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Routing Optimization for Nested Mobile Networks

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SUMMARY Network Mobility (NEMO) Basic Support is the standard protocol to provide continuous network connectivity and movement transparency to a group of nodes moving together, as in a vehicle. However, the protocol suffers from sub-optimal routing and packet overhead caused by a bi-directional tunnel between the Mobile Router (MR) connecting the mobile network to the Internet and its Home Agent (HA). When a nested NEMO is formed, these inefficiencies become intolerable for real-time multimedia applications. To optimize the delivery of these packets, this study proposes Optimized NEMO (ONEMO) that is capable of providing an optimal path with minimum packet overhead in various scenarios with nested mobility. The protocol is designed to offer the path with minimum signaling overhead and functional requirements are limited to its MRs. Evaluation through measurements against NEMO Basic Support and comparison among other solutions showed effectiveness of the protocol.

key words: *network mobility, routing optimization, IPv6, mobile computing, NEMO*

1. Introduction

Nowadays, vehicles contain many sensor devices and built-in computers, not to mention the various devices carried by passengers. Intelligent Transportation Systems (ITS) organizations are now aiming at connecting these devices to the Internet using various access technologies [1]. The benefit is to assist each driver with an efficient route to their destination, to provide multimedia entertainment, and most importantly, to ensure safety.

In connecting these devices to the Internet, the Internet Engineering Task Force (IETF) has standardized a network mobility support protocol, known as NEtwork MObility (NEMO) Basic Support [2], to provide continuous network connectivity to a group of hosts moving together. The router serving as a gateway between such mobile network and the Internet is known as the MR whereas the nodes located behind the MR are known as the Mobile Network Nodes (MNNs). The change of the attachment point of the MR to the Internet through various wireless access technologies is transparent to such nodes. The mechanism is much like as that of Mobile IPv6 [3], a protocol to provide host mobility. Each MR relies on a Home Agent (HA) located at the infrastructure for forwarding [4] all packets addressed to and from the MNNs.

While this simple forwarding mechanism is beneficial for implementors and operators, the path via the HA(s) are often sub-optimal, posing intolerable delay along with many other inefficiencies [5] which are critical for real-time multimedia applications dealing with interactive voice and video data over IP. Such phenomenon was already known with Mobile IPv6 where it has been resolved by including in the base specification a function to bypass HAs known as Route Optimization. The NEMO Working Group of the IETF in charge of standardization, decided to leave such optimization as an extension to the base specification [6] and to solve together a number of additional NEMO specific issues [5] which are known to make the problem more complex than in Mobile IPv6 solely. Several solutions have been proposed in this area [7]–[9], however each of them has limited applicability in its solution, and some sufferes severely from signaling and packet overhead. Additionally, [8], [9] focuses on offering Mobile IPv6 Route Optimization over NEMO and therefore its applicability differs from NEMO to NEMO Route Optimization.

In this paper, we detail the sub-optimality issues of NEMO Basic Support and the specific issues related with providing Route Optimization for NEMO, and we also present a solution which offers sufficient optimization. The applicability of the solution includes cases where a MR is attached behind another MR (MRs are then respectively referred to as the sub-MR and the root-MR, and the aggregation forms a topology known as a nested NEMO [10]). Section 2 describes NEMO Basic Support and addresses issues surrounding Route Optimization. The approach taken toward the problems and the concept of Route Optimization that is proposed is covered in Section 3. Additionally, the proposed protocol is described. The results through experiments and evaluation of the proposition against other protocols are shown in Section 4, followed by a conclusion in Section 5. This paper is an improved version of an earlier work presented in [11]. The problem statement and the proposal is refined and extended results

