IPv4 Care-of Address Registration for IPv4 Support on the NEMO Basic Support Protocol

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On the Internet, two different IP protocols are deployed such as IPv4 [7] and IPv6 [1]. The Mobile Router uses the basic NEMO protocol [2] which is IPv6 protocol specific. During the early period of time that IPv6 transition is occurring it is very likely that a Mobile Router will move to an IPv4 only access network. When this occurs the Mobile Router will no longer be able to operate using the basic NEMO protocol. There has already been some earlier work to provide IPv6 capability over an IPv4 access network for a Mobile Router [9] [10]. This paper provides a capability by to maintain IPv6 connectivity for the Mobile Router via its Home Agent with IPv4-in-IPv6 encapsulation with no special boxes to be deployed elsewhere in the network.

1 Introduction

Along with the advancement in mobile networking technology, the mobile population of the Internet is expected to contain more than a billion mobile devices, such as user terminals, sensors, and telephone handsets. Specially, a large number of vehicles and Personal Area Network (PAN) are considered to connect the Internet with network mobility technology.

The basic NEMO protocol [2] for network mobility is currently being standardized at IETF and is ready for the deployment phase with high interest on the Internet. However, the basic NEMO protocol supports only IPv6 network. To move to IPv4 only access networks, the basic NEMO protocol requires additional technology for IPv4 traversal such as ISATAP, etc. This paper proposes new mechanism called IPv4 care-of address registration to support IPv4 on the basic NEMO protocol.

This paper consists of following sections. We first give our problem statement in Section 2 and show related work in Section 3. Then we shows our solution in Section 4 and describes the protocol specification in Section 5. We evaluate our solution in Section 6 and finally conclude in Section 7.

2 Problem Statement

The current Internet is based on both IPv4 and IPv6 network. We cannot assume that pure IPv6 access networks will be quickly deployed everywhere. It takes certain periods to shift to IPv6 only Internet. However, IPv6 support is required in the architecture of mobility support protocols such as Mobile IPv6 and the Basic NEMO protocol. This is because the Mobile IPv6 is not protocol independent. IPv6 was designed with an integrated support for Mobile IP as native IPv6 feature. As such Mobile IPv6 and the Basic NEMO protocol for Mobile Routers is designed to use the rich feature set of IPv6; hence, there exist a tight coupling of mobility signaling and IPv6 used in the media plane. Operation of Mobile Router would not be guaranteed since that also depends on the IPv6 capabilities of

