              Network Mobility (NEMO) Extensions for Mobile IPv4

Status of This Memo

Abstract

   This document describes a protocol for supporting Mobile Networks
   between a Mobile Router and a Home Agent by extending the Mobile IPv4
   protocol. A Mobile Router is responsible for the mobility of one or
   more network segments or subnets moving together. The Mobile Router
   hides its mobility from the nodes on the Mobile Network. The nodes
   on the Mobile Network may be fixed in relationship to the Mobile
   Router and may not have any mobility function.

   Extensions to Mobile IPv4 are introduced to support Mobile Networks.

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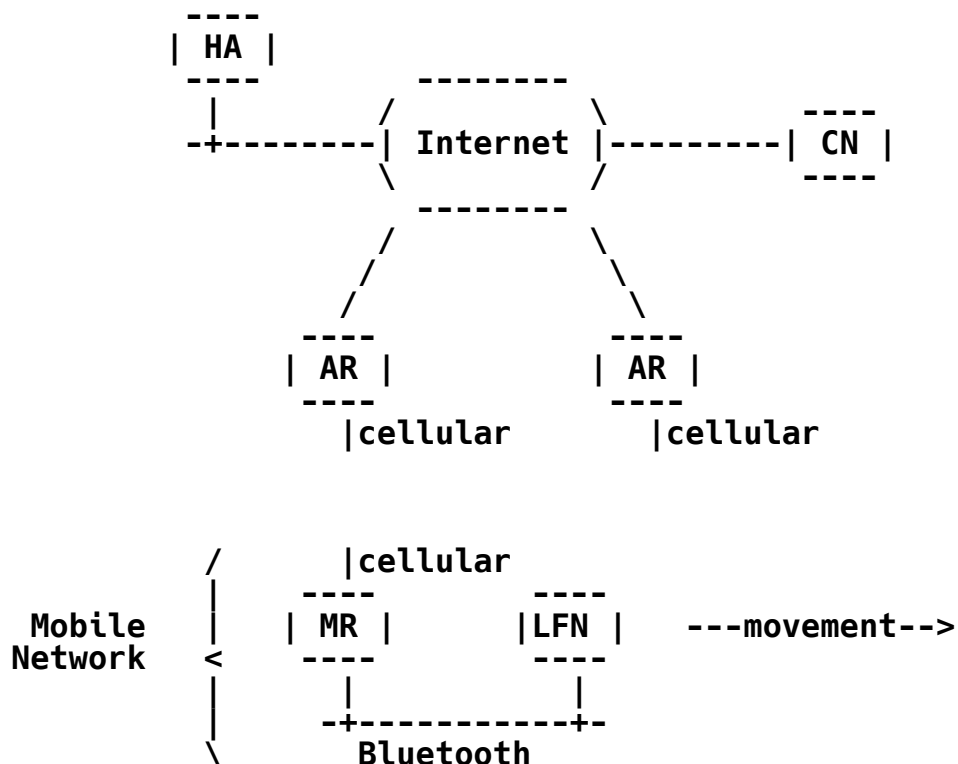
1. Introduction

   This document describes network mobility extensions to the Mobile
   IPv4 protocol. The goal of introducing these extensions is to
   accommodate mobility scenarios where groups of hosts and routers move
   homogeneously (as a whole). It is required that all hosts and
   routers in a Mobile Network be able to run applications connecting to
   the Internet, and be reachable from the Internet.

   For details regarding terminology related to network mobility (NEMO),
   a quick read of RFC 4885 [RFC4885] is suggested.

1.1. Examples of Mobile Networks

   A Mobile Network links together a set of hosts and routers.
   Connecting this Mobile Network to the Internet is ensured at two
   levels: first, a Mobile Router is connected on one side to the Mobile
   Network and on another side to a wireless access system; second, a
   Home Agent placed on the home link manages traffic between the
   Correspondent Node and a Local Fixed Node (LFN, a node in the Mobile
   Network) by means of encapsulating traffic.

