Network Working Group
Internet-Draft
Expires: December 2, 2003

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June 3, 2003

Taxonomy of Route Optimization models in the Nemo Context
draft-thubert-nemo-ro-taxonomy-01

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Abstract

Nemo enables Mobile Networks by extending Mobile IP to support Mobile Routers. This paper documents how the MIPv6 concept of Route Optimization can to be adapted for Nemo to optimize:

1. the nested tunnels of the nested Nemo configuration

2. router-to-router in the infrastructure as opposed to end-to-end.

and much more ... :)

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1. Introduction

This document assumes the reader is familiar with Mobile IPv6 defined in [1], with the concept of Mobile Router (MR) and with the Nemo terminology defined in [2].

From the discussions on the mailing list, it appears that the common current understanding of the problem space of Route Optimization (RO), in the Nemo context, is still limited.

This paper attempts to clarify the state of the discussion and propose a taxonomy of the various aspects of the problem. We will look at different possible types of route optimizations related to mobile network.

Firstly, route optimizations involving nested mobile networks are explored. This involves minimizing the number of tunnels required when there is multiple levels of nesting.

Secondly, the Mobile Router can initiate route optimization with corresponding nodes (CN) on behalf of the mobile network nodes (MNN).

Thirdly, we consider the feasibility of having a visiting mobile node (VMN) performing MIPv6 RO over the NEMO base protocol.

Lastly, we explore the prospect of performing RO over the routing infrastructure. This involve optimizing the route between two routers situated near to each end point.

2. Nested Mobile Network

2.1 Nested Tunnels Optimization

Let us illustrate the problem by an example. In this example, the nested Mobile Network has a tree topology. In the tree each node is

a basic Mobile Network, represented by its MR.


```
                          +---------------------+
                          |     Internet        |---CN
                          +---------------|-----+
                           /         Access Router
                      MR3_HA              |
                                ======?======
                                     MR1
                                      |
                         ====?=============?==============?===
                            MR5           MR2            MR6
                             |             |              |
                       ===========   ===?=========   =============
                                       MR3
                                        |
                                 ==|=========?==  Net3
                                  LFN1      MR4
                                             |
                                        =========
```

An example nested Mobile Network

This example focuses on a Local Fixed Node (LFN) at depth 3 (in Net3) inside the tree, represented by its mobile router MR3. The path to the Top Level Mobile Router (TLMR) MR1 and then the Internet is:

MR3 -> MR2 -> MR1 -> Internet

Consider the case where a LFN belonging to Net3 sends a packet to a Correspondent Node (CN) in the Internet, and the CN replies back.

With no Nested Tunnels Optimization, we would have three bi-directional nested tunnels, as described in [3] and illustrated in the following drawings:

```
                                 -----------.
                       --------/          /-----------.
              -------/        |          |           /-----------
    CN ------( -  - | -  -  - |  -  -  - | -  -  -  |  -  -  -  (-------- LFN
       MR3_HA -------\        |          |           \----------- MR3
                MR2_HA --------\          \----------- MR2
                          MR1_HA ----------- MR1
```

No Nested Tunnels Optimization

Such a solution introduces the following problems:

"Pinball" routing

Both inbound and outbound packets will flow via the HAs of all the MRs on their path within the NEMO, with increased latency, less resilience and more bandwidth usage.   To illustrate this effect, the figure below shows the route taken by a packet sent from LFN to CN:

```
                +--> HAofMR1 ---------------------+
                |                                 |
                +----------------- HAofMR2 <--+   |
                                              |   |
                              +---------------+   |
                              |                   V
                           HAofMR3 <------+       CN
                                          |
                                          |
                 LFN --> MR1 --> MR2 --> MR3
```

'Pinball' Routing

Packet size

An extra IPv6 header is added per level of nesting to all the packets. The header compression suggested in [4] cannot be applied because both the source and destination (the intermediate MR and its HA), are different hop to hop.

On the other hand, with a Nested Tunnel Optimization, we would have at most one bi-directional tunnel outside the Mobile Network, that may depend on the traffic flow:

```
                                                       __- --_
         Tunnel---------------------------- MR1 ( Mobile  ) MR3
  CN ----------(  -  -  -  -   -  -  -  -  -  - ( -  -  -  - )--------- LFN
       Endpoint---------------------------- MR1 ( Network ) MR3
                                                      --___---
```

Nested Tunnels Optimization

The end-point of such a Tunnel on the Mobile side may either be MR1 or MR3, depending on the solution. In the case of a Mobile Node visiting Net3, that Mobile Node may also be the end-point.