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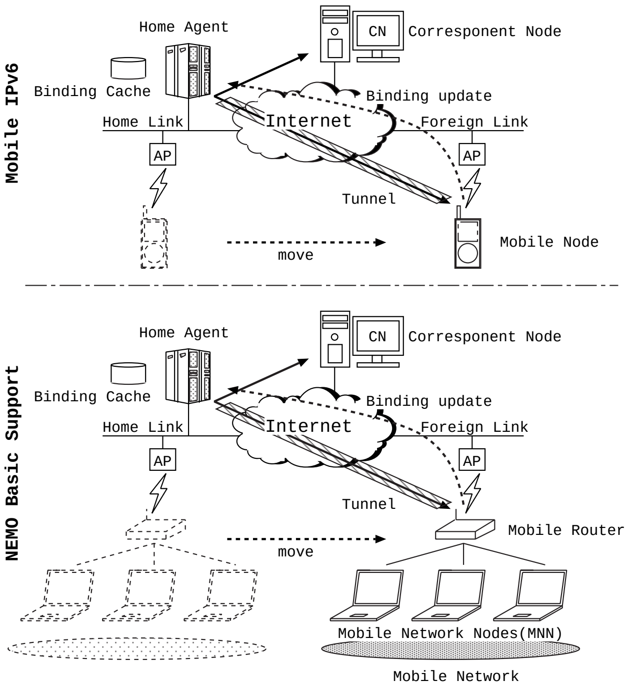


Fig. 1 Overview of Mobile IPv6 and NEMO Basic Support

are now presented.

2. Network Mobility and Route Optimization

2.1 The NEMO Basic Support Protocol

The NEMO Basic Support protocol is originally designed based on the experiences gained through standardization of Mobile IPv6, and therefore many of the functionalities remain the same while a few new functions are introduced as extensions. Fig. 1 highlights Mobile IPv6 and NEMO Basic Support. In NEMO Basic Support, each HA allocates a Mobile Network Prefix (MNP) to the mobile network carried by the MR. All packets with this prefix are forwarded through a bi-directional tunnel established between the MR and its HA. A Home Address is also allocated to each MR. When the MR changes its attachment point to the Internet, it sends a Binding Update message to its HA to bind its new Care-of Address to the MNP and to re-establish the bi-directional tunnel.

Compared to approaches like Mobile IPv6 where each host has the mobility support, only the MR and the HA need support of new functionalities. As such, MNNs can benefit from the continuous connectivity offered by NEMO Basic Support and managed by the sole MR without requiring changes in their protocol stack nor requiring any mobility support mechanism of any kind. As a result, MNNs can be very simple network components since they don't necessarily need complex network interfaces in order to be connected to the Internet. This is very valuable for sensor devices which can be deployed at a minimum cost.

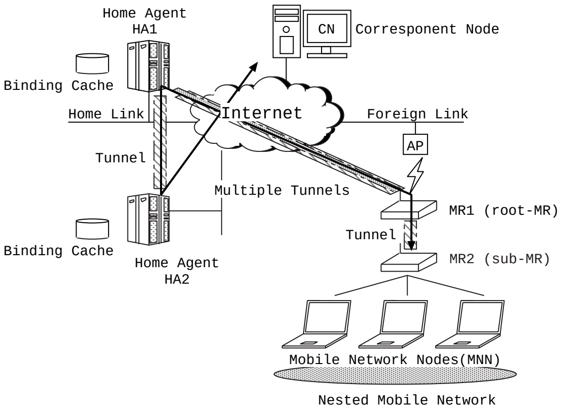


Fig. 2 Overview of Nested Mobile Network

2.2 Nested NEMO

NEMO Basic Support does not prevent a MR to attach behind another MR in order for them to maintain reachability to the Internet. An example scenario is when a passenger with a NEMO enabled Personal Area Network (PAN) takes a NEMO embeded train. When such a nested NEMO is formed, a bi-directional tunnel would be established between each MR and its own HA, and packets would travel through a multitude of HAs and levels of encapsulation.

Fig. 2 shows a nested NEMO. Packets between MNN and Correspondent Node (CN) would transit through the tunnel established between MR2 and HA2, which travel through the tunnel established between MR1 and HA1. Note that a similar routing path would be taken when a Mobile IPv6 host relying on its own HA attaches behind one of the MRs, creating a nesting of mobility management protocols.

Although nested NEMO is often considered to be up to 2 or 3 at most in depth, however there are scenarios where a deeper nesting may occur. Consider a highway with very heavy traffic which continues on throughout a tunnel. The tunnel has no Internet connectivity provided and therefore each vehicle must rely on others to obtain reachability provided from the vehicle near the exit. Such multi-hop interconnecting of the vehicles may form a deep nesting of NEMOs.

2.3 NEMO Route Optimization Problem Statement

The inefficiencies of packet delivery introduced by NEMO Basic Support are considered more critical than that of Mobile IPv6 with the possibility of multiple MRs forming a nested NEMO as shown in Fig. 2. The NEMO Working Group has worked to document the problems of NEMO Basic Support in [5]. Among many, the following two problems are detailed below: 1) the delay caused by sub-optimal routing and 2) the overhead caused by multiple encapsulations.