   A scenario of applicability for this Mobile Network is described
   next. A Mobile Network is formed by a wireless-enabled Personal
   Digital Assistant (PDA) and a portable photographic camera, linked
   together by Bluetooth wireless link-layer technology. This is
   sometimes referred to as a Personal Area Network (PAN). In the
   illustration below, one can notice the PDA playing the role of a
   Mobile Router and the camera the role of Local Fixed Node.

```
                    ----
                   | HA |
                    ----        --------
                     |         /        \              ----
                   -+--------| Internet |--------| CN |
                             \        /               ----
                              --------
                             /        \
                            /          \
                           /            \
                        ----            ----
                       | AR |          | AR |
                        ----            ----
                           |cellular       |cellular


             /        |cellular
             |        ----            ----
   Mobile    |       | MR |          |LFN |    ---movement-->
   Network   <        ----            ----
             |          |              |
             |        -+-----------+-
             \              Bluetooth
```
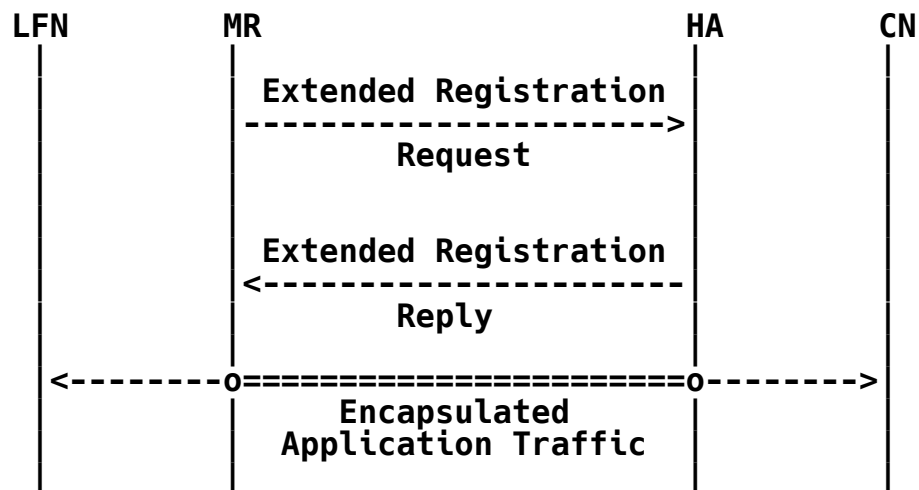
The camera (Local Fixed Node) uploads photographic content to a
Correspondent Node (CN) server. When the Mobile Network moves away,
the Mobile Router serving the Mobile Network changes its point of
attachment from one cellular access (Access Router) to another,
obtaining a new Care-of Address. The Home Agent (HA) encapsulates
application traffic for the CN and LFN.

Whereas the illustration above is a very simple instantiation of the
applicability of Mobile IP-based Mobile Networks, more complex Mobile
Networks are easily accommodated by the Mobile IPv4 extensions
presented in this document (NEMOv4). For example, laptop computers
used by passengers in a bus, train, ship, or plane should all be
considered as forming Mobile Networks, as long as they move together
(homogeneously).

1.2. Overview of Protocol

   As introduced previously, this document presents extensions to the
   Mobile IPv4 protocol. The entities sending and receiving these
   extensions are the Mobile Router and the Home Agent. The Local Fixed
   Node is relieved from running Mobile IP software and, although it
   moves (together with the Mobile Network), its IP stack is not seeing
   any change in addressing.

   Mobility for the entire Mobile Network is supported by the Mobile
   Router registering its current point of attachment (Care-of Address)
   to its Home Agent: the Mobile Router sends an extended Registration
   Request to the Home Agent, which returns an extended Registration
   Reply. This signaling sets up the tunnel between the two entities,
   as illustrated in the following figure:

```
            LFN           MR                        HA          CN
             |             |                         |           |
             |             | Extended Registration   |           |
             |             |------------------------>|           |
             |             |        Request          |           |
             |             |                         |           |
             |             | Extended Registration   |           |
             |             |<------------------------|           |
             |             |         Reply           |           |
             |             |                         |           |
             |<--------o===========================o-------->|
             |             |      Encapsulated       |           |
             |             |   Application Traffic   |           |
             |             |                         |           |
```

   The prefix(es) used within a Mobile Network (either implicitly
   configured on the Home Agent or explicitly identified by the Mobile
   Router in the Registration Request) is/are advertised by the Home
   Agent for route propagation in the home network. Traffic to and from
   nodes in the Mobile Network are tunneled by the Home Agent to the
   Mobile Router, and vice versa. Though packets from a Local Fixed
   Node placed in the Mobile Network can be forwarded by the Mobile
   Router directly without tunneling (if reverse tunneling were not
   used), these packets will be dropped if ingress filtering is turned
   on at the Access Router.

   Extensively relating to Mobile IPv4 [RFC3344], this specification
   addresses mainly the co-located Care-of Address mode. Foreign Agent
   Care-of Address mode (with 'legacy' Foreign Agents [RFC3344]) is

supported but without optimization, and with double encapsulation being used. For an optimization of this mode, the gentle reader is directed to an extension document [NEMOv4-FA].

Compared to Mobile IPv4, this document specifies an additional tunnel between a Mobile Router's Home Address and the Home Agent. This tunnel is encapsulated within the normal tunnel between the Care-of Address (CoA) and Home Agent. In Foreign Agent CoA mode, the tunnel between the Mobile Router and Home Agent is needed to allow the Foreign Agent to direct the decapsulated packet to the proper visiting Mobile Router. However, in co-located CoA mode, the additional tunnel is not essential and could be eliminated because the Mobile Router is the recipient of the encapsulated packets for the Mobile Network; a proposal for this feature is in the extending document mentioned above [NEMOv4-FA].

All traffic between the nodes in the Mobile Network and the Correspondent Nodes passes through the Home Agent. This document does not touch on aspects related to route optimization of this traffic.

A similar protocol has been documented in RFC 3963 [RFC3963] for supporting IPv6 Mobile Networks with Mobile IPv6 extensions.

Multihoming for Mobile Routers is outside the scope of this document.

2. Terminology

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 [RFC2119].