The potential approaches for avoiding the nesting of tunnels include:

Mobile Aggregation

This model applies to a category of problems were the Mobile Networks share a same administration and consistently move together (e.g. a fleet at sea). In this model, there is a cascade of Home Agents.

The main Home Agent is fixed in the infrastructure, and advertises an aggregated view of all the Mobile Networks. This aggregation is actually divided over a number of Mobile Routers, the TLMRs. The TLMRs subdivide some of their address space to the other Mobile Routers forming their fleet, for which they are Home Agent.

As Home Agents, the TLMRs terminate MIP Tunnels from the inside of the Mobile Network. As Mobile Router, they also terminate their home Tunnels. As routers, they forward packets between the 2 tunnels.

Surrogate

The TLMR acts as a proxy in the MIP registration, in a fashion of MIPv4 Foreign Agent or HMIP MAP (see [8]). For instance, the TLMR maintains a Tunnel to each MR, a Tunnel to the HA of each MR, and switches packets between the two.

Internal Routing and gateway

This item can be approached from a MANET standpoint. This was already done for DSR (see [9]) and AODV (see [10] and [7]) From a Nemo standpoint, a full MANET is not necessary since the goal is to find a way to the infrastructure, as opposed to any-to-any connectivity.

RRH

The Reverse Routing Header (RRH) approach avoids the multiple encapsulation of the traffic but maintains the home tunnel of the first MR on the egress path. It is described in details in [5]. The first MR on the way out (egress direction) encapsulates the packet over its reverse tunnel, using a form of Record Route header, the RRH.

The next MRs simply swap their CoA and the source of the packet, saving the original source in the RRH. The HA transforms the RRH in a Routing Header to perform a Source Routing across the nested Mobile Network, along the ingress path to the target MR.

Access Router Option

The Access Router Option (ARO) approach [6] is somewhat similar to the RRH in that only the home tunnel of the first MR in the egress path is maintained. This is done by having MR to send an ARO in Binding Update to inform its HA the address of its access router. Using this information, HA can build a Routing Header to source-

route a packet to the target MR within in a nested mobile network. Details can be found in [6].

2.1.1 Pitfalls and threats

2.1.1.1 Securing the protocol

These approaches are generally difficult to secure unless all the Mobile Routers and Visiting Mobile Node belong to a same administrative domain and share predefined Security Associations.

Even if an intermediate MR is 'trusted', this does not prove it is able to provide the necessary bandwidth, and may not provide a good service. Eventually, a MR that is capable of securing (IPSec) its traffic may select a Mobile Access Router based on quality of service heuristics as opposed as trust.

The problem is global to the whole Mobile Network in the case of a MANET-based solution. For an RRH-based solution, the threat comes from on-axis MRs in the nested Mobile Network but is mostly limited to denial of service. This is detailed in [5]. The approach taken is to limit the threat to Black Hole and Grey Hole by using IPSec.

2.1.1.2 Recursive complexity

A number of drafts and publications suggest -or can be extended to- a model where the Home Agent and any arbitrary Correspondent would actually get individual binding from the chain of nested Mobile Routers, and form a routing header appropriately.

An intermediate MR would keep track of all the pending communications between hosts in its subtree of Mobile Networks and their CNs, and a binding message to each CN each time it changes its point of attachment.

If this was done, then each CN, by receiving all the binding messages and processing them recursively, could infer a partial topology of the nested Mobile Network, sufficient to build a multi-hop routing header for packets sent to nodes inside the nested Mobile Network.

However, this extension has a cost:

1. Binding Update storm

   when one MR changes its point of attachment, it needs to send a BU to all the CNs of each node behind him. When the Mobile Network is nested, the number of nodes and relative CNs can be huge, leading to congestions and drops.

2. Protocol Hacks

   Also, in order to send the BUs, the MR has to keep track of all the traffic it forwards to maintain his list of CNs. In case of IPSec tunneled traffic, that CN information may not be available.

3. CN operation

   The computation burden of the CN becomes heavy, because it has to analyze each BU in a recursive fashion in order to infer nested Mobile Network topology required to build a multi hop routing header.

4. Missing BU

   If a CN doesn't receive the full set of PSBU sent by the MR, it will not be able to infer the full path to a node inside the nested Mobile Network. The RH will be incomplete and the packet may or may not be delivered.

