The design and implementation of a dual-stack mobile network using IPv6 only network infrastructure

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Abstract. This paper discusses a mechanism which enables network mobility (NEMO) in both IPv4 and IPv6. There is an IETF standard NEMO protocol, NEMO Basic Support (NEMO BS). However it is designed only for IPv6 mobile networks. The basic concept of NEMO BS is a kind of dynamic tunnel configuration protocol. NEMO BS assumes that only IPv6 packets are passed over the tunnel. We permit to forward IPv4 packets over the configured tunnel created by NEMO BS too, and we add a mechanism to exchange IPv4 network information between a mobile router and its home agent. With this mechanism, we can obtain a dual-stack mobile network even if the mobile router does not have access to an IPv4 access network. A mobile router can move around the IPv6 Internet keeping IPv4 connectivity. It will provide a mobility function to IPv4 nodes accommodated under the mobile router without changing any IPv4 subsystems. We think the benefit is important during the transition period from IPv4 to IPv6. We have implemented the idea and confirmed that the proposed mechanism enables an IPv4/IPv6 dual-stack network over IPv6 only network.

1 IPv6 and mobility deployment problem and solution

Adding mobility functions to the Internet Protocol (IP) has been discussed for a long time. There are two kind of mobility protocols in IP area. One is a host mobility protocol, which is specified as Mobile IP (MIPv4) [1] for IP version 4 (IPv4) and Mobile IPv6 (MIPv6) [2] for IP version 6 (IPv6). The other is a network mobility (NEMO) protocol specified as NEMO Basic Support (NEMO BS) [3] for IPv6. Although we have host mobility protocols for both IPv4/IPv6, there is no standard protocol for IPv4 network mobility. When the standardization activity of NEMO started, many people thought that there was no need to specify a protocol for IPv4. We think IPv6 is the next generation IP and IPv4 will be replaced by IPv6 finally. Considering the situation it is not always a wrong way to focus only on IPv6. However, with regard to the network mobility function, we think supporting IPv4 is important because of the delay of IPv6 service deployment. We recently notice that the shift to IPv6 needs more time than we expected initially. We are now forecasting that we will have a long period that requires a dual-stack (IPv4/IPv6) network operation before IPv6 is fully deployed. During the long transition period, we think most people will need not only IPv6 mobile networks but also IPv4 mobile networks.

In this paper we will propose a mechanism to realize a dual-stack NEMO. We do not design a new mechanism for IPv4, since we think the IP infrastructure is changing from IPv4 to IPv6. Instead, we design the mechanism as an extension to NEMO BS, which works only on the IPv6 infrastructure. Anyone who is interested in NEMO, but has not introduced the technology because of lack of IPv4 support, can use this mechanism without changing the existing IPv4 infrastructure. All they have to do is to prepare the IPv6 access infrastructure and allocate their own IPv4 and IPv6 address blocks for their mobile networks. All packets from their mobile networks are transmitted to IPv4/IPv6 Internet using NEMO BS with our extension, which runs on the IPv6 infrastructure. The IPv6 access infrastructure may be a little difficult to prepare at this time, however, the difficulty will become smaller as the IPv6 deployment progresses. Moreover, it may accelerate the transition from the IPv4 infrastructure to the IPv6 infrastructure, because IPv4 users can use their IPv4 services over the IPv6 only infrastructure with our proposed mechanism.

2 NEMO Basic Support overview

NEMO BS adds a mobility function to IPv6 routers. An entire IPv6 network served by a *mobile router (MR)* which supports NEMO BS, can be a *mobile network*. The nodes inside the mobile network can use static IPv6 addresses which never change regardless of the attachment point of the MR.

Every MR has a home network. A home network is a network which a MR is originally attached to. A MR has a mobile network behind it. A mobile network can attach anywhere in the Internet thanks to the MR. A mobile network has a fixed network prefix (*MNP, mobile network prefix*). MNP never changes regardless of the location of the MR.