Terminology for Mobile IPv4 mobility support is defined in RFC 3344 [RFC3344]. Terminology for network mobility support (NEMO), from an IPv6 perspective, is described in RFC 4885 [RFC4885]. In addition, this document defines the following terms for NEMOv4.

Mobile Router

> RFC 3344 [RFC3344] defines a Mobile Router as a mobile node that can be a router that is responsible for the mobility of one or more entire networks moving together, perhaps on an airplane, a ship, a train, an automobile, a bicycle, or a kayak.

   Mobile Network Prefix

         The network prefix of the subnet delegated to a Mobile Router
         as the Mobile Network.

   Prefix Table

         A list of Mobile Network Prefixes indexed by the Home Address
         of a Mobile Router. The Home Agent manages and uses the
         Prefix Table to determine which Mobile Network Prefixes
         belong to a particular Mobile Router.

   Local Fixed Node

         RFC 4885 [RFC4885] defines a Local Fixed Node (LFN) to be a
         fixed node belonging to the Mobile Network and unable to
         change its point of attachment. This definition should not
         be confused with "Long, Fat Network, LFN" of RFC 1323
         [RFC1323], at least because the latter is pronounced
         "elephan(t)" whereas a NEMO LFN is distinctively pronounced
         "elefen".

3. Requirements

   Although the original Mobile IPv4 specifications stated that Mobile
   Networks can be supported by the Mobile Router and Home Agent using
   static configuration or running a routing protocol (see Section 4.5
   of RFC 3344 [RFC3344]), there is no solution for explicit
   registration of the Mobile Networks served by the Mobile Router. A
   solution needs to provide the Home Agent a means to ensure that a
   Mobile Router claiming a certain Mobile Network Prefix is authorized
   to do so. A solution would also expose the Mobile Network Prefixes
   (and potentially other subnet-relevant information) in the exchanged
   messages, to aid in network debugging.

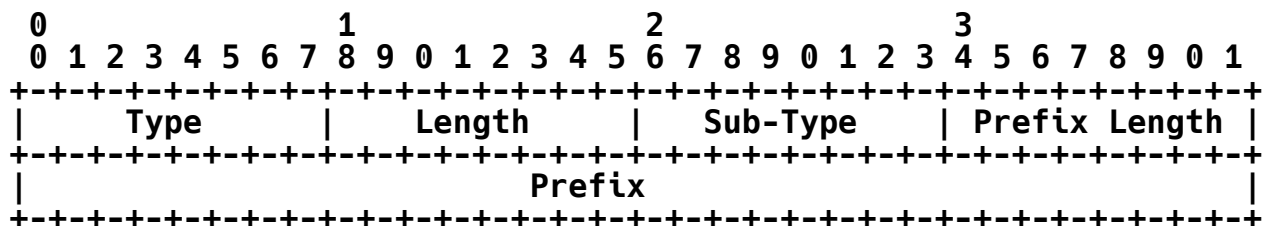   The following requirements for Mobile Network support are enumerated:

   o A Mobile Router should be able to operate in explicit or implicit
      mode. A Mobile Router may explicitly inform the Home Agent which
      Mobile Network(s) need to be propagated via a routing protocol. A
      Mobile Router may also function in implicit mode, where the Home
      Agent may learn the Mobile Networks through other means, such as
      from the AAA server, via pre-configuration, or via a dynamic
      routing protocol.

   o The Mobile Network should be supported using Foreign Agents that
      are compliant to RFC 3344 [RFC3344] without any changes ('legacy'
      Foreign Agents).

   o The Mobile Network should allow Fixed Nodes, Mobile Nodes, or
      Mobile Routers to be on it.

   o The Local Fixed Nodes on a Mobile Network should be able to
      execute their sessions without running Mobile IP stacks. The
      Mobile Router managing the LFNs' Mobile Network is 'hiding'
      mobility events like the changes of the Care-of Address from the
      Local Fixed Nodes in that Mobile Network.