5. Obsolete BU

   If the Binding messages are sent asynchronously by each MR, then, when the relative position of MRs and/or the TLMR point of attachment change rapidly, the image of Mobile Network that the CN maintains is highly unstable. If only one BU in the chain is obsolete due to the movement of an intermediate MR, the connectivity may be lost.

2.2 Route Optimization inside the Nested Mobile Network

This is not part of the Nemo Charter.

The expectation is that the mobile routes installed by Nemo can cohabit with a MANET support that would perform the RO inside the Nested Mobile Network. In other words, MIP redistributes its prefixes locally to a MANET and the MR-HA tunnel is bypassed.

3. MR-to-CN

This section covers the case where the Route Optimization is performed between the MR and the Correspondent Node.

A major issue is that the MIPv6 Reverse Routability test is broken, since it is meant to ensure that the CoA (the MR) an the Home Address (the Mobile Node) are collocated. With a Mobile Network, a LFN is reachable via the Care-Of Address, but not at the Care-Of Address. Some tricks may be performed on the fly by the MRs but it seems that a clean MR-to-CN optimization for Nemo will impact the CN function.

Once we modify the CN behavior, we need to introduce a negotiation from the start of the RR test to determine the protocol. In particular, the Mobile Node and the CN must decide whether checking the collocation is possible, and if not, whether a CN is willing to accept the risk. If not, the optimization may be limited to triangular routing MR->CN->HA->MR.

This is a major evolution from [1], since MIPv6 has no such negotiation capability at this time.

4. MIPv6 Route Optimization over Nemo

When a Mobile Node visits a Mobile Network, the best Route Optimization is obtained if the path in the Infrastructure is the same as if the Mobile Network was attached at the attachment point of the Mobile Router (i.e., there is not additional Tunneling that is linked to Nemo).

A possible approach to this is to extend the solution for nested mobile network optimization to include VMN as well. In this case, the VMN is treated as though it is an MR. This type of solution will most likely require some extensions for a MIPv6 VMN and CN.

5. Optimization within the infrastructure

This section elaborates on cases where the Route Optimization is performed within the Routing Infrastructure. In this model, both the LFN behind the MR and the Correspondent can be MIP agnostic. The drawback is the introduction of Mobile Routes in specific Routers, causing additional signaling and load to the Routing Fabric.

The general idea is that there is a correspondent-side Router in the infrastructure that is located "closer" to the Correspondent than the HA. That Router can terminate MIP on behalf of the CN.


```
    Correspondent nnnnnnnnnnnnnnnnnnnnnnnn  Home Agent
                                              # n #
         o                                    # n #   # :== Tunnel
         o                                    # n #   o :== Optimized
         o                                    # n #   n :== Non-Optimized
         o                                    # n #
             ################################## n #
     C-Side  oooooooooooooooooooooooooooooooo Mobile
     Router  ################################ Router
                                                |
                           ====Mobile Network=======
```

Optimization in the Infrastructure

This optimization is only valid when the path via the correspondent-side Router is shorter than the path via the Home Agent.

The Optimization can take place independently for the 2 directions of the traffic:

Egress

The MR locates the correspondent-side Router, establishes a Tunnel with that Router and sets a route to the Correspondent via the correspondent-side Router over the Tunnel. At this point, the traffic to the Correspondent does not flow via the Home Agent anymore.

Ingress

The correspondent-side Router is on the way of the traffic from the Correspondent to the Home Agent. Also, it is aware of the MR and the Mobile Networks behind the MR and establishes the appropriate Tunnel and Route. At that point, it is able to reroute the traffic to the Mobile Network over the Tunnel to the MR.

5.1 Route Optimization within a ISP network

This form of Route Optimization provides local savings for a ISP. This idea was described in Ohnishi's Mobile Border Gateway draft. The goal is to locate the closest (BGP) gateway for a Correspondent that is located outside of the domain, and tunnel between the MR and that gateway as opposed to the Home Agent for that specific Correspondent.

