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        Mobile IPv6 Route Optimisation for Network Mobility (MIRON)
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Status of this Memo

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Abstract

   The Network Mobility Basic Support protocol enables networks to roam
   and attach to different access networks without disrupting the
   ongoing sessions that nodes of the network may have. By extending
   the Mobile IPv6 support to Mobile Routers, nodes of the network are

not required to support any kind of mobility, since packets must go
through the Mobile Router-Home Agent (MRHA) bi-directional tunnel.
Communications from/to a mobile network have to traverse the Home
Agent, and therefore better paths may be available. Additionally,
this solution adds packet overhead, due to the encapsulation.

This document describes an approach to the Route Optimisation for
NEMO, called Mobile IPv6 Route Optimisation for NEMO (MIRON). MIRON
enables mobility-agnostic nodes within the mobile network to directly
communicate (i.e. without traversing the MRHA bi-directional tunnel)
with Correspondent Nodes. The solution is based on the Mobile Router
performing the Mobile IPv6 Route Optimisation signalling on behalf of
the nodes of the mobile network.

This document (in an appendix) also analyses how MIRON fits each of
the NEMO RO Aeronautics requirements.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
"SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
document are to be interpreted as described in RFC 2119 [1].

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1. Introduction

   This document assumes that the reader is familiar with the
   terminology related to Network Mobility [9] and [10] (Figure 1), and
   with the Mobile IPv6 [2] and NEMO Basic Support [3] protocols.

   The goals of the Network Mobility (NEMO) Support are described in
   [11]. Basically, the main goal is to enable networks to move while
   preserving the communications of their nodes (Mobile Network Nodes,
   or MNNs), without requiring any mobility support on them. The NEMO
   Basic Support protocol [3] consists on setting a bi-directional
   tunnel (Figure 2) between the Mobile Router (MR) of the network (that
   connects the mobile network to the Internet) and its Home Agent
   (located at the Home Network of the mobile network). This is
   basically the Bi-directional Tunnel (BT) operation of Mobile IPv6
   (MIPv6) [2], but without supporting Route Optimisation. Actually,
   the protocol extends the existing MIPv6 Binding Update (BU) message
   to inform the Home Agent (HA) of the current location of the mobile
   network (i.e. the MR's Care-of Address, CoA), through which the HA
   has to forward the packets addressed to the network prefix managed by
   the MR (Mobile Network Prefix, or MNP).

```
                        ---------
                       | HA_MR |
                        ---------
                            |
    ------      +-----------+---------+
   | CN |----|      Internet       |
    ------      +---+-----------------+
                    |
                 ------        -------------------------------
                | AR |       | AR: Access Router           |
                 ------        | CN: Correspondent Node       |
                    |          | MR: Mobile Router            |
            ===?==========      | HA_MR: MR's Home Agent        |
                MR             | MNP: Mobile Network Prefix  |
                 |             | MNN: Mobile Network Node     |
        ===|========|====(MNP)  -------------------------------
            MNN       MNN
```
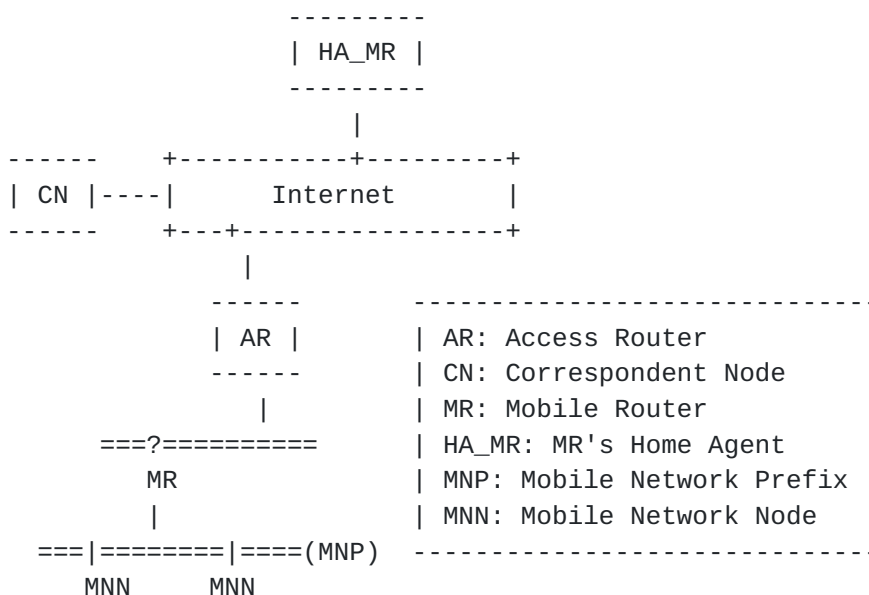
              Figure 1: Basic scenario of Network Mobility

   Because of the bi-directional tunnel that is established between HA
   and MR to transparently enable the movement of networks, the NEMO
   Basic Support protocol introduces the following limitations:
   o It forces suboptimal routing (known as angular or triangular
      routing), since packets are always forwarded through the HA
      following a suboptimal path and therefore adding a delay in the

        packet delivery.
    o It introduces non-negligible packet overhead, reducing the Path
       MTU (PMTU). An additional IPv6 header (40 bytes) is added to
       every packet because of the MRHA bi-directional tunnel.
    o The HA becomes a bottleneck of the communication. This is
       because, even if a direct path is available between a MNN and a
       CN, the NEMO Basic Support protocol forces traffic to follow the
       CN-HA=MR-MNN path. This may cause the Home Link to be congested,
       resulting in some packets discarded.