4. Mobile Network Extensions

4.1. Mobile Network Request Extension

   For Explicit Mode, the Mobile Router informs the Home Agent about the
   Mobile Network Prefixes during registration. The Registration
   Request contains zero, one, or several Mobile Network Request
   extensions in addition to any other extensions defined by or in the
   context of RFC 3344 [RFC3344]. When several Mobile Networks need to
   be registered, each is included in a separate Mobile Network Request
   extension, with its own Type, Length, Sub-Type, Prefix Length, and
   Prefix. A Mobile Network Request extension is encoded in Type-
   Length-Value (TLV) format and respects the following ordering:

```
    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      |   Sub-Type    | Prefix Length |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                            Prefix                             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   Type:

        148   Mobile Network Extension

   Length:

        Decimal 6.

   Sub-Type:

        0   (Mobile Network Request)

Prefix Length:

                8-bit unsigned integer indicating the number of
                leftmost bits covering the network part of the
                address contained in the Prefix field.
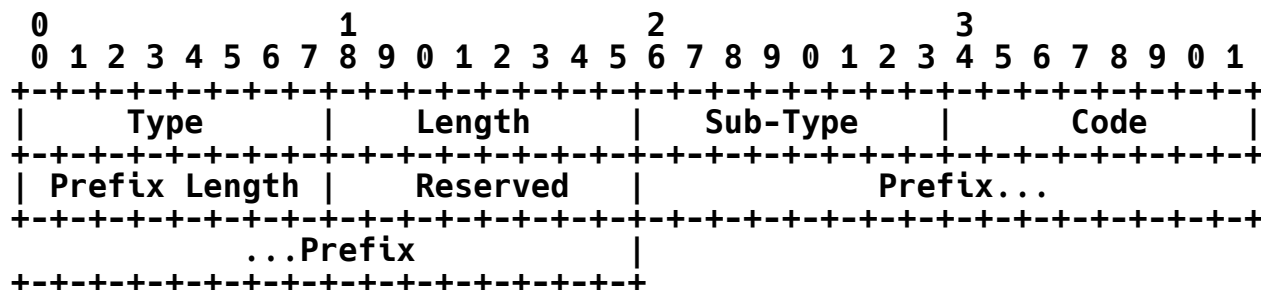
    Prefix:

                32-bit unsigned integer in network byte-order containing an
                IPv4 address whose leftmost Prefix Length bits make up the
                Mobile Network Prefix.

4.2. Mobile Network Acknowledgement Extension

    The Registration Reply contains zero, one or several Mobile Network
    Acknowledgement extensions in addition to any other extensions
    defined by or in the context of RFC 3344 [RFC3344]. For Implicit
    Mode, the Mobile Network Acknowledgement informs the Mobile Router
    the prefixes for which the Home Agent sets up forwarding with respect
    to this Mobile Router. Policies such as permitting only traffic from
    these Mobile Networks to be tunneled to the Home Agent may be applied
    by the Mobile Router. For Explicit Mode, when several Mobile
    Networks need to be acknowledged explicitly, each is included in a
    separate Mobile Network Acknowledgement extension, with its own Type,
    Sub-Type, Length, Prefix, and Prefix Length fields. At least one
    Mobile Network Acknowledgement extension MUST be in a successful
    Registration Reply to indicate to the Mobile Router that the Mobile
    Network Request extension was processed, and therefore was not
    skipped by the Home Agent.

    A Registration Reply may contain any non-zero number of Explicit Mode
    and Implicit Mode Acknowledgements sub-types. Both sub-types can be
    present in a single Registration Reply. A Mobile Network
    Acknowledgement extension is encoded in Type-Length-Value (TLV)
    format. When the registration is denied with Code HA_MOBNET_ERROR
    (Code field in the Registration Reply), the Code field in the
    included Mobile Network Extension provides the reason for the
    failure.

```
     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     |    Sub-Type     |     Code      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    | Prefix Length |     Reserved    |            Prefix...
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
            ...Prefix         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   Type:

         148   Mobile Network Extension

   Length:

         Decimal 8.

   Sub-Type:

         1   (Explicit Mode Acknowledgement)

         2   (Implicit Mode Acknowledgement)

   Code:
         Value indicating success or failure:

         0   Success

         1   Invalid prefix (MOBNET_INVALID_PREFIX_LEN)

         2   Mobile Router is not authorized for prefix
                   (MOBNET_UNAUTHORIZED)

         3   Forwarding setup failed (MOBNET_FWDING_SETUP_FAILED)

   Prefix Length:

                   8-bit unsigned integer indicating the number of
                   leftmost bits covering the network part of the
                   address contained in the Prefix field.

   Reserved:

            Sent as zero; ignored on reception.

   Prefix:

            32-bit unsigned integer in network byte-order containing an
            IPv4 address whose leftmost Prefix Length bits make up the
            Mobile Network Prefix.

5. Mobile Router Operation

   A Mobile Router's operation is generally derived from the behavior of
   a Mobile Node, as set in RFC 3344 [RFC3344]. In addition to
   maintaining mobility bindings for its Home Address, the Mobile
   Router, together with the Home Agent, maintains forwarding
   information for the Mobile Network Prefix(es) assigned to the Mobile
   Router.

   A Mobile Router SHOULD set the 'T' bit to 1 in all Registration
   Request messages it sends to indicate the need for reverse tunnels
   for all traffic. Without reverse tunnels, all the traffic from the
   Mobile Network will be subject to ingress filtering in the visited
   networks. Upon reception of a successful Registration Reply, the
   Mobile Router processes the registration in accordance to RFC 3344
   [RFC3344]. In addition, the following steps are taken:

   o Check for Mobile Network Acknowledgement extension(s) in
      Registration Reply.

   o Create tunnel to the Home Agent if the Mobile Router is registered
      in reverse tunneling mode.

   o Set up default route via this tunnel or egress interface when the
      Mobile Router is registered with or without reverse tunneling,
      respectively.

   In accordance with this specification, a Mobile Router may operate in
   one of the following two modes: explicit and implicit. In explicit
   mode, the Mobile Router includes Mobile Network Prefix information in
   all Registration Requests (as Mobile Network Request extensions),
   while in implicit mode it does not include this information in any
   Registration Request. In the latter case, the Home Agent obtains the
   Mobile Network Prefixes by other means than Mobile IP. One example
   of obtaining the Mobile Network Prefix is through static
   configuration on the Home Agent.