2.3.1 Sub-optimal routing

Sub-optimal routing is a state at which packets are routed through a path other than the direct routing path between two points on the Internet. Under the operation of NEMO Basic Support, packets addressed to MNNs are always routed through the path via at least one HA. When the MR is away from home, the path can often be considered sub-optimal.

Sub-optimal routing is not preferred for various reasons. Depending on the attachment point of the MRs, sub-optimal routing causes considerable packet delay and poses crucial problems for real-time applications. Such routing also wastes network resources such as bandwidth, causing traffic congestion and packet losses. Moreover, heavy traffic load is given to the HA regardless of the location of the two end nodes making the home link a bottleneck.

2.3.2 Multiple encapsulations overhead

When a mobile network is nested, the number of encapsulation simply increases as the nest becomes deeper. Fig. 3 shows that nest depth of N would require $N+1$ number of IPv6 headers, including the original IPv6 header before encapsulation. Such multiple encapsulation can become a severe overhead for wireless links where additional bits consumed over the air effect the overall performance. The total *Ratio* of headers to payload of a packet can be calculated as shown below where the depth of the nest is denoted by N, the total size of extension headers such as IPsec is denoted by H_{Ext}, the total size of the payload denoted by *Payload*, and the size of the IPv6 header as 40.

$$Ratio = \frac{(N+1) \times 40 + H_{Ext}}{(N+1) \times 40 + H_{Ext} + Payload} \quad (1)$$

Fig. 4 shows an example of such *Ratio* when sizes of *Payload* are at 50 bytes, 100 bytes, and 400 bytes. As shown, a large proportion of a packet is used for control headers especially with packets of small sizes such as 50, which is the payload size for VoIP applications defined in the G.729 recommendation of the International Telecommunication Union [12].

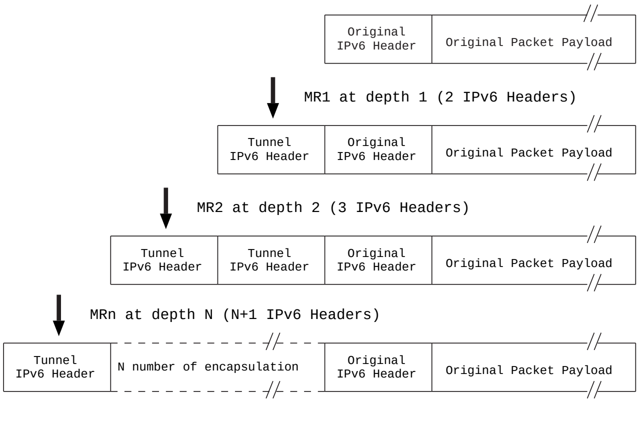


Fig. 3 Multiple Encapsulations

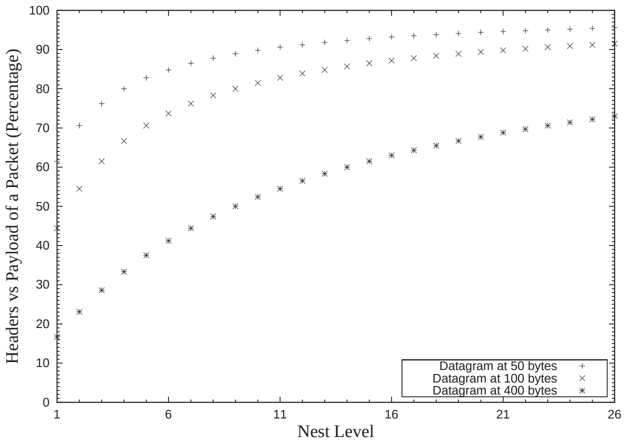


Fig. 4 Header to Payload Ratio

Multiple encapsulations may also exceed the Maximum Transmission Unit (MTU) of a link leading to fragmentation of the packets into multiple series of smaller packets for transmission. This causes further congestion of the network and lead to delay or losses.