    In order to overcome such limitations, it is necessary to provide
    what have been called Route Optimisation for NEMO [12], [13], [14],
    [15]. In Mobile IPv6, the Route Optimisation is achieved by allowing
    the Mobile Node (MN) to send Binding Update messages also to the CNs.
    In this way the CN is also aware of the CoA where the MN's Home
    Address (HoA) is currently reachable. The Return Routability (RR)
    procedure is defined to authenticate new CoAs that the MN may use,
    thus securing the change that the CN makes in the IPv6 destination
    address (using the MN's CoA) of the packets it sends addressed to the
    MN's HoA [16].

```
      __           _____                          __           ___
     |  |         |     |                        |  |         |   |
     |CN|         |HA_MR|                        |MR|         |MNN|
     |__|         |_____|                        |__|         |___|
      |             |                             |             |
      | -----------   | -----------------------------   | -----------   |
      | |S:CN,D:MNN|   | |S:HA_MR,D:MR_CoA[S:CN,D:MNN]|   | |S:CN,D:MNN|   |
      | |   DATA   |   | |            DATA            |   | |   DATA   |   |
      | -----------   | -----------------------------   | -----------   |
      |------------->|----------------------------->|------------->|
      |             |                             |             |
      |   -----------   | -----------------------------   | -----------   |
      |   |S:MNN,D:CN|   | |S:MR_CoA,D:HA_MR[S:MNN,D:CN]|   | |S:MNN,D:CN|   |
      |   |   DATA   |   | |            DATA            |   | |   DATA   |   |
      |   -----------   | -----------------------------   | -----------   |
      |<-------------|<-----------------------------|<-------------|
      |             |                             |             |
```
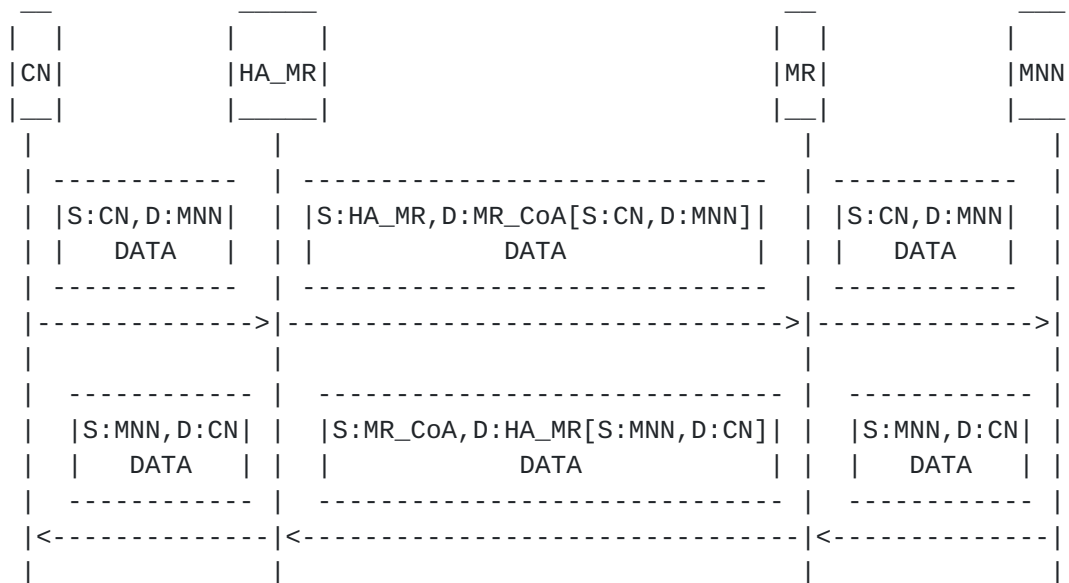
               Figure 2: NEMO Basic Support protocol

    This document describes a Route Optimisation solution for nodes of a
    mobile network that do not have (or use) any kind of mobility
    support, that is, the so-called Local Fixed Nodes (LFNs). The
    solution enables direct path communication between an LFN and a CN,
    without requiring any change on the operation of CNs nor LFNs. In
    order to do that, the MR performs all the Route Optimisation
    signalling and mobility tasks defined by Mobile IPv6 on behalf of the

LFNs attached to the mobile network.

2. **Protocol Overview**

The mechanism, called Mobile IPv6 Route Optimisation for NEMO
(MIRON), essentially consists in enabling a MR to behave as a proxy
for nodes that do not have any kind of mobility support (i.e. LFNs),
performing the Mobile IPv6 Route Optimisation signalling and packet
handling on behalf of the LFNs.