A network which is not a home network is called a foreign network. When a MR attaches to a foreign network, it configures an address of its interface connected to the foreign network by some means, usually by the IPv6 address auto-configuration mechanism. The address assigned on the interface on a foreign network is called a *care-of address (CoA)*. On the other hand, the address assigned while a MR is on its home network is called a *home address (HoA)*. To track the location of the MR, a *home agent (HA)* needs to manage the information of a pair of a HoA and a CoA. The information is called *binding*. A HA is a special node located on a home network. When the binding information of a MR changes, the MR provides the new binding information to its HA. After the procedure, the MR and its HA configure an IPv6 tunnel between a CoA and a HA. While exchanging the binding information, the MR and its HA also provides the MNP to the HA. Routing information of the MNP will be advertised from the HA, so that all packets to the nodes behind the MR are routed to the HA. Those packets are intercepted by the HA and forwarded to the MR using the IPv6 tunnel. On the contrary, all packets generated by the nodes inside the mobile network are tunneled by the MR to its HA. All nodes can communicate with the nodes inside a mobile network, as if they are located on a home network. They even do not notice that the communicating nodes are in a moving network. Fig.1 describes the concept of the NEMO BS protocol.

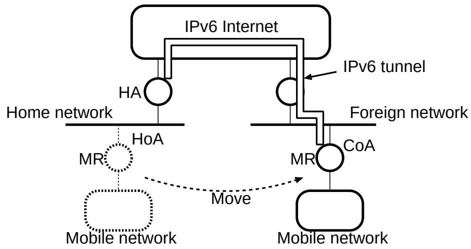


Fig. 1. The concept of the NEMO technology

3 Comparison with other similar proposals

MIPv4 mentions an idea to operate a MIPv4 node as a router to provide an IPv4 mobile network in [1]. This mechanism has one problem. The nodes inside the mobile network send their packet directly from the mobile network. Such packets will be topologically incorrect because routing information of mobile networks are advertised from home network of the mobile router. This kind of traffic is recently not recommended because of security concerns.

NEMOv4 [4] proposes an extension for MIPv4 similar to NEMO BS. This proposal does not have the problem the above proposal has, since this mechanism can use a bi-directional tunnel like NEMO BS.

The above two proposals can support IPv4 NEMO, however we think these proposals are not suitable when considering transition to the future IPv6 Internet. These proposals are both based on IPv4. If we think about providing a dual-stack mobile network that is necessary during transition, we have to operate both IPv4 NEMO and IPv6 NEMO independently. Such a paralized operation increases the operational overhead. In addition, it may cause unstability because of the asynchronous behavior between IPv4 NEMO and IPv6 NEMO.

Our proposal does not have such problems, since it is based on IPv6 NEMO only. All packets are sent in a topologically correct manner. There is no asynchronous behavior since IPv4 mobile network operation is done with that of IPv6 in one atomic operation. Moreover, our proposal does not require any new IPv4 technology. Fig.2 depicts the transition scenario using our proposed mechanism. The end users can use their IPv4 service (a) in the same manner during transition period (b) without any modification on their IPv4 subsystems. In addition, IPv4 users can benefit from mobility for both IPv4/IPv6. When transition has completed, all we have to do is just to disable IPv4 (c), without changing any already deployed IPv6 network.

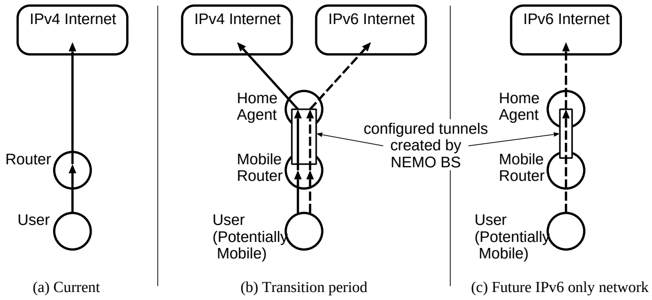


Fig. 2. Transition from IPv6 to IPv4 with our proposed mechanism

V4traversal [5] is the most similar mechanism to our proposal. It discusses a protocol which enables IPv4 HoA and IPv4 MNP as a part of the protocol. The idea is almost the same with ours. However the draft was originally focusing on IPv4 host mobility and lacking to describe detailed procedures when operating NEMO BS for IPv4. We are now trying to merge our work to [5] in IETF.