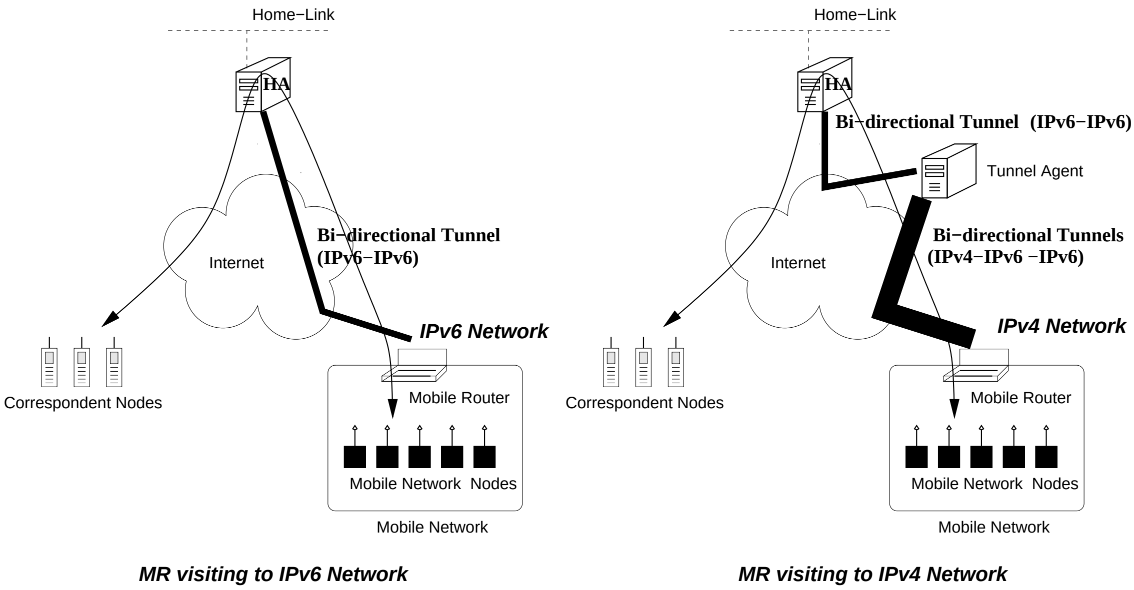

Figure 1: MR visiting to either IPv4 or IPv6 networks

the networks the Mobile Router is visiting i.e.: a Mobile Router attempting to connect via a IPv4 only network would not be able to maintain IPv6 connectivity.

Figure 1 shows two scenarios when a Mobile Router (depicted as MR) visiting to either IPv4 or IPv6 networks. When MR visits IPv6 access networks, it setup IPv6-IPv6 bi-directional tunnel between MR and a Home Agent (HA). On the other hand, visiting to IPv4 access networks, MR needs to setup IPv4-IPv6 tunnel with a Tunnel Agent to reach IPv6 networks from the IPv4 access network and IPv6-IPv6 bi-directional tunnel for the basic NEMO protocol between MR and HA. The basic NEMO protocol needs to have IPv6 access all the time. There are many mechanisms for IPv6 support on IPv4 networks such as ISATAP, v4-v6 tunnel, etc. These existing mechanisms required infrastructures such as tunnel server and ISATAP routers (depicted as tunnel agent in Figure 1).

As shown in Figure 1, there are double encapsulation when MR sends packets to the Internet from IPv4 access networks. This additional overhead caused by double tunneling prevents efficient network performance and cannot be negligible.

3 Related Work

There are earlier works at the IETF MIP6 working group such as " Dual Stack Mobile IPv6"[9] and "Doors" [10].

Dual Stack Mobile IPv6 is a mechanism to support both IPv4 and IPv6 mobility on Mobile IPv6. It assigns both an IPv4 home address and an IPv6 home address to each Mobile Node. A Home Agent and a Mobile Node maintain two bindings for an IPv4 and an IPv6 home address. When a Mobile

Node visits to IPv4 only network, it sends a Binding Update with an IPv4-mapped IPv6 address. This mechanism does not support Mobile Nodes' movement to Network Address Translation (NAT) / Port Address Translation (PAT) network, but can does with ISATAP.

The Doors is a mechanism to allow Mobile Nodes to roam over IPv4 only access networks. The Doors supports IPv4 private networks (NAT/PAT). The Doors introduces a new agent called Door Router. When a Mobile Node visits to IPv4 only network, Door Routers located between the Mobile Node and Home Agent establish IPv4-UDP automatic tunnel. The Doors mechanism relies on infrastructure. It has additional tunnel overhead for tunneling IPv6 packets from IPv4 networks.

4 IPv4 Care-of Address Registration

The genuine concept of the basic NEMO protocol is to create, establish, and deletes IPv6-IPv6 bi-directional tunnel by means of binding. It is easy to extend the concept of the basic NEMO protocol to support bi-directional tunnels other than IPv6-IPv6 tunnel for mobile network prefixes. Our proposal aims to support variety of tunnels between Mobile Router and Home Agent regardless of tunnel type. It also supports a tunnel mechanism to cross over IPv4 NAT/PAT access network.

However, the binding of the basic NEMO protocol cannot be easily extended to support different address family (i.e. IPv4). The mobility signaling (ex. binding update) is designed on IPv6 with tight dependency. We simply disable the basic NEMO protocol's IPv6-IPv6 tunnel between a Mobile Router and a Home Agent and establishes a new tunnel between them. When a Mobile Router visits to IPv4 access networks, it prefers not using the IPv6-IPv6 bi-directional tunnel, but only IPv4-IPv6 bi-directional tunnel. Therefore, the Mobile Router operates binding de-registration to disable the IPv6-IPv6 tunnel for the basic NEMO protocol at IPv4 access networks.

4.1 Protocol Overview

This research extends Home Agent address acquisition, binding registration, bi-directional tunnel of the basic NEMO protocol to support IPv4.