3. Enhanced Network Mobility Support

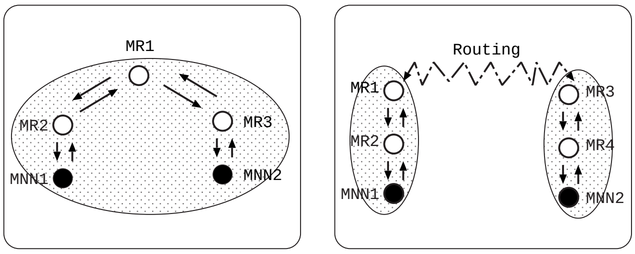
3.1 General Issues with NEMO Route Optimization

Route Optimization is a conceptual solution and in the NEMO context refers to any approach that optimizes the transmission of packets between a MNN and its peer. Often, such optimization is focused on solving sub-optimal routing and packet overhead by providing an alternative path other than the default bi-directional tunnel to the HA. Several solutions have been proposed in that area, each with its own definition of Route Optimization, solving the problems for its target scenario. As a result, the degree of optimization varies and the path remains sub-optimal in other configurations.

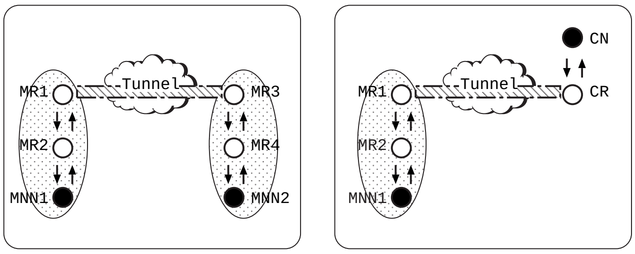
Prior to the standardization of NEMO Route Optimization, the NEMO Working Group is working on an analysis of the solution space in [13]. The document discusses at a generic level, the various issues and tradeoffs between path optimality and optimization overhead, and additionally on security and complexity issues that are brought by nested NEMO configurations.

3.2 Proposed Concept of Route Optimization

One of the difficulties known in providing Route Optimization for NEMO is that it requires the initiator to discover the attachment point of the correspondent



Case 1: Routing within the nest **Case 2: with Ad-hoc Routing**



Case 3: A tunnel between MRs **Case 4: A tunnel with CR**

Fig. 5 Concept of Route Optimization

while the nesting of mobile networks makes this complex. For example, a CN can be a MNN attached behind another nested NEMO or it can be a MNN attached within the same nested NEMO tree. In either case, optimization can not be ensured without determining the full topological path between the two communicating peers. Especially for the latter case, it is clearly preferable that packets do not get routed over the Internet.

The concept of our Route Optimization is based on a simple algorithm with the capability to cover all potential scenarios; first check whether the CN is attached within the same nested NEMO, if not present then assume that the node is reachable via the Internet.

As for the first step, we assume that each MR knows other MRs that are hanging within the same nested NEMO tree. A possible way for this is to have each MR to dynamically exchange routes for its MNP with other MRs forming the nested NEMO. This will allow MRs to utilize their routing tables for forwarding packets and avoid tunneling to their HAs. Mechanisms similar to Mobile Ad-hoc Networks [14] or extensions to Neighbor Discovery are assumed for such purpose, but details of such protocol is out of scope of this paper.

If the MR finds that it does not have a route for the CN in its routing table, the MR then determines that the node is reachable via the Internet. While a MR operating NEMO Basic Support would tunnel the packet to its HA, Route Optimization must avoid such path, and instead should tunnel the packet directly to or near the destination. Such tunnel should be dynamically established and in a way that the number of encapsulation is independent from the nest depth to avoid packet overhead.

With the described concept, Route Optimization can be provided in various scenarios which need its support. Fig. 5 shows the different scenarios as discussed in [5] and [13]. By having MRs within the nested NEMO exchange their routes with other MRs, packets can be forwarded based on routing (cases 1 and 2). If a route can not be discovered within the nest, MR searches for its correspondent, and exchanges bindings to establish a single bi-directional tunnel between the two nests (cases 3 and 4). As shown in case 4, the introduction of Correspondent Router (CR) [15] of our earlier work allows establishment of an optimal route even for standard IPv6 CNs that are located in the fixed infrastructure. CR is a router located close to the CN, preferably in the CN's network. A CR has functions very similar to that of a MR, but does not necessarily have the mobility handover functionalities.