4 Usage scenarios

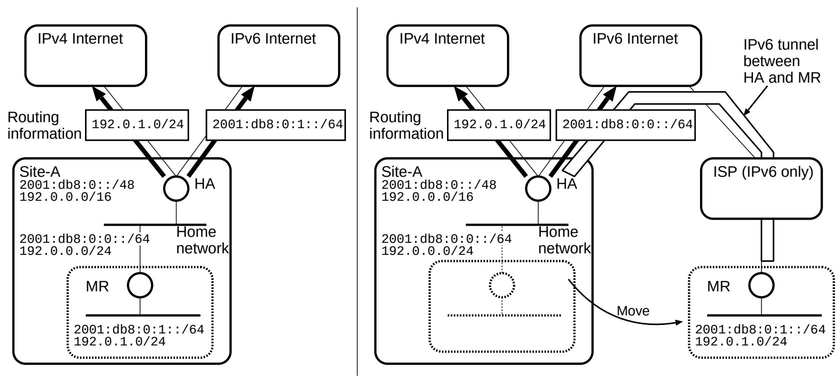
When considering to provide NEMO services to e.g. buses or trains, it is unrealistic to provide only IPv6 NEMO, since most people are still using IPv4. Our proposed mechanism can provide a dual-stack NEMO in such situations. The access line to buses or trains need to be IPv6 [6], however, it is not very difficult. Most of advanced ISPs are already IPv6 ready and it is easy to provide dedicated IPv6 lines for such a specialized purpose [7]. From the user's point of view, it is not important if the access line is IPv6 only or not, as long as users can use IPv4. The benefit of this scenario is that we can provide IPv4 transparently to users in addition to IPv6. Also we can change the access line to IPv6 transparently. This mechanism can be applied even to a static network, like a small SOHO site. Thanks to NEMO BS, such a dual-stack static network can provide the access line redundancy by subscribing multiple IPv6 ISPs. If one of the ISPs goes down, the site can use another ISP's address as a new CoA. This may be a good reason to transit to the IPv6 infrastructure for users keeping the current IPv4 alive.

5 Proposed mechanism

NEMO BS provides IPv6 connectivity over a tunnel connection created between a MR and a HA. To provide IPv4 connectivity simultaneously, we need to transmit IPv4 traffic over the tunnel. The NEMO BS specification does not mention the upper layer protocol carried over the tunnel, although the specification assumes IPv6 implicitly. Technically speaking, we can carry any kind of layer 3 protocols over the tunnel as long as we have proper routing entries. We introduced the following new operation rules to NEMO BS.

1. A MR can have an IPv4 network on its internal interface.
2. The MR notifies the IPv4 network information it has on its internal interface with its HA.
3. The HA advertises the IPv4 MNP information which is located behind the MR.
4. The MR forwards IPv4 packets from its internal interface to its HA using the tunnel created between them.
5. The HA forwards IPv4 packets which destination prefix is the MNP behind the MR to the tunnel created between them.

Fig.3 depicts a sample network configuration. Site-A is a dual-stack site and has one home network which prefixes are `2001:db8:0:0::/64` and `192.0.0.0/24`. There is one HA and one MR attached to the home network. The MR has MNPs which are `2001:db8:0:1::/64` and `192.0.1.0/24`. The HA advertises the route information of MNPs to the Internet. Fig.3.(a) describes a logical topology of the mobile network. The MR is logically attached to its home network. Fig.3.(b) is an actual network topology when the MR is on a foreign network. The MR only needs IPv6 connectivity to provide both IPv4/IPv6 access to its mobile network. When the MR attaches to a foreign network, it registers the IPv6 CoA assigned on the foreign network to its HA.