In order to enable packets to be directly routed between the CN and
the LFN (avoiding the MRHA tunnel), the MR sends a MIPv6 Binding
Update message on behalf of the LFN, binding the LFN's address to the
MR's CoA.

Mobile IPv6 requires an additional security procedure to be performed
before actually sending a Binding Update message to a certain CN (and
therefore enabling the Route Optimisation between MN and CN).
Basically, this procedure, called Return Routability (RR) -- needed
in order to mitigate possible security concerns [16] -- is used to
verify that the MN, besides being reachable at the HoA, is also able
to send/respond to packets sent to a given address (different to its
HoA). This mechanism can be deceived only if the routing
infrastructure is compromised or if there is an attacker between the
verifier node and the CoA (HoA and CoA) that are being verified.
With these exceptions, the test is used to ensure that the MN's Home
Address (HoA) and MN's Care-of Address (CoA) are collocated.

Since MIRON proposes the MR to behave as a "proxy" (Figure 3), the MR
has to perform the Mobile IPv6 Return Routability procedure on behalf
of the LFNs. This involves the MR sending the Home Test Init (HoTI)
and Care-of Test Init (CoTI) messages to the CN and processing the
replies (Home Test message HoT -- and Care-of Test message -- CoT).
These messages are sent as specified in [2], using the LFN's address
as the source address in the HoTI message -- which is sent
encapsulated through the MR's HA --, and the MR's CoA as the source
address in the CoTI message. With the information contained in the
HoT and CoT messages, sent by the CN in response to the HoTI and CoTI
messages respectively, the MR is able to build a BU message to be
sent to the CN on behalf of the LFN. This message is sent using the
MR's CoA as the packet source address and carries a Home Address
destination option set to the LFN's address.

Once the Return Routability procedure has been done and the MR has
sent the BU message -- binding the address of the LFN (belonging to
the MR's MNP) to the MR's CoA -- packets between the CN and the LFN
do not follow the suboptimal CN-HA=MR-LFN path anymore, but the CN-

MR-LFN optimised route (Figure 4). This signalling has to be
repeated periodically, as specified by MIPv6 IPv6 (the RR procedure
has to be repeated at least every 7 minutes, to avoid time-shifting
attacks).

```
  __              _____                            __        ___
 |  |            |     |                          |  |      |   |
 |CN|            |HA_MR|                          |MR|      |LFN|
 |__|            |_____|                          |__|      |___|
  |                 |                              |          |
  |    -----------  | ----------------------------  |          |
  |   |S:LFN,D:CN|  | |S:MR_CoA,D:HA_MR[S:LFN,D:CN]| |          |
  |   |  HoTI    |  | |            HoTI           | |          |
  |    -----------  | ----------------------------  |          |
  |<----------------|<----------------------------|          |
  |                 |               -------------- |          |
  |                 |              |S:MR_CoA,D:CN| |          |
  |                 |              |    CoTI     | |          |
  |                 |               -------------- |          |
  |<-------------------------------------------------|          |
  |                 |                              |          |
  |  -----------    | ----------------------------  |          |
  | |S:CN,D:LFN|    | |S:HA_MR,D:MR_CoA[S:CN,D:LFN]| |          |
  | |   HoT    |    | |            HoT            | |          |
  |  -----------    | ----------------------------  |          |
  |---------------->|--------------------------------->|          |
  | --------------  |                              |          |
  | |S:CN,D:MR_CoA| |                              |          |
  | |    CoT     | |                              |          |
  | -------------- |                              |          |
  |-------------------------------------------------->|          |
  |                 |                              |          |
  |                 |               -------------- |          |
  |                 |              |S:MR_CoA,D:CN| |          |
  |                 |              | BU(HoA:LFN) | |          |
  |                 |               -------------- |          |
  |<-------------------------------------------------|          |
  |                 |                              |          |
```
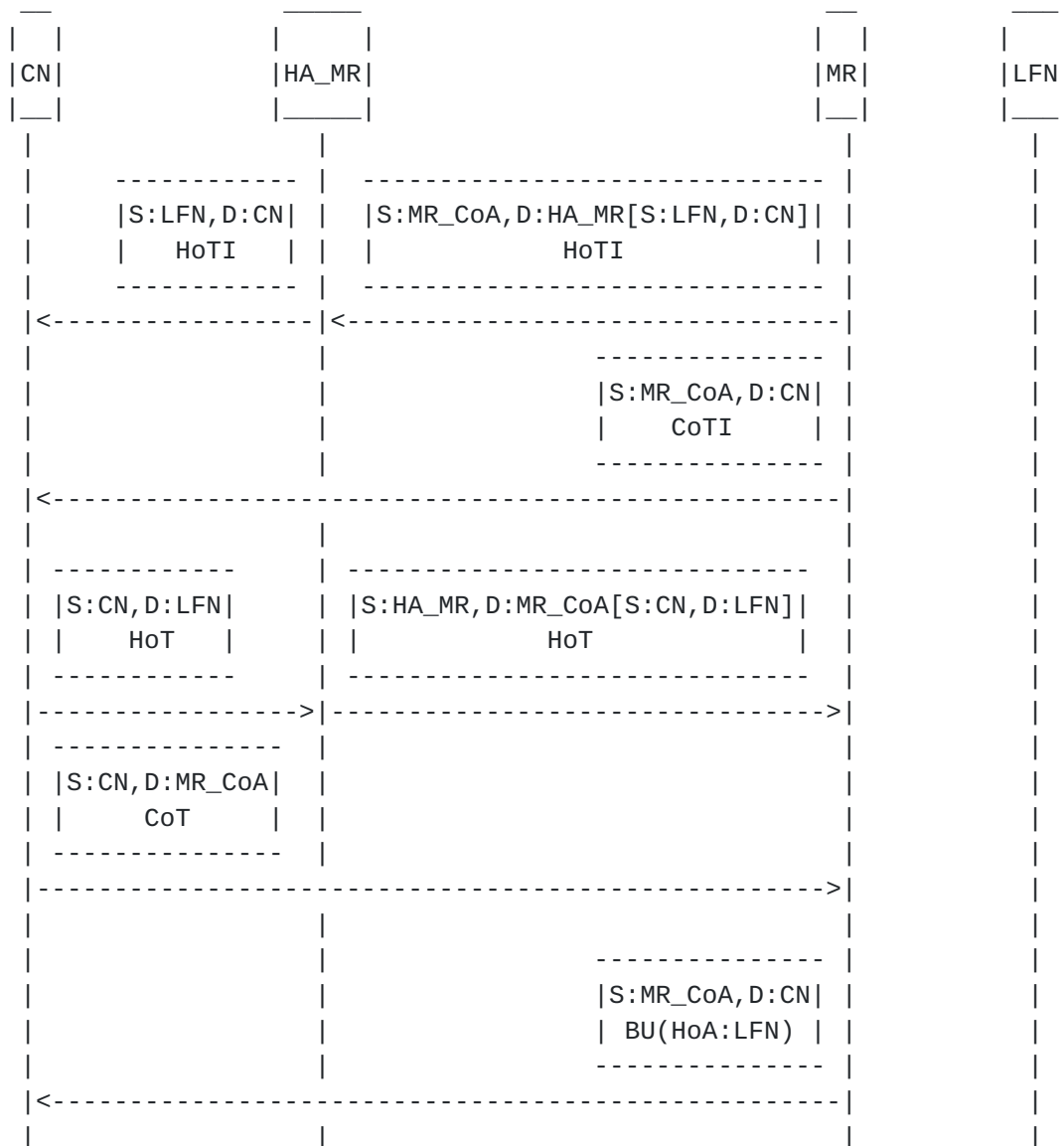
Figure 3: MIRON signalling