3.3 Protocol Overview

Based on the concept described in Section 3.2, we propose Optimized NEMO (ONEMO) as a solution to provide efficient Route Optimization under various scenarios involved with nested NEMO. ONEMO is based on an extension to NEMO Basic Support [2] adding the capabilities to enable Route Optimization. These include a new forwarding algorithm, a new signaling protocol for dynamic discovery of the peer, extension to the Router Advertisement (RA) message for carrying the gateway address of a nested NEMO, and a new Binding Update mechanism for constructing an optimal path under various forms of nested NEMO. As described in Section 3.2, this paper does not describe how routes within a nested NEMO is exchanged, but is based on an assumption that each MR has routes for other MRs within the nested NEMO.

ONEMO introduces a notion of Nest Entrance Point to be used as the tunnel end point of a nested NEMO. The Nest Entrance Point is the Care-of Address of the root-MR. With cases 3 and 4 of Fig. 5 for example, packets from MNN1 to MNN2 and from MNN1 to CN are directly tunneled from MR1 to the Care-of Address of MR3 and CR, respectively. Since the root-MR has routes for all its sub-MRs, packets can then be decapsulated and routed to the destination based on the routing tables of each sub-MR.

The RA message is extended to deliver the Nest Entrance Point in the newly defined Nest Entrance Option. When the root-MR moves and changes its point of attachment to the Internet, the RA message is updated accordingly. Each sub-MR of the nest must relay the Nest Entrance Option down the nest using its own RA message. The sub-MR must also maintain the Nest Entrance Point obtained from the RA message in a Nest Entrance Table so that Route Optimization can be triggered when necessary. If a MR is multihomed and multiple RA messages are announced, the MR may choose to maintain all Care-of Addresses obtained from the

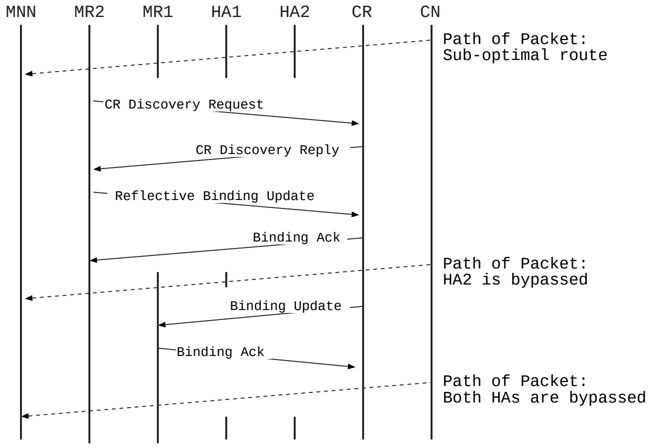


Fig. 6 Signaling Flow (Case 4)

option field. Similar extension to RA is also introduced in [16].

Using case 4 of Fig. 5 as an example, we show the signaling flow of ONEMO in Fig. 6. The Route Optimization is first initialized by MR2 when receiving a tunneled packet from its HA. If MR2 decides that Route Optimization is needed for this flow, it performs a CR Discovery to discover the anchor router for the tunnel end point. The destination address of the CR Discovery Request message is an anycast address derived from the prefix of the CN. The CR can also be a MR for application to case 3 of Fig. 5. After receiving a valid CR Discovery Reply message, MR2 notifies the peer of its Nest Entrance Point using a new mechanism called, "Reflective Binding Update". The message is indicated with a corresponding flag in the Binding Update message, together with a Care-of Address of the root-MR in the sub-option.

Fig. 7 shows the overview of the Reflective Binding Update message. When the CR receives this message, it creates a Binding Cache for the prefix carried by MR2. The CR then sends a regular Binding Update message to the address in the Nest Entrance Point retrieved from the Reflective Binding Update, and establishes a bi-directional tunnel with MR1. As shown, a single Reflective Binding Update enables to construct an optimal path regardless of the attachment point of MRn. Details of the packet formats are described in [17].

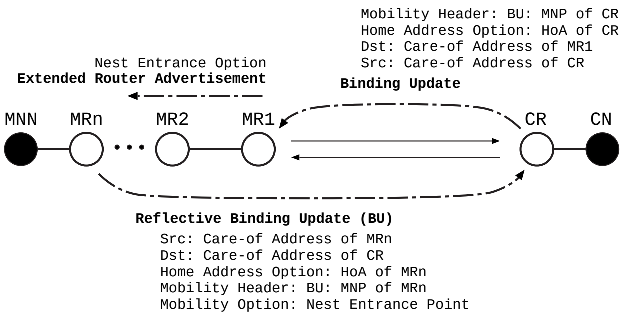


Fig. 7 Overview of Reflective Binding Update

4. Evaluation

ONEMO is implemented as an extension to Atlantis [18], a NEMO Basic Support implementation provided by the Nautilus6 Working Group of WIDE Project. Static routes were configured for other MRs within the nested NEMO. With the purpose to show the effectiveness of ONEMO, we conducted some performance measurements against NEMO Basic Support with no Route Optimization.