(a) Logical network topology

(b) Actual network topology

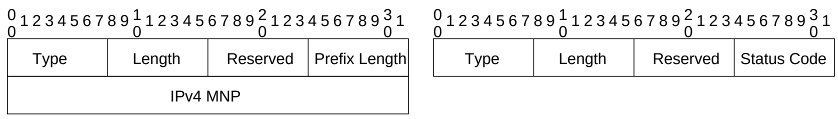
Fig. 3. Network topologies

During the registration procedure, the MR notifies the IPv4 MNP which is attached to the MR to its HA in addition to normal NEMO BS operation. There are two possible mechanisms to exchange the IPv4 MNP.

1. Configuring the MNP value on a HA and a MR in advance
2. Notifying the MNP value using NEMO BS signaling messages

In the first method, a HA and a MR already know that the MNP value, in this case `192.0.1.0/24`. After finishing the registration, the HA will install a routing entry, which indicates all packets sent to `192.0.1.0/24` will be forwarded via a tunnel interface created between the HA and MR. Similarly, the MR installs a forwarding entry which indicates all traffic from its internal interface will be forwarded via the tunnel.

The second method is to notify IPv4 MNP using a Binding Update message and a Binding Acknowledgment message, those messages are used by the NEMO BS signaling procedure to carry binding information of a MR. We defined new options for the messages to carry IPv4 MNP information. Fig.4 depicts the option formats.



(a) IPv4 MNP Option (b) IPv4 MNP Registration Status Option

Fig. 4. The option format to exchange IPv4 network information

The IPv4 MNP Option (Fig.4.(a)) is put in a Binding Update message sent from a MR to a HA. The IPv4 MNP field contains the IPv4 MNP assigned to the internal interface of the MR. In the sample case, `192.0.1.0` is put in the field. The prefix length of the mobile network, 24 in this case, is put in the Prefix Length field. A HA will reply a Binding Acknowledgment message with the IPv4 MNP Registration Status Option (Fig.4.(b)), if it recognizes the IPv4 MNP Option. If a HA does not know the option, it simply ignores the option. A MR can know weather its HA supports IPv4 NEMO or not by checking that the received Binding Acknowledgment has the IPv4 MNP Registration Status Option or not. If a HA does not support the function, a MR gives up to provide IPv4 connectivity to its nodes connected to its internal network. The Status Code field of the IPv4 MNP Registration Status indicates that the information exchange of the IPv4 network succeeded or failed. Once the exchange has been succeeded, a HA and a MR install routing entries so that the nodes inside the mobile network can send and receive their IPv4 packets, similar to the first method.

The detailed specification of the protocol extension is described in [8].

6 Implementation details

We have implemented the mechanism in the SHISA MIPv6/NEMO BS protocol stack [9]. SHISA is a part of the KAME IPv6 protocol stack provided by the KAME project [10] and it is freely available from the home page of the project.

6.1 SHISA overview

SHISA consists of several function components. The packet forwarding and extension header manipulation for normal packets are handled in a kernel. For NEMO BS signal packet processing, SHISA provides 4 daemon programs in user space. The first program is `mrd`, which processes NEMO BS signaling messages to be handled on a MR. The second program is `had`, which processes NEMO BS signaling messages to be handled on a HA. The third program is `babymdd`, which detects movement of a MR and notifies the event to `mrd` program. The last program is `nemonetd`, which manages bi-directonal tunnel connections between a MR and a HA. Each program communicates with other programs using a dedicated socket interface [11]. For example, when `babymdd` detects movement, it broadcasts the event to other programs. `mrd` receives the event, it start the registration procedure since movement means change of binding information. After `mrd` completes the registration procedure, it broadcasts the event to other programs. `nemonetd` updates a tunnel interface and routing entries based on the registration information.