5.2 Correspondent Router

A globally better optimization is obtained if the tunnel from the MR is terminated closer to the destination on the Correspondent side. This is the role of a Correspondent Router (CR).

```
       +-------------------+                    # :== Tunnel
       | Autonomous System |                    o :== Optimized
       | ----------------- |                    n :== Non-Optimized
       |                   |
       |                   |
       |   Correspondent nnnnnnnnnnnnnnnnnnnnnnnnnnnnn  Home Agent
       |                   |                             # n #
       |        o          |                             # n #
       |        o          |                             # n #
       |        o          |                             # n #
       |        o          |                             # n #
       |        o          |                             # n #
       |            ####################################   ?
       |        CR oooooooooooooooooooooooooooooooooooooo Mobile
       |            ####################################  Router
       |                   |                               |
       +-------------------+    ===========Mobile Network========
```

Correspondent Router

The MR locates the CR for a given Correspondent and establishes a Tunnel to the CR for that destination and its prefix(es). Then, the CR establishes the Tunnel back to the MR and the Mobile Routes to the

MR's Mobile Networks via that Tunnel.

A key point is that the CR must be on the interception path of the traffic from the Correspondent to the Mobile Networks in order to reroute the traffic over the appropriate Tunnel. This can be achieved in several fashions:

Redistribution

There's a limited Number of CRs that cover an Autonomous System. They redistribute the Mobile Routes on the fly, or within rate and amount limits. Garbage Collection is done at appropriate time to limit the perturbation on the Routing.

Default Router

The CR is a Default Router for the Correspondent, or for the whole AS of the Correspondent (it's a border gateway). In this case, redistribution is not needed.

Core Routers

The Core Routers for the network of the Correspondent are all CRs. If the path from the correspondent to the Home Agent does not pass via a CR, then it's not worth optimizing. If it is, then the CRs are on the way. Again, redistribution is not needed.

5.3 Distributed Anchor Routers

Taking the idea of a correspondent router a step further, it is possible to have a distributed set of anchor routers across the Internet. Outgoing packets sent from a mobile network will be tunneled to one of the nearest anchor router (instead of to the home agent of the mobile router). This M-Side (Mobile Network Side) anchor router will decapsulate the packet, inspect the destination, and tunnel the packet to another anchor router situated near the CN (C-Side Anchor Router). From there, the packet will be decapsulated and forwarded to the CN.

```
 Correspondent  nnnnnnnnnnnnnnnnnnnnnnn  Home Agent
      o                                    # n #
```

```
     o                                        # n #    # :== Tunnel
     o                                        # n #    o :== Optimized
     o                                        # n #    n :== Non-Optimized
     o                                        # n #
   C-Side  ##################  M-Side  ###### n #
   Anchor  oooooooooooooooooo  Anchor  oooo Mobile
   Router  ##################  Router  #### Router
                                               |
                           ====Mobile Network=======
```

Optimization in the Infrastructure

The C-Side Anchor Router will be subjected to the same condition as listed in the previous sub-section if packets sent from the CN to the mobile network are to be route-optimized too. Otherwise, the solution will only partially optimize routing to a triangular routing (i.e. packet sent by CN will still go through the home agent of the mobile network).

The anchor router share many similarities with the concept of Mobility Anchor Point (MAP) proposed in Hierarchical MIPv6 (HMIPv6) [8]. In fact, it can be combined with HMIPv6 whereby each M-Side anchor router is also an MAP, and the MR obtains a regional care-of-address from the MAP.

6. Conclusion

The Problem space of Route Optimization in the Nemo context is multifold and can be split is several work areas. It will be critical, though, that the solution to a given piece of the puzzle be compatible and integrate smoothly with the others.

Hopefully, the solutions will build on MIPv6 ([1]), as recommended by the Nemo Charter. On the other hand, MIPv6 seems to be evolving in a direction that makes it more and more difficult to provide a Nemo solution with backward compatibility, since:

1) The RR test prevents a MR-LFN dichotomy on the Mobile Side,

2) The RR test has no negotiable option and is not open for

extension, and

3) The HaO and RH type 2 are designed for a collocated CareOf Address. More specifically, they are not designed to be multi-hop as RRH is, and not extensible, though RRH can be considered as an extension of HaO.

The authors intent is to trigger fruitful discussions that in turn will enhance our common understanding of the problem space so that at some point, this paper turns into a problem statement for the Nemo Route Optimization.

7. Acknowledgements

The authors wish to thank: Greg Daley, Thierry Ernst, Hiroyuki Ohnishi, T.J. Kniveton, Alexandru Petrescu, Hesham Soliman, Ryuji Wakikawa and Patrick Wetterwald for their various contributions.

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Acknowledgement

Funding for the RFC Editor function is currently provided by the Internet Society.