4.1 Local Testbed Measurements

In the following experiments, we measured throughput and Round Trip Time (RTT) values between two MNNs under 3 different configurations using the local testbed shown in Fig. 8. All links are connected with FastEthernet. For the measurement of throughput, we used Netperf using TCPIPV6_STREAM test for a duration of 60 seconds. MNN1 is configured as the client and MNN2 is configured as the server. For the measurement of RTT, we used ping6 with a packet size of 56 bytes. The results are averaged over a number of 100 packets.

The first configuration is used to evaluate the performance provided by ONEMO. Both MRs are attached on the same visited link as their HAs, creating a path similar to that of NEMO Basic Support using its bi-directional tunnels. The second configuration is used to measure the overhead of nesting MRs. An additional MR is added within the path to form a nested topology. The results should indicate the overhead of nesting when compared to the previous case. Finally, the third configuration is used to demonstrate the benefits of Route Optimization when both sub-MRs reside inside the same nested NEMO.

4.1.1 Non-Nested NEMO Configuration

Table 1 shows the measured results of NEMO Basic Support and ONEMO using the Non-Nested NEMO configuration of Fig. 8.

Table 1 Measurements in Non-Nested NEMO Configuration

Protocol	Throughput	RTT
NEMO Basic Support	43.55 Mbps	1.006ms
ONEMO	82.50 Mbps	0.567ms

As the results show, ONEMO provides better performance to NEMO Basic Support under both conditions. The throughput of NEMO Basic Support being about the half of ONEMO is due to the HA being

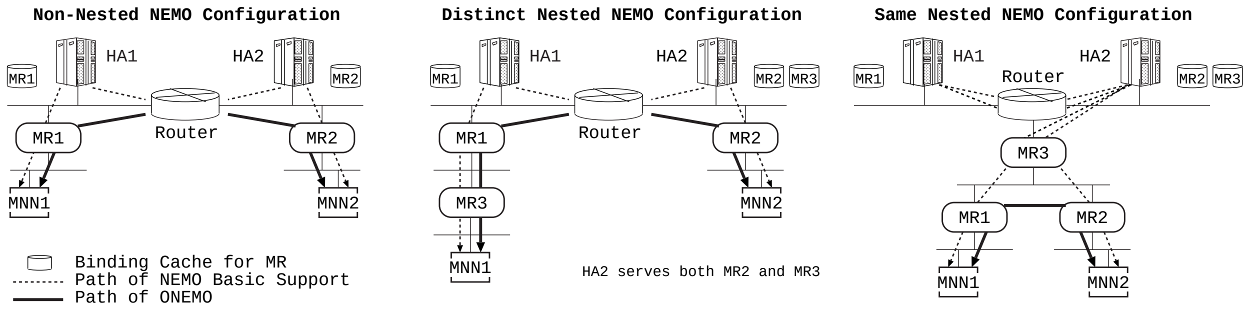


Fig. 8 Local Testbed Configurations

the bottleneck. In terms of packet delay, ONEMO decreased RTT values by 44% on average. Since HAs and MRs for both protocols have very similar functionalities using equivalent hardware specifications, the differences in values are clearly from the number of hops and encapsulations. For instance, while the path with NEMO Basic Support had a total of 12 hops with 4 sets of encapsulations both ways, the path with ONEMO had only 8 hops with 2 sets of encapsulations.

4.1.2 Distinct Nested NEMO Configuration

Table 2 shows the measured results of NEMO Basic Support and ONEMO using the Distinct Nested NEMO configuration of Fig. 8.

Table 2 Measurements in Distinct Nested NEMO Configuration

Protocol	Throughput	RTT
NEMO Basic Support	26.92 Mbps	1.182ms
ONEMO	78.55 Mbps	0.732ms

Compared to the results of Table 1, the performance degraded by 38% with NEMO Basic Support while only by 5% with ONEMO. Since the path remains the same for both protocols, the differences in values are from the effect of nested tunnels with NEMO Basic Support. The RTT values for ONEMO retain better to NEMO Basic Support.