6.2 Implementation of the proposed mechanism

We need to extend following two functions.

1. An IPv4 MNP exchange mechanism.
2. A mechanism to install IPv4 route entries.

The IPv6 MNP is managed by `mrd` and `had` when NEMO BS is operated for IPv6 NEMO. We extended the prefix management database to handle IPv4 MNP. `mrd` and `had` may exchange the MNP information explicitly. As we discussed in the previous section, we defined new options to exchange the IPv4 MNP information. `mrd` and `had` programs were also extended to send and receive the configured IPv4 MNP in the form of options described in Fig.4.

`nemonetd` configures a tunnel interface between a MR and a HA, once the NEMO BS registration message processing has been completed successfully. IPv6 route information for a mobile network is installed at this tunnel setup time. Our extended `nemonetd` program also installs IPv4 route entries on the same configured tunnel at the same time on both MR/HA.

Fig.5 shows the sample database file for MNP definition. In the original SHISA, one can only specify IPv6 MNP in a `prefixtable` section. We extended the format to accept both IPv4/IPv6 MNPs by changing the internal data storage from `in6_addr{}` structure, which can only keep IPv6 address, to `sockaddr_storage{}` structure which can store any kind of layer 3 address.

```
interface mip0 {
    prefixtable {
        2001:240:1:280::beef    2001:240:1:281::/64    explicit;
        2001:240:1:280::beef    10.0.0.0/24            explicit;
    };
};
ipv4-dummy-tunnel {
    nemo0    169.254.0.1    169.254.0.2;
};
```

Fig. 5. MNP database file

The NEMO BS implementation on SHISA uses an unnumbered tunnel for the tunnel created between a MN and a HA. In our implementation, both IPv4 and IPv6 traffic are forwarded by the tunnel too. However, BSD systems have one problem concerning to this design. BSD systems do not have a mechanism for an unnumbered tunnel for IPv4. We have to assign some addresses on the tunnel interfaces to inject IPv4 route information. `ipv4-dummy-tunnel` specifies IPv4 addresses assigned to a tunnel interface. The addresses are taken from the IPv4 address space reserved for link-local use in this example. This implementation decision works in most cases except one case. When a MR itself initiates traffic to an IPv4 node, the address assigned on the outgoing interface is used as a source address. In the example case, a link-local IPv4 address is chosen and a MR cannot receive reverse traffic. To solve the problem, we need to implement an unnumbered tunnel for IPv4. All other nodes connected to a mobile network do not have any problem.

6.3 Verification of the implementation

Fig.6 is the topology we used to verify the function. We used 3 IPv6 networks and two IPv4 networks. `2001:240:0:280::/64` is a home network, `2001:240:0:200::/64` is a foreign network and `2001:240:0:281::/64` is a mobile network for IPv6. `192.168.64.0/25` is an IPv4 network for the home link and `10.0.0.0/24` is an IPv4 mobile network. A MR is logically attached to the home network (`2001:240:0:280::/64`). When the MR moves to the foreign network, it registers two MNPs, one is `2001:240:0:281::/64` and the other is `10.0.0.0/24` using our proposed mechanism.

As a result of the protocol operation, a MR and a HA have a routing tables as shown in Fig.7. We can find there is a route entry to `10.0.0.0/24` on the HA. The traffic is routed to `nemo0` interface, which is a tunnel interface between the HA and the MR. Also, the MR has an IPv4 default route entry which destination is `nemo0`. This means all IPv4 traffic on the MR will be forwarded to the HA through `nemo0` interface.

We have confirmed the following IPv4 applications are operatable.