In addition to generating and receiving all the signalling related to
Route Optimisation on behalf of the LFNs, the MR has also to process
the "route optimised" packets sent by/directed to the LFNs
(Figure 4):
o Packets sent by a CN are addressed to the MR's CoA and contain
   IPv6 extension headers (a type 2 Routing Header) that are not
   understood by the LFN. Therefore, the MR has to change the

    destination address and remove the routing header before
    delivering the packet to the LFN.
 o Packets sent by an LFN have to be also processed. The MR, in
    order to be able to send packets directly to the CN, has to use
    its CoA as source address of the packets and has also to add a
    Home Address destination option to every packet (set to the LFN's
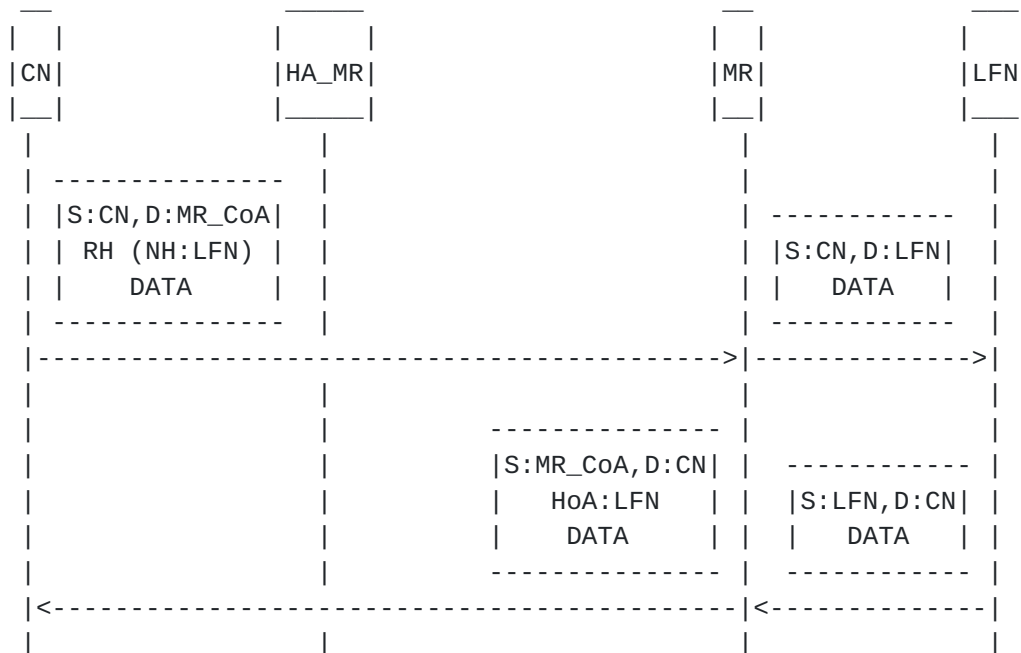   address).

```
    __                 _____                __                  ___
   |  |               |     |              |  |                |   |
   |CN|               |HA_MR|              |MR|                |LFN|
   |__|               |_____|              |__|                |___|
    |                    |                   |                   |
    | ---------------    |                   |                   |
    | |S:CN,D:MR_CoA|    |                   | -----------    |
    | | RH (NH:LFN) |    |                   | |S:CN,D:LFN|    |
    | |    DATA     |    |                   | |   DATA    |    |
    | --------------     |                   | -----------    |
    |-------------------------------------------------->|-------------->|
    |                    |                   |                   |
    |                    |     ---------------    |                   |
    |                    |     |S:MR_CoA,D:CN|    | -----------    |
    |                    |     |   HoA:LFN   |    | |S:LFN,D:CN|    |
    |                    |     |    DATA     |    | |   DATA    | |
    |                    |     --------------     | -----------    |
    |<-------------------------------------------|<--------------|
    |                    |                   |                   |
```