4.1.3 Same Nested NEMO Configuration

Table 3 shows the measured results of NEMO Basic Support and ONEMO using the Same Nested NEMO configuration of Fig. 8.

Table 3 Measurements in Same Nested NEMO Configuration

Protocol	Throughput	RTT
NEMO Basic Support	16.78 Mbps	2.132ms
ONEMO	85.07 Mbps	0.477ms

As the results show, ONEMO offers about 5 times better throughput compared to NEMO Basic Support. For RTT values, ONEMO was one fifth of that of NEMO Basic Support. Such drastic differences are a result of NEMO Basic Support requiring 20 hops both ways, while ONEMO only required 6 hops. Furthermore, ONEMO used zero encapsulation while NEMO Basic Support required two sets of nested tunnels.

4.2 Global Measurements

With the purpose to evaluate the protocol on a global scale, two operational HAs are placed on the Internet as shown in Fig. 9. HA1 and Router1 are placed at University Louis Pasteur (ULP) in Strasbourg, France. Router2, HA2, and the two MRs and their MNNs are placed at Keio University in Kawasaki, Japan. The experiment assumes an environment where vehicles and passengers with a PAN each have a network mobility support. The vehicle uses the HA of the manufacturer, precisely in Japan were it was sold and is currently used while PAN uses the HA of its origin country, precisely in France. In Fig. 9, MR2 represents the vehicle and MR1 represents the PAN.

The measurements of RTT were conducted from 05:00AM till 11:00AM on January 8, 2005 (JST), using ping6 with a packet size of 56 bytes. The RTT between the two fixed routers were 296ms. The results shown in Table 4 are averaged over a number of 100 packets.

The effectiveness of ONEMO is significant because the packets are not routed via the HAs. Furthermore, packet loss was not observed for ONEMO, where up to

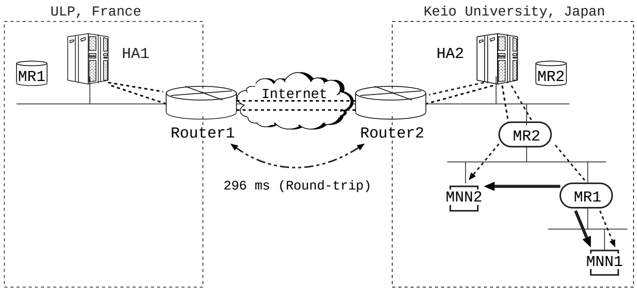


Fig. 9 Global Configuration

Table 4 Measurements in Global Configuration

Protocol	Min	Ave	Max	Stdv
NEMO BS	594.11ms	595.00ms	598.65ms	0.51ms
ONEMO	0.46ms	0.57ms	0.72ms	0.07ms

60% of the packets were lost when fragmentation of the packets occurred. Further analysis of the loss showed that packets over 1193 bytes required fragmentation at both MRs, and the loss of these packets were due to a exceed in time while reassembling the fragments at the sub-MR. Although these values may vary, the experiments clearly showed that overhead of multiple encapsulation results in fragmentation of IP datagrams, which could lead to packet loss.

4.3 Achievements vs Related Work

As described in Section 3, Route Optimization in NEMO context refers to any approach that optimizes the transmission of packets between a MNN and its peer. Existing proposals on Route Optimization, for instance [7]–[9] therefore have different achievements based on their target scenarios and problems. In this section, we attempt to evaluate ONEMO against these solutions based on the following metrics.

- Packet overhead per nest depth
- Additional signaling overhead
- Degree of optimization and applicability

4.3.1 Packet Overhead

The correlation between the nesting level of the mobile networks and the number of encapsulation needed for a packet has been a known problematic issue for NEMO Basic Support. ONEMO was therefore designed in such a way that these overhead is independent from the level of nesting. As an evaluation of this design, Fig. 10 compares the overhead of ONEMO, where the vertical axis shows the packet size in bytes and the horizontal axis shows the nest depth. Nest depth of 1 represents a mobile network directly attached to an access router and the total overhead given to such mobile network is 80 bytes with the original IPv6 header and a single encapsulation.