When a Mobile Router visits an IPv4 only network, it uses the acquired IPv4 address as its Care-of address (named IPv4 Care-of Address) to tunnel packets between the Mobile Router and the Home Agent. The IPv4 address is acquired by the Mobile Router through any address configuration mechanism such as DHCP. The Mobile Router registers its IPv4 Care-of address bound to the IPv6 Home Address to a Home Agent The operation is called IPv4 Care-of Address Registration.

In our solution, each Home Agent supports IPv4 and IPv6 dual stack and has an IPv4 global address (Home Agent IPv4 address). While a Mobile Router lives in IPv6 network, it acquires Home Agent IPv4 addresses with extended Dynamic Home Agent Address Discovery operations described in Section 5.1. Whenever the Mobile Router moves into an IPv4 only access network, it gets an IPv4 address and creates a Binding Update with 'I' flag set and processes IPsec for the Binding Update as described in [4]. It sends the extended Binding Update to the Home Agent IPv4 address by using IPv4-in-IPv6 encapsulation. The detailed operations of mobility signaling are described in Section 5. In the inner IPv6 header, the source address is a Mobile Router's Home Address and the destination address is Home Agent address. According to the basic NEMO specification, the Binding Update requests to delete the regular binding cache for the Mobile Router because the home address is stored in both the source address and the home address

IPv6 destination option. But then, IPv4 address is stored in the IPv4 Care-of Address sub-option and can be used to setup an IPv4 forwarding which is an IPv4-IPv6 tunnel for the Mobile Router's Home Address and Mobile Network Prefixes on behalf of regular forwarding on the basic NEMO protocol. The Mobile Router cannot set zero lifetime in the Binding Update for de-registration, but it set the lifetime for the IPv4 Care-of Address.

When the Home Agent receives the Binding Update, it first disables or removes the regular binding cache and sets up an IPv4 forwarding. Our mechanism supports various kinds of tunnel methods such as Generic IP Encapsulation [8], GRE tunneling [3], IPsec tunneling [6] [5], and UDP tunneling for NAPT address. These tunnel method is specified in the IPv4 Care-of Address sub-option by the Mobile Router. The Home Agent replies a Binding Acknowledgment with an IPv4 Care-of Address sub-option to the Mobile Router's IPv4 Care-of address by using IPv4 forwarding.

After getting successful Binding Acknowledgment, the Mobile Router forwards all packets meant to the Internet via the Home Agent IPv4 address by using the specified IPv4-in-IPv6 encapsulation. Without our proposal, the double encapsulation such as IPv4-in-IPv6-in-IPv6 tunnels are occurred. By using IPv4 forwarding, the basic NEMO protocol can reduce one IPv6 header which is used for regular forwarding of the basic NEMO protocol. Any outgoing packets at a Mobile Router are simply encapsulated with an IPv4 header including a Home Agent IPv4 address and a IPv4 care-of address.

5 Protocol Specification

This section gives detailed protocol specification for IPv4 Care-of Address Registration on the basic NEMO protocol.

5.1 Home Agent IPv4 Address Discovery

A Mobile Router acquires Home Agent IPv4 address. Dual Stack Mobile IPv6[9] has already proposed mechanism for this. However, our system is not aimed to use an IPv4 Home Address on Mobile Router, we slightly extended the Dynamic Home Agent Address Discovery.

When a Mobile Router requests lists of Home Agents, it sends Dynamic Home Agent Address Discovery Request to Home Agent anycast address. In that time, the Mobile Router can set "I" flag in the message. The Home Agent who received the request with I flag set contains Home Agent IPv4 address if its available. A Mobile Router maintain the Home Agent's IPv4 address as same as Home Agent IPv6 address in the home agent list. It is important to acquire Home Agent's IPv4 addresses from IPv6 network. When a Mobile Router moves to IPv4 only network, it cannot acquire Home Agent addresses from IPv4 network. In case of supporting Mobile Routers' bootstrap at an IPv4 network, the similar transaction of Dynamic Home Agent Address Discovery must be defined with IPv4 address family. However, our research is aimed to support IPv4 on the basic NEMO protocol (that is IPv6) and not to invent a new basic NEMO protocol for IPv4. Therefore, we do not discuss the detailed mechanism in this paper.