        Figure 4: MIRON packet handling (Route Optimised operation)

[3]. Mobile Router operation

   The Mobile Router operation defined by the NEMO Basic Support
   protocol [3] is extended in order to be able to generate and process
   the Mobile IPv6 Route Optimisation signalling (i.e. Return
   Routability and Binding Update) [2], since the MR is behaving as a
   "Proxy-MR" for their LFNs.

[3.1]. Data Structures

   In addition to the data structures defined in [3], the MR need also
   to maintain the following information:
 o The MR extends the Binding Update List (BUL) to contain also some
    information per each LFN-CN communication that is being optimised.
    Basically the added fields are those described in [2] that are
    related to the Route Optimisation procedure defined by Mobile IPv6
    (such as IP addresses of CNs, binding lifetimes, Return

      Routability state, etc.), since the MR is behaving as Proxy-MR for
      the LFNs attached to it.
   o The BUL is not indexed only by the address of the CN, since there
      is a different binding per each CN-LFN pair. Therefore, the LFN's
      address has to be also included in every BUL entry.

3.2. Performing Route Optimisation

   Since the proposed optimisation has to be done per each LFN-CN
   communication, the MR should track the different ongoing
   communications that attached LFNs may have, in order to identify
   potential LFN-CN communications that may be worth optimising. Due to
   the fact that optimising a certain LFN-CN communication involves a
   cost -- in terms of signalling and computation resources at the MR --
   it may not be worth to perform such a optimisation to some kinds of
   flows (e.g., DNS queries). The decision about whether to perform
   Route Optimisation to a certain LFN-CN communication or not is out of
   the scope of this document.

   Per each LFN-CN communication that has been decided to be route
   optimised, the MR has to perform the following actions:
   o The MR performs the Return Routability procedure as described in
      Section 2.
   o The MR sends a MIPv6 Binding Update message to the CN on behalf of
      the LFN. The BU contains the address of the LFN as the MN's Home
      Address (HoA) and the MR's CoA as the MN's CoA (the MR's CoA is
      the only address that is reachable without requiring any agent to
      be deployed to forward packets to the current location of the
      mobile network). This procedure binds the LFN's address to the
      MR's CoA at the CN (i.e. an entry is added at the CN's Binding
      Cache).
   o The MR processes every packet received from the CN as follows:
      * These packets carry the MR's CoA as destination address, and
         also carry a Type 2 Routing Header with the LFN's address as
         next hop. The MR processes the Routing Header of the packet,
         checking if the next hop address belongs to one of its LFNs
         and, if so, delivering the packet to the LFN.
   o The MR processes every packet received from the LFN as follows:
      * The MR's CoA is set as IPv6 source address.
      * An IPv6 Home Address destination option, carrying the address
         of the LFN, is inserted.

   When MIRON is used to perform RO for a certain LFN-CN communication,
   the resulting PMTU of the path between LFN and CN might be bigger
   than the one when the MRHA tunnel is used. A MIRON MR implementation
   MAY decide to modify ICMPv6 Packet Too Big messages [4], [5] to
   include in the MTU field a value that takes into account the 24-byte
   overhead of MIRON (due to the Routing Header and Home Address

destination option) instead of the 40-byte overhead added when the
MRHA bi-directional tunnel is used (due to the IPv6-in-IPv6
encapsulation).

[4](#). **Home Agent, Local Fixed Node and Correspondent Node operation**

The operation of the Home Agent, the Local Fixed Nodes and the
Correspondent Nodes remains unchanged. The only requirement is that
CNs must implement the Correspondent Node part of the Route
Optimisation defined by Mobile IPv6 (Section 9 of [[2](#)]).