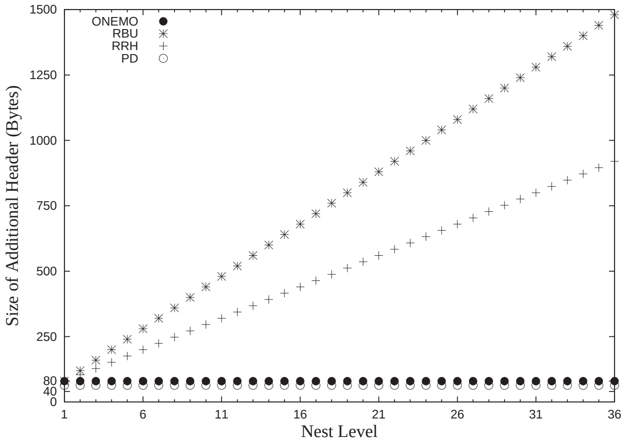


Fig. 10 Comparison of Packet Overhead

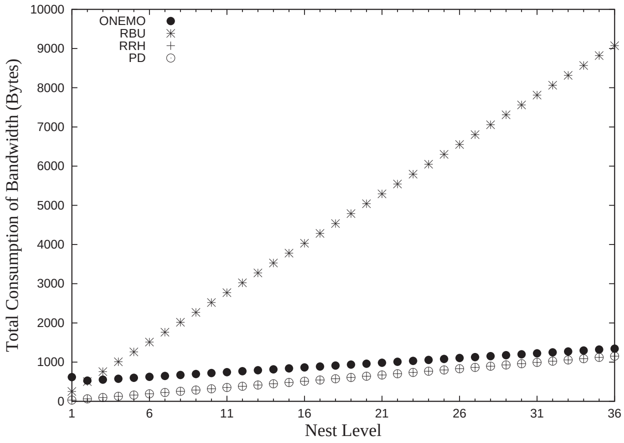


Fig. 11 Comparison of Signaling Overhead

As the figure shows, RBU [8] shows a linear increase in its overhead given to each packet, since an encapsulation is added for every increase in nest depth. RRH [7] shows a slight declination compared to RBU, however a linear increase given with routing headers. On the other hand, the overhead of both ONEMO and PD [9] is independent from the nest depth. In terms of deployment however, PD requires all access routers to support its functionalities, while ONEMO limits this only to its MRs, making the deployment easier for the protocol.

4.3.2 Additional Signaling Overhead

When performing Route Optimization without any prior knowledge of the peer, additional signaling messages can not be avoided. Fig. 11 compares such signaling cost based on calculations of all signaling messages required to build the optimal path. The vertical axis shows the total consumption of all signaling messages in bytes and the horizontal axis shows the nest depth.

As Fig. 11 shows, bits consumed by ONEMO is far less than that of RBU but slightly more than that of RRH or PD. Again, such an overhead of ONEMO can be considered as a tradeoff of limiting its modifications only to MRs.

4.3.3 Degree of Optimization and Applicability

Most solutions which provide Route Optimization often limit their applicability to specific configurations. As a result the path remains sub-optimal and packets travel through several HAs.

The proposed ONEMO on the other hand provides a path that bypasses all HAs for all nested mobility configurations known in [5]. This includes flows between a Mobile IPv6 host and a standard IPv6 host, which is known to be especially difficult to provide Route Optimization without avoiding modification to end hosts. ONEMO achieves Route Optimization even for those nodes by applying our previous work on Binding Proxy Agent (BPA) [19] at CRs. BPAs are routers similar to CRs, only their functionalities are focused on providing Mobile IPv6 Route Optimization. The work has similar goals and scenarios to ONEMO. Although the implementation has not been merged, easily integration of the two stacks can be expected with the similar functionalities of the two protocols.

5. Conclusion

This study focused on the sub-optimal routing with communications involving nested NEMO, and proposed a solution which provides sufficient optimization. The proposed concept of Route Optimization enhances the overall performance by dynamically discovering and utilizing shorter paths to a destination. ONEMO was designed and implemented and used to verify the validity of our proposal. Evaluation of ONEMO showed effective in various nested configurations. The protocol enhanced communication performance while decreasing packet and signaling overhead. The scheme retains interoperability and provides easy adaptability for deployment. Future work of this study includes enhancements to signaling overhead and to investigate security threats of ONEMO.

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