   A Mobile Router can obtain a co-located or Foreign Agent Care-of
   Address while operating in explicit or implicit modes.

   For deregistration, the Mobile Router sends a registration request
   with lifetime set to zero without any Mobile Network Request
   extensions.

5.1. Error Processing

   In a Mobile IP Registration Reply message, there may be two Code
   fields: one proper to the Registration Reply header (the 'proper'
   Code) and one within the Mobile Network Acknowledgement Extension
   (simply the 'Code'). A Mobile Router interprets the values of the
   Code field in the Mobile Network Acknowledgement Extension of the
   Registration Reply in order to identify any error related to managing
   the Mobile Network Prefixes by the Home Agent. It also interprets
   the values of the Code field in the Registration Reply header (the
   proper Code).

   If the value of the Code field in the Registration Reply (the proper)
   is set to HA_MOBNET_DISALLOWED, then the Mobile Router MUST stop
   sending Registration Requests with any Mobile Network Prefix
   extensions to that Home Agent.

   If the value of the Code field in the Registration Reply (the proper)
   is set to HA_MOBNET_ERROR, then the Mobile Router MUST stop sending
   Registration Requests that contain any of the Mobile Network Prefixes
   that are defined by the values of the fields Prefix and Prefix Length
   in the Mobile Network Acknowledgement extension. Note that the
   registration is denied in this case, and no forwarding for any Mobile
   Network Prefixes would be set up by the Home Agent for the Mobile
   Router.

   It is possible that the Mobile Router receives a Registration Reply
   with no Mobile Network extensions if the registration was processed
   by a Mobile IPv4 Home Agent that does not support this specification
   at all. In that case, the absence of Mobile Network extensions must
   be interpreted by the Mobile Router as the case where the Home Agent
   does not support Mobile Networks.

   All the error code values have been assigned by IANA; see Section 11.

5.2. Mobile Router Management

   Operating a Mobile Router in a Mobile IPv4 environment has certain
   requirements on the management of the necessary initial configuration
   and supervision of the ongoing status information. Mobile Router
   maintenance indicators may need to be exposed in a manner consistent
   with other Mobile IPv4 indicators.

   The objects for the Management Information Base (MIB) for Mobile IPv4
   are defined in RFC 2006 [RFC2006]. The structure of the basic model
   of Mobile IP protocol describes three entities: Mobile Node, Home
   Agent, and Foreign Agent. In addition to these entities, this
   document proposes a functional entity to be the Mobile Router.

The necessary initial configuration at a NEMOv4-enabled Home Agent
includes, but is not limited to, the contents of the Prefix Table.
The Mobile Router MAY need to store the Mobile Network Prefixes as
the initial configuration.

The definition of MIB objects related to the Mobile Router and to a
NEMOv4-enabled Home Agent is outside the scope of this document.

6. Home Agent Operation

6.1. Summary

A Home Agent MUST support all the operations specified in RFC 3344
[RFC3344] for Mobile Node support. The Home Agent MUST support both
implicit and explicit modes of operation for a Mobile Router.

The Home Agent processes the registration in accordance to RFC 3344
[RFC3344], which includes route setup to the Mobile Router's Home
Address via the tunnel to the Care-of Address. In addition, for a
Mobile Router registering in explicit mode, the following steps are
taken:

1. Check that the Mobile Network Prefix information is valid.

2. Ensure the Mobile Network Prefix(es) is/are authorized to be on
    the Mobile Router.

3. Create a tunnel to the Mobile Router if it does not already
    exist.

4. Set up route for the Mobile Network Prefix via this tunnel.

5. Propagate Mobile Network Prefix routes via routing protocol if
    necessary.

6. Send the Registration Reply with the Mobile Network
    Acknowledgement extension(s).

If there are any subnet routes via the tunnel to the Mobile Router
that are not specified in the Mobile Network extensions, these routes
are removed.

In the case where the Mobile Node is not permitted to act as a Mobile
Router, the Home Agent sends a Registration Reply message whose Code
field is HA_MOBNET_DISALLOWED (the proper Code field of the
Registration Reply).

For a Mobile Router registering in implicit mode, the Home Agent
performs steps 3-6 above, once the registration request is processed
successfully.

For deregistration, the Home Agent removes the tunnel to the Mobile
Router and all routes using this tunnel. The Mobile Network
extensions are ignored.

6.2. Data Structures

6.2.1. Registration Table

The Registration Table in the Home Agent, in accordance with RFC 3344
[RFC3344], contains binding information for every Mobile Node
registered with it. RFC 3344 [RFC3344] defines the format of a
Registration Table. In addition to all the parameters specified by
RFC 3344 [RFC3344], the Home Agent MUST store the Mobile Network
Prefixes associated with the Mobile Router in the corresponding
registration entry, when the corresponding registration was performed
in explicit mode. When the Home Agent is advertising reachability to
Mobile Network Prefixes served by a Mobile Router, the information
stored in the Registration Table can be used.