[5](#). **Conclusions**

This document describes a Route Optimisation for NEMO for LFN-CN
flows. The MR performs all the Route Optimisation tasks on behalf of
the LFNs that are attached to it. This involves generating and
processing all the related signalling (that is, the Return
Routability procedure and the Binding Update message), but also
handling the packets sent and received by the LFNs, in order to
enable the direct CN-MR-LFN route (avoiding the suboptimal CN-HA=MR-
LFN path) without requiring any change on the operation of CNs nor
LFNs.

The Route Optimisation here described is intended for LFN-CN
communications in a non-nested NEMO. However, nothing prevents this
solution to be also applied in a nested NEMO, avoiding the last
tunnel, or even all the tunnels if the MR is provided somehow with a
topologically valid IPv6 address that is reachable without traversing
any HAs (for example, as described in [[17](#)]).

MIRON has been implemented [[18](#)] within the framework of the European
DAIDALOS project (http://www.ist-daidalos.org). The implementation
of the NEMO Basic Support protocol of MR and HA and the MIRON code at
the MR have been done for Linux (2.6 kernel), mostly at user space
(in C). The implementation used at the CNs is MIPL-2.0
(http://wwww.mobile-ipv6.org).

Conducted tests [[17](#)] show that the performance obtained with MIRON is
much better -- in terms of latency and effective TCP throughput --
than the obtained by the NEMO Basic Support protocol, specially when
the "distance" (i.e. RTT) between the HA and the CN is increased.

[6](#). **Security Considerations**

Because an LFN trusts its MR for the routing of all its traffic (both

for inbound and outbound packets), allowing the MR to perform some
signalling and processing on behalf of the LFNs attached to it does
not introduce any new threat. From the architectural point of view,
the solution is also natural, since the Route Optimisation support
defined by Mobile IPv6 [2] conceptually could be implemented in
multiple boxes. MIRON just applies this mechanism, by splitting the
mobility functions among two different physical boxes, but actually
the conceptual basis of the solution is the same as the one defined
by Mobile IPv6.

7. IANA Considerations

This document has no actions for IANA.

8. Acknowledgements

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Appendix A. Analysis of MIRON and the Aeronautics requirements

   This appendix looks at the Aeronautics requirements described in [19]
   and analyses how MIRON fits each of them. If a certain requirement
   cannot be fulfilled by MIRON as it is described in this document,
   possible modifications/extensions are also considered. This analysis
   aims at understanding if MIRON could be a good candidate to be used
   as a NEMO RO solution for the aeronautics scenario.

   This appendix only analyses those requirements that involve LFNs,
   since the MIRON solution described here does only address the Route
   Optimisation of LFN-CN communications. For those requirements
   involving VMNs, an extended MIRON solution should be applied, such as

the one described in [17].

A.1. Req1 - Separability

This requirement basically states that a NEMO "RO scheme MUST have
the ability to be bypassed by applications that desire to use bi-
directional tunnels through an HA".

This requirement is fulfilled by MIRON, since the Route Optimisation
is performed in a per-flow basis and the decision about which flows
are optimised is taken by the MR. Therefore, different approaches
can be implemented in the MR (it is open to the particular MIRON
implementation how to do it) to take this decision: static and
dynamic policies (using a protocol to update MR's policies),
decisions based on current load of the MR, etc.

A.2. Req2 - Multihoming

This requirement states that "RO schemes MUST permit an MR to be
simultaneously connected to multiple access networks, having multiple
prefixes and Care-Of Addresses in a MONAMI6 context".

In MIRON, RO is achieved by the MR performing all the MIPv6-RO
operations on behalf of connected LFNs. Therefore, MIRON can
potentially benefit directly from any mechanism developed in the
MONAMI6 WG. For example, MIRON could use Multiple-CoA mechanism [6]
to enable an MR register different CoAs at CNs.

We should also mention that although MIRON can benefit from
multihoming solutions developed within the MONAMI6 WG, multihoming
issues in Network Mobility [20] should be tackled specifically by a
general NEMO multihoming framework. Since MIRON does not modify in
any way the NEMO Basic Support operation, it will also be compatible
with such a general NEMO multihoming solution.

A.3. Req3 - Latency

This requirement says: "an RO solution MUST be capable of configuring
and reconfiguring itself (and reconfiguring after mobility events)
without blocking unoptimized packet flow during its initiation and
before or after transitions in the active access links".

This means that an RO solution MUST not prevent data packets from
being forwarded through the MRHA bi-directional tunnel while the
required RO operations are being performed. This requirement is also
fulfilled by MIRON, since while the MR performs all the MIPv6-RO
operations on behalf of LFNs, their communications still use the MRHA
tunnel.

A.4. Req4 - Availability

   This requirement states that "an RO solution MUST NOT imply a single
   point of failure, whether that be a single MR, a single HA, or other
   point within the ground network".

