as determined by Internet routing protocols, without needing to be tunneled over successive HAs. This would result in zero tunneling overhead thereby showing dramatic reduction in the RTD of packets and exhibiting a constant performance irrespective of the depth of the nest. This accounts for an overall efficient utilization of bandwidth and network resources and will especially favor real-time applications with smaller payloads, such as VoIP.

Since NERON is modeled using the MIPv6 prescribed RO process therefore it uses the same security policies as defined for MIPv6 and NBSP.

The NERON solution fits within the solution space prescribed in [8] and is light-weight in the sense that it does not introduce any new signaling messages except minor modification in the form of small size message sub-options (T3RH, MNG and RNO sub-option). The main feature of NERON that sets it apart from other RO mechanisms is that it uses the legacy MIPv6 prescribed Return Routability process as a base of its RO process and IPv6 Neighbor Discovery methods for its operation. Since NERON does not introduce any new functional and/or network entity it can therefore be readily deployed with no additional cost or complexity.

At present we are in the process of extending the NERON protocol to enable *intra-nest* communication between two MNNs that are located within the same mobile network domain and further experiments and analytical analysis are being carried out to quantify the performance of NERON in reference to real time applications and in terms of the reduction of header to payload ratio with respect to increasing nest depths.

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