– ping from the node A to the node B
– SSH remote login from the node A to the node B

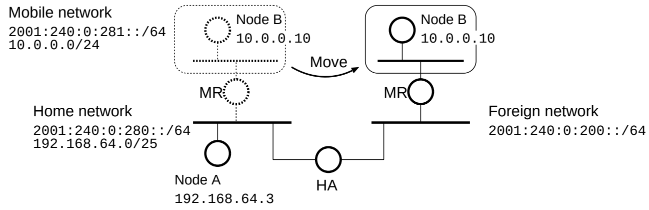


Fig. 6. The topology used to verify the proposed mechanism

– Accessing to the Web service running on the node A from the node B

The result means that the node A, which is behind the MR, can use their IPv4 applications without any modification thanks to the MR and our proposed mechanism, even if the MR is connected to the Internet only with the IPv6 infrastructure.

Routing table on HA (NetBSD2.0.2 + SHISA with our extension)

Internet:

Destination	Gateway	Flags	Refs	Use	Mtu	Interface
10/24	127.0.0.1	UGS	0	0	-	nemo0
192.168.64/25	link#1	UC	3	0	-	fxp0
192.168.64.1	00:02:b3:3a:8a:6f	UHLc	1	2	-	fxp0

Internet6:

Destination	Gateway	Flags	Refs	Use	Mtu	Interface
2001:240:1:280::	00:02:b3:3a:84:ac	UHL	0	0	-	lo0 =>
2001:240:1:280::/64	link#2	UC	0	0	-	fxp1 =>
2001:240:1:280::/64	link#2	UC	0	0	-	fxp1 =>
2001:240:1:280::/57	::1	UR	0	0	-	lo0
2001:240:1:280::1	00:02:b3:3a:84:ac	UHL	0	0	-	lo0
2001:240:1:280::beef	00:02:b3:3a:84:ac	UHLS2	2	0	-	fxp1
2001:240:1:281::/64	::1	UGS	0	0	-	nemo0

Routing table on MR (FreeBSD5.4-RELEASE + SHISA with our extension)

Internet:

Destination	Gateway	Flags	Refs	Use	Netif	Expire
default	127.0.0.1	UGS	0	0	nemo0	
10.0.0.1	10.0.0.1	UH	0	0	lo0	
10.0.1/24	link#1	UC	0	0	em0	
10.0.1.1	00:11:25:32:d9:8c	UHLW	0	2	lo0	
169.254.0.2	169.254.0.1	UH	0	0	nemo0	

Internet6:

Destination	Gateway	Flags	Netif	Expire
default	::1	UGS	nemo0	
2001:240:1:200:202:b3ff:fe3a:87d9	00:02:b3:3a:87:d9	UHL	em0	
2001:240:1:200:211:25ff:fe32:d98c	00:11:25:32:d9:8c	UHL	lo0	
2001:240:1:280::beef	link#2	UHL	lo0	
2001:240:1:281::/64	::1	U	lo0	
2001:240:1:281::1	link#3	UHL	lo0	

Fig. 7. Routing tables on MR and HA

7 Conclusion

NEMO BS provides a mobility function to IPv6 network, which is necessary in the coming ubiquitous IPv6 Internet that tons of moving node connect to the Internet with variety of access mechanisms. However, because of transition problems, we think we need to support both IPv4 and IPv6 for a long time. We proposed a dual-stack NEMO technology which depends only on the IPv6 infrastructure. There are other proposals to enable IPv4 mobile network as described in [1] and [4] and it is possible to operate them and NEMO BS in parallel to provide a dual-stack NEMO. However, such a combination has a problem generating topologically incorrect packets or an unstability problem due to asynchronous behavior of two mobility protocols. Our proposed mechanism does not have such problems and it is more efficient when considering the transition scenario from IPv4 to IPv6. We have implemented the mechanism on the SHISA stack and shown the mechanism works as we designed. The code is available as a part of the KAME stack from its project web page [10].

Acknowledgment

We thank to the Nautilus6 project [12] members, the SHISA development team members [10] [9], the IETF NEMO working group members and the WIDE project members for their valuable advice and support.

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