6.2.2. Prefix Table

The Home Agent must be able to authorize a Mobile Router for use of
Mobile Network Prefixes when the Mobile Router is operating in
explicit mode. Also, when the Mobile Router operates in implicit
mode, the Home Agent must be able to locate the Mobile Network
Prefixes associated with that Mobile Router. The Home Agent may
store the Home Address of the Mobile Router along with the Mobile
Network prefixes associated with that Mobile Router. If the Mobile
Router does not have a Home Address assigned, this table may store
the Network Access Identifier (NAI) [RFC2794] of the Mobile Router
that will be used in dynamic Home Address assignment.

6.3. Mobile Network Prefix Registration

The Home Agent must process Registration Requests coming from Mobile
Routers in accordance with this section. RFC 3344 [RFC3344]
specifies that the Home Address of a mobile node registering with a
Home Agent must belong to a prefix advertised on the home network.
In accordance with this specification, however, the Home Address must
be configured from a prefix that is served by the Home Agent, not
necessarily the one on the home network.

If the Registration Request is valid, the Home Agent checks to see if
there are any Mobile Network Prefix extensions included in the
Registration Request.

If so, the Mobile Network Prefix information is obtained from the
included extensions, and the Home Address from the Home Address field
of the Registration Request. For every Mobile Network Prefix
extension included in the registration request, the Home Agent MUST
perform a check against the Prefix Table. If the Prefix Table does
not contain at least one entry pairing that Home Address to that
Mobile Network Prefix, then the check fails; otherwise, it succeeds.

Following this check against the Prefix Table, the Home Agent MUST
construct a Registration Reply containing Mobile Network
Acknowledgement extensions. For a Mobile Network Prefix for which
the check was unsuccessful, the Code field in the corresponding
Mobile Network Acknowledgement extension should be set to
MOBNET_UNAUTHORIZED.

For a Mobile Network Prefix for which the check was successful, the
Code field in the respective Mobile Network Acknowledgement
extensions should be set to 0.

The Home Agent MUST attempt to set up forwarding for each Mobile
Network Prefix extension for which the Prefix Table check was
successful. If the forwarding setup fails for a particular Mobile
Network Prefix (for reasons such as not enough memory available or
not enough devices available), the Code field in the respective
Mobile Network Acknowledgement extension should be set to
MOBNET_FWDING_SETUP_FAILED.

If forwarding and setup was successful for at least one Mobile
Network Prefix, then the Code field (the proper) of the Registration
Reply message should be set to 0. Otherwise, when forwarding and
setup was unsuccessful for each and every Mobile Network Prefixes,
that Code (the proper) should be HA_MOBNET_ERROR.

If the Registration Request is sent in implicit mode, i.e., without
any Mobile Network Request extension, the Home Agent may use pre-
configured Mobile Network prefix information for the Mobile Router to
set up forwarding.

If the Home Agent is updating an existing binding entry for the
Mobile Router, it MUST check all the prefixes in the Registration
Table against the prefixes included in the Registration Request. If
one or more Mobile Network prefixes are missing from the included

information in the registration request, the Home Agent MUST delete
those prefixes from the registration table. Also, the Home Agent
MUST disable forwarding for those prefixes.

If all checks are successful, the Home Agent either creates a new
entry for the Mobile Router or updates an existing binding entry for
it and returns a successful registration reply back to the Mobile
Router or the Foreign Agent (if the Registration Request was received
from a Foreign Agent).

In accordance with RFC 3344 [RFC3344], the Home Agent does proxy
Address Resolution Protocol (ARP) for the Mobile Router Home Address
when the Mobile Router Home Address is derived from the home network.

If the 'T' bit is set, the Home Agent creates a bi-directional tunnel
for the corresponding Mobile Network prefixes or updates the existing
bi-directional tunnel. This tunnel is maintained independent of the
reverse tunnel for the Mobile Router home address itself.

6.4. Advertising Mobile Network Reachability

If the Mobile Network prefixes served by the Home Agent are
aggregated with the home network prefix and if the Home Agent is the
default router on the home network, the Home Agent does not have to
advertise the Mobile Network Prefixes. The routes for the Mobile
Network Prefix are automatically aggregated into the home network
prefix (it is assumed that the Mobile Network Prefixes are
automatically aggregated into the home network prefix). If the
Mobile Router updates the Mobile Network prefix routes via a dynamic
routing protocol, the Home Agent SHOULD propagate the routes on the
appropriate networks.

6.5. Establishment of Bi-directional Tunnel

The Home Agent creates and maintains a bi-directional tunnel for the
Mobile Network prefixes of a Mobile Router registered with it. A
Home Agent supporting IPv4 Mobile Router operation MUST be able to
forward packets destined to the Mobile Network prefixes served by the
Mobile Router to its Care-of Address. Also, the Home Agent MUST be
able to accept packets tunneled by the Mobile Router with the source
address of the outer header set to the Care-of Address of the Mobile
Router and that of the inner header set to the Mobile Router's Home
Address or an address from one of the registered Mobile Network
prefixes.

6.6. Sending Registration Replies

The Home Agent MUST set the status code in the registration reply to
0 to indicate successful processing of the Registration Request and
successful setup of forwarding for at least one Mobile Network prefix
served by the Mobile Router. The Registration Reply MUST contain at
least one Mobile Network Acknowledgement extension.