   This requirement requires special attention to be achieved by MIRON.
   On the one hand, current NEMO Basic Support protocol [3] does not
   fulfil that today, and therefore needs additional work to be carried-
   out. On the other hand, if we focus only on MIRON availability, the
   following are the potential points of failure that should be tackled:
   o Home Agent: a failure of the Home Agent -- in addition to
      disrupting communications that are being forwarded using the MRHA
      bi-directional tunnel -- could also cause Route Optimised
      communications to stop, since the Return Routability procedure
      (which is part of the MIPv6-RO mechanism) performed by the MR on
      behalf of LFNs requires the MRHA tunnel to be up. This Return
      Routability procedure should be repeated every seven minutes
      (MAX_RR_BINDING_LIFETIME=420 seconds) to avoid time-shifting
      attacks, and therefore, depending on how long a Home Agent is down
      and when the failure happens, route optimised communications might
      be affected. This issue is actually not introduced by MIRON,
      hence it could be avoided by using a general redundancy mechanism
      aimed for the NEMO Basic Support protocol.
   o Mobile Router: a failure of the MR would obviously disrupt
      established connections in a single-MR NEMO. In the case of a
      multiple-MR NEMO, additional mechanisms would be required in order
      to guarantee that route optimised communications managed by a
      particular MR would survive in case this MR fails. Although MIRON
      currently does not address this issue, additional mechanisms --
      such as deploying back-to-back MRs in aircrafts or designing/
      reusing existing protocols to keep the RO state of several MRs
      synchronised -- might be used here.
   o Home Network reachability: in case of single-homed NEMOs, if the
      Home Network is not reachable, traffic through the MRHA bi-
      directional tunnel will be disrupted. Additionally, Return
      Routability checks performed by a MIRON MR on behalf of attached
      LFNs would also fail. Again, this issue is not introduced by
      MIRON, hence it needs to be addressed by a general redundancy
      mechanism suited for the NEMO Basic Support protocol.

A.5. Req5 - Integrity

   The Integrity requirement says: "an RO scheme MUST NOT cause packets
   to be dropped at any point in operation, when they would not normally
   have been dropped in a non-RO configuration".

   It takes longer to finish a handover of a route optimised flow using

   MIRON than a normal NEMO Basic Support protocol handover, due to the
   additional RTT required to complete the MIPv6-RO signalling with CNs.
   If this additional RTT component in the overall handover delay is
   considered too much for a certain application, either this
   application could not use MIRON to provide NEMO RO or a make-before-
   break solution would be needed. Note that extending MIRON to support
   existing micromobility solutions -- such as Fast Handovers for Mobile
   IPv6 [7] -- would not require too much additional work, since MIRON
   basically re-uses standard MIPv6 mechanisms.

   Alternatively, MIRON may decide to perform packet bi-casting and send
   route optimised traffic also through the MRHA bi-directional tunnel,
   during the time required to finish the MIPv6-RO signalling with CNs.
   That would allow not to lose any additional packets in the LFN-CN
   direction, but traffic from the CN would not be received by the LFN
   until the RO signalling has been completed. Therefore, this solution
   would only alleviate the problem for outbound packets.

A.6. Req6 - Scalability

   This requirement says that "an RO scheme MUST be simultaneously
   usable by ten thousand nodes without overloading the ground network
   or routing system".

   Basically, there are two different aspects that may affect to the
   scalability of MIRON:
   o Memory consumption at the MR. MIRON needs some additional
      information to be stored at the MR, such extended BUL (since state
      information regarding each LFN-CN optimised pair is required).
      The required memory to store a BUL entry is relatively small and
      grows linearly with the number of LFN-CN route optimised pairs.
   o Processing load at the MR. MIRON requires the MR to perform some
      additional operations: inspection of every packet and special
      handling (that is, removal of the Routing Header in the CN-to-LFN
      direction and addition of the Home Address destination option in
      the LFN-to-CN direction) of route optimised packets. Regarding
      packet inspection, MIRON just needs to look at the source and
      destination addresses of every packet to track LFN-CN flows, so
      this inspection is quite similar to the normal inspection that a
      router does. Even if some local policies are implemented at the
      MR to enable smarter decisions about whether a certain flow should
      be optimised or not -- requiring the MR to look also at other
      fields in a packet (such as transport headers) -- this inspection
      is not much different than the inspection than typical firewall
      software does in a border (access) router.
   o Impact on the global routing system. MIRON does not have any
      impact on the global routing tables, and therefore it does not
      introduce any routing scalability issue, even with large

   deployments.

   We can conclude that MIRON required resources grow linearly with the
   number of optimisations being performed, and that these required
   resources do not impose any constraint for modern available routers.
   Besides, MIRON does not impact in any way the global routing system.

[A.7](#). **Req7 - Throughput**

   This requirement is related to the additional signalling required by
   a NEMO RO solution, and basically states that "an RO scheme MUST be
   capable of operating on traffic streams with individual rates up to 5
   Mbps, and aggregates of 50 Mbps, while accounting for less than 9.6
   kbps of bandwidth for its own signaling overhead".