If the Home Agent is unable to set up forwarding for one or more
Mobile Network prefixes served by the Mobile Router, it MUST set the
Mobile Network Acknowledgement Extension status Code in the
Registration Reply to MOBNET_FWDING_SETUP_FAILED. When the prefix
length is zero or greater than decimal 32, the status Code MUST be
set to MOBNET_INVALID_PREFIX_LEN.

If the Mobile Router is not authorized to forward packets to a Mobile
Network prefix included in the request, the Home Agent MUST set the
Code to MOBNET_UNAUTHORIZED.

6.7. Mobile Network Prefix Deregistration

If the received Registration Request is for deregistration of the
Care-of Address, the Home Agent, upon successful processing of it,
MUST delete the entry (or entries) from its Registration Table. The
Home Agent tears down the bi-directional tunnel and stops forwarding
any packets to/from the Mobile Router. The Home Agent MUST ignore
any included Mobile Network Request extension in a deregistration
request.

7. Data Forwarding Operation

For traffic to the nodes in the Mobile Network, the Home Agent MUST
perform double tunneling of the packet, if the Mobile Router had
registered with a Foreign Agent Care-of Address. In this case, the
Home Agent MUST encapsulate the packet with the tunnel header (source
IP address set to Home Agent, and destination IP address set to
Mobile Router's Home Address) and then encapsulate one more time with
the tunnel header (source IP address set to Home Agent, and
destination IP address set to CoA).

For optimization, the Home Agent SHOULD only encapsulate the packet
with the tunnel header (source IP address set to Home Agent, and
destination IP address set to CoA) for co-located CoA mode.

When a Home Agent receives a packet from the Mobile Network prefix in
the bi-directional tunnel, it MUST de-encapsulate the packet and
route it as a normal IP packet. It MUST verify that the incoming

packet has the source IP address set to the Care-of Address of the
Mobile Router. The packet MUST be dropped if the source address is
not set to the Care-of Address of the Mobile Router.

For traffic from the nodes in the Mobile Network, the Mobile Router
encapsulates the packet with a tunnel header (source IP address set
to Mobile Router's Home Address, and destination IP address set to
Home Agent) if reverse tunnel is enabled. Otherwise, the packet is
routed directly to the Foreign Agent or access router.

In co-located CoA mode, the Mobile Router MAY encapsulate one more
time with a tunnel header (source IP address set to the CoA and
destination IP address set to Home Agent).

8. Nested Mobile Networks

Nested Network Mobility is a scenario where a Mobile Router allows
another Mobile Router to attach to its Mobile Network. There could
be arbitrary levels of nested mobility. The operation of each Mobile
Router remains the same whether the Mobile Router attaches to another
Mobile Router or to a fixed Access Router on the Internet. The
solution described here does not place any restriction on the number
of levels for nested mobility. Two issues should be noted though.
First, whenever physical loops occur in a nested aggregation of
Mobile Networks, this protocol neither detects nor solves them --
datagram forwarding may be blocked. Second, Mobile Routers in a deep
nested aggregation of Mobile Networks might introduce significant
overhead on the data packets as each level of nesting introduces
another tunnel header encapsulation. Applications that do not
support MTU discovery are adversely affected by the additional header
encapsulations because the usable MTU is reduced with each level of
nesting.

9. Routing Protocol between Mobile Router and Home Agent

There are several benefits of running a dynamic routing protocol
between the Mobile Router and the Home Agent. If the Mobile Network
is relatively large, including several wireless subnets, then the
topology changes within the moving network can be exposed from the
Mobile Router to the Home Agent by using a dynamic routing protocol.
The purpose of the NEMOv4 protocol extensions to Mobile IPv4, as
defined in previous sections, is not to inform the Home Agent about
these topology changes, but to manage the mobility of the Mobile
Router.

Similarly, topology changes in the home network can be exposed to the
Mobile Router by using a dynamic routing protocol. This may be
necessary when new fixed networks are added in the home network.

Here too, the purpose of NEMOv4 extensions is not to inform the
Mobile Router about topology changes at home.

Examples of dynamic routing protocols include, but are not limited
to, OSPF Version 2 [RFC2328], BGP [RFC4271], and RIP [RFC2453].

The recommendations are related to how the routing protocol and the
Mobile IPv4 implementation work in tandem on the Mobile Router and on
the Home Agent (1) without creating incoherent states in the
forwarding information bases at home and on the Mobile Router, (2)
without introducing topologically incorrect addressing information in
the visited domain, and (3) without duplicating sent data or over-
provisioning security.

The information exchanged between the Mobile Router and the Home
Agent is sent over the bi-directional tunnel established by the
Mobile IPv4 exchange Registration Request - Registration Reply (see
Section 6.5). If a network address and prefix of a subnet in the
moving network is sent by the Mobile Router within a routing protocol
message, then they SHOULD NOT be sent in the Mobile IPv4 Registration
Request too. This avoids incoherencies in the forwarding information
bases. The Mobile Router SHOULD use NEMOv4 implicit mode in this
case (see Section 3).

The Mobile Router SHOULD NOT send routing protocol information
updates in the foreign network. The subnet addresses and prefixes
valid in the moving network are topologically incorrect in the
visited network.

If the Mobile Router and the Home Agent use a dynamic routing
protocol over the tunnel interface, and if that protocol offers
security mechanisms to protect that protocol's messages, then the
security recommendations in Section 10.1 apply.

10. Security Considerations

The Mobile Network extension is protected by the same rules as for
Mobile IP extensions in registration messages. See the Security
Considerations section in RFC 3344 [RFC3344].

The Home Agent MUST be able to verify that the Mobile Router is
authorized to provide mobility service for the Mobile Networks in the
Registration Request, before anchoring these Mobile Network Prefixes
on behalf of the Mobile Router. Forwarding for prefixes MUST NOT be
set up without successful authorization of the Mobile Router for
those prefixes. The Mobile Router MUST be notified when there is a
registration failure because it cannot be successfully authorized for
prefixes it requested.

All Registration Requests and replies MUST be authenticated by the
MN-HA Authentication Extension as specified in RFC 3344 [RFC3344].
When the registration request is sent in explicit mode, i.e., with
one or more Mobile Network Prefix extensions, all the Mobile Network
Prefix extensions MUST be included before the MN-HA Authentication
extension. Also, these extensions MUST be included in the
calculation of the MN-HA authenticator value.

The Mobile Router should perform ingress filtering on all the packets
received on the Mobile Network prior to reverse tunneling them to the
Home Agent. The Mobile Router MUST drop any packets that do not have
a source address belonging to the Mobile Network.

The Mobile Router MUST also ensure that the source address of packets
arriving on the Mobile Network is not the same as the Mobile Router's
IP address on any interface. These checks will protect against nodes
attempting to launch IP spoofing attacks through the bi-directional
tunnel.

The Home Agent, upon receiving packets through the bi-directional
tunnel, MUST verify that the source addresses of the outer IP header
of the packets are set to the Mobile Router's Care-of Address. Also,
it MUST ensure that the source address of the inner IP header is a
topologically correct address on the Mobile Network. This will
prevent nodes from using the Home Agent to launch attacks inside the
protected network.

10.1. Security when Dynamic Routing Protocol Is Used

If a dynamic routing protocol is used between the Mobile Router and
the Home Agent to propagate the Mobile Network information into the
home network, the routing updates SHOULD be protected with IPsec ESP
confidentiality between the Mobile Router and Home Agent, to prevent
information about home network topology from being visible to
eavesdroppers.

11. IANA Considerations

IANA has assigned rules for the existing registry "Mobile IPv4
numbers - per RFC 3344". The numbering space for Extensions that may
appear in Mobile IP control messages (those sent to and from UDP port
number 434) should be modified.

The new Values and Names for the Type for Extensions appearing in
Mobile IP control messages are the following:

```
+-------+---------------------------+
| Value | Name                      |
+-------+---------------------------+
|   148 | Mobile Network Extension  |
+-------+---------------------------+
```

        Table 1: New Values and Names for Extensions in Mobile IP Control
                                    Messages

A new number space has been created for the Values and Names for the
Sub-Type for Mobile Network Extensions. This number space is
initially defined to hold the following entries, allocated by this
document:

```
+-------+----------------------------------------+
| Value | Name                                   |
+-------+----------------------------------------+
|     0 | Mobile Network Request Extension       |
|     1 | Explicit Mode Acknowledgement Extension|
|     2 | Implicit Mode Acknowledgement Extension|
+-------+----------------------------------------+
```

         Table 2: New Values and Names for the Sub-Type for Mobile Network
                                    Extensions

The policy of future assignments to this number space is following
Standards Action or IESG Approval (see [RFC2434]).

The new Code Values for Mobile IP Registration Reply messages are the
following (for a registration denied by the Home Agent):

```
+-------+------------------------------------------------------+
| Value | Name                                                 |
+-------+------------------------------------------------------+
|   147 | Mobile Network Prefix operation error (HA_MOBNET_ERROR) |
|   148 | Mobile Router operation is not permitted             |
|       | (HA_MOBNET_DISALLOWED)                               |
+-------+------------------------------------------------------+
```

          Table 3: New Code Values for Mobile IP Registration Reply

A new number space has been created for the Code Values for the
Mobile Network Acknowledgement Extension. This number space is
initially defined to hold the following entries, allocated by this
document (result of registration, as sent by the Home Agent):

```
+---+-------------------------------------------------------------+
| 0 | Success                                                     |
| 1 | Invalid prefix length (MOBNET_INVALID_PREFIX_LEN)           |
| 2 | Mobile Router is not authorized for prefix                  |
|   | (MOBNET_UNAUTHORIZED)                                       |
| 3 | Forwarding setup failed (MOBNET_FWDING_SETUP_FAILED)        |
+---+-------------------------------------------------------------+
```

Table 4: New Code Values for Mobile Network Acknowledgement Extension

The policy of future assignments to this number space is following
Standards Action or IESG Approval (see [RFC2434]).

12. Acknowledgements

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