   MIRON's overhead comes from two different components:
   o Signalling load. In order to optimise a CN-LFN flow, the MR has
      to perform the MIPv6-RO signalling with the CN on behalf of the
      LFN. This signalling grows linearly with the number of CN-LFN
      pairs being optimised. In order to optimise an LFN-CN flow, the
      RR signalling (HoTI+CoTI+HoT+CoT) plus a Binding Update message
      should be sent every seven minutes. This means that 6.4 bps are
      required to keep each LFN-CN flow route optimised (without the MR
      moving), and therefore, 1500 LFN-CN flows can be optimised with
      9.6 kbps. Obviously, previous numbers have been calculated
      without considering MR's movements, hence a NEMO that changes its
      point of attachment very frequently -- although this is not likely
      to happen in aircraft scenarios -- would support less optimised
      flows.
   o Data traffic overhead. MIRON introduces a 24-byte per packet
      overhead in every route optimised data packet, because of the
      Routing Header type 2 (added by the CN to the data packets sent to
      an LFN) and the Home Address destination option (added by the MR
      to the data packets sent by the LFN). Actually, the overhead
      introduced by MIRON is 16-byte less than the the overhead
      introduced by the NEMO Basic Support protocol, and therefore this
      means that MIRON reduces the overhead when compared with the NEMO
      non-optimised scenario.

   MIRON's overhead shows to be low enough to achieve target numbers
   provided in [19], although it would obviously depend on which
   communication flows are required to be route optimised.
   Additionally, [19] indicates that those numbers have been chosen
   somewhat arbitrarily, and may be subject to revision.

A.8. **Req8 - Security**

   This requirement is summarised as "IPsec MUST be usable over the RO
   scheme, and the data used to make RO decisions MUST be authenticable
   authenticable, perhaps using some form of IPsec".

   MIRON supports to route optimise communications that use IPsec ESP
   data traffic, since the ESP header comes after the Routing Header and
   Home Address destination option, and therefore MIRON does not affect
   ESP semantics.

   If IPsec AH is used in an LFN-CN communication, outbound (from the
   LFN to the CN) AH packets need to be to be reverse-tunnelled through
   the MRHA tunnel instead of being forwarded following the RO path,
   since adding the Home Address destination option would affect the AH
   integrity check. For inbound packets, there is no problem, since the
   MR just advances the source route and LFN can process these packets
   normally, without affecting AH semantics.

   If IPsec is preferred to secure RO signalling, MIRON could be
   extended to support solutions like [8], [21].

A.9. **Req9 - Adaptability**

   This requirement states that "New applications, potentially using new
   transport protocols or IP options MUST be possible within an RO
   scheme".

   In addition to RO decisions taken based on the lifetime of current
   communications (e.g., every data communication flow involving more
   packets than a particular threshold is route optimised), MIRON MAY
   make use of information about higher layer protocols to classify
   between flows that prefer the MRHA tunnel or a route optimised path.
   Depending on the mechanisms used to feed the decision intelligence
   mechanism at the MR, it might be required to perform some
   reconfiguration actions on MRs in order to enable new applications
   and/or protocols benefit from RO. However, the use of unexpected/new
   higher layer protocols and/or applications would not make MIRON fail,
   but just revert on using the MRHA bi-directional tunnel for those
   flows that cannot be classified using existing filters/policies at
   the MR.

A.10. **Des1 - Configuration**

   This requirement is not considered as a strict one, and basically
   states that "it is desirable that a NEMO RO solution be as simple to
   configure as possible and also easy to automatically disable if an
   undesirable state is reached".

MIRON configuration is not detailed in this document, since it is
open to implementation. However, even if complex policies are used
to determine which communication flows/applications are route
optimised, MIRON configuration would be as simple as configuring
today's firewalls. A MIRON MR does not require more configuration
than a MIPv6 MN.

A.11. Des2 - Nesting

This requirement is not considered as a strict one, and basically
states that "it is desirable if the RO mechanism supports RO for
nested MRs".

MIRON, as it is described in this document, does not provide RO
capabilities for nested MRs. However, it can be extended to support
also these configurations. [17] describes one possible way of doing
that.

A.12. Des3 - System Impact

This requirement is not considered as a strict one, and basically
states that "low complexity in systems engineering and configuration
management is desirable in building and maintaining systems using the
RO mechanism".

Since MIRON RO solution only requires changes on the MR, deploying
MIRON is extremely easy in terms of global system impact. Only the
MR is required to be configured, maintained and updated.

A.13. Des4 - VMN Support

This requirement is not considered as a strict one, and basically
states that "it is strongly desirable for VMNs to be supported by the
RO technique, but not strictly required".

As previously mentioned, this document has only described MIRON
operation to optimise LFN-CN traffic flows. An extended MIRON
version, such as the one described in [17], could be used to provide
VMNs with Route Optimisation.

A.14. Des5 - Generality

This requirement is not considered as a strict one, and basically
states that "an RO mechanism that is "general purpose", in that it is
also readily usable in other contexts outside of aeronautics and
space exploration, is desirable".

MIRON has been designed as a general NEMO RO framework, not being

focused to address any particular scenario, but to be broadly-scoped.
Therefore, MIRON could also be considered as a solution for other
scenarios such as the vehicular [22] or consumer electronics ones.

Appendix B. Change Log

Changes from -00 to -01:
o Added appendix "Analysis of MIRON and the Aeronautics
   requirements".
o Some text cleanup and minor changes.

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