5.2 Binding Signaling with IPv4 Care-of Address sub-option

Figure 2 shows the format of the IPv4 care-of address sub-option and the extended Binding Update message. If a Mobile Router wants to register IPv4 care-of addresses which would be bound to a IPv6 home address, the Mobile Router set IPv4 support flag (I) flag and includes a IPv4 Care-of Address sub-option. In the lifetime field of the Binding Update, the Mobile Router set the Lifetime of IPv4 Care-of Address that is stored in a IPv4 Care-of Address sub-option.

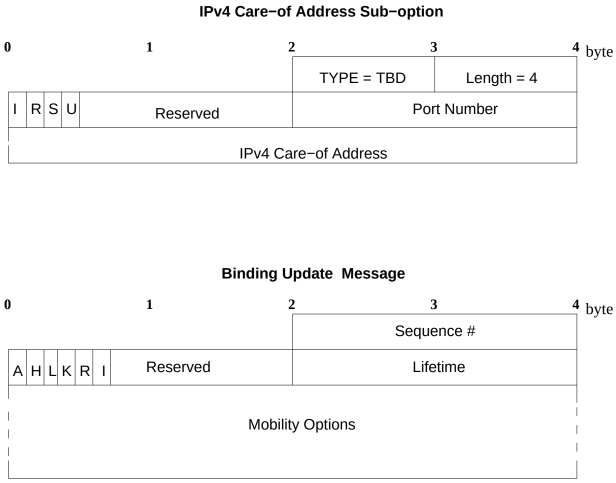

Figure 2: Options and Message

The IPv4 Care-of Address sub-option is a mobility header sub-option and has following fields. The Type field contains type value of the IPv4 Care-of address sub-option and the Length field is set always by 4. In Flag field, there are following options:

Generic IP in IP Encapsulation tunnel (I) Flag
: The home agent uses Generic Encapsulation tunneling for IPv4-IPv6 encapsulation.

GRE tunnel (R) Flag
: The home agent uses GRE tunneling for IPv4-IPv6 encapsulation.

IPsec tunnel (S) Flag
: The home agent uses IPsec tunneling for IPv4-IPv6 encapsulation.

UDP tunnel (U) Flag
: The home agent uses the Port value for UDP tunneling to go through NAPT.

The Reserved field must be set with all 0. The Port Number field contains a port number which is used for UDP-IP tunnel to traverse NAPT. The IPv4 Care-of Address field contains an IPv4 address of a Mobile Router.

When a Mobile Router sends the Binding Update (shown in Figure 3), the source address of IPv6 header is the Home Address of the Mobile Router. The Binding Update is always encapsulated by IPv4 to Home Agent IPv4 Address. The packet sent from a Mobile Router is shown in Figure 3.

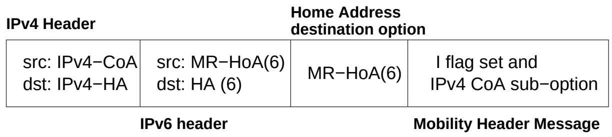

Figure 3: Format of Binding Update

From the view of the Basic NEMO Protocol, this Binding Update is treated as de-registration Binding Update. A Mobile Router sets I flag in the Binding Update with an IPv4 Care-of Address sub-option in the Binding Update and tunnels the Binding Update to a Home Agent IPv4 address. Although the Mobile Router sets its Home Address as the Source Address field of the inner IPv6 header, it set appropriate lifetime value to the Lifetime filed of Binding Update. The Mobile Router cannot set zero lifetime for the IPv4 Care-of Address Binding Update.

The message format of Binding Acknowledgment is not changed, but operations listed below are added for IPv4 care-of address registration. If a Binding Update has 'I' flag and an IPv4 Care-of Address sub-option is present, a receiver node replies a Binding Acknowledgment containing an appropriate IPv4 Care-of Address sub-option. If the requesting tunnel method is not supported by a Home Agent, the Home Agent replies with the status code "Tunnel Method is not valid". In such case, the Home Agent can set the flag of tunnel methods which Home Agent currently support. This is useful when a Mobile Router decides the tunnel method from available methods at a Home Agent. Our proposal defines a new status number (Tunnel Method is not valid) for 'I' flag handling. When a receiver is somehow legacy Home Agent and can not process an IPv4 Care-of Address sub-option, it de-registers the binding and returns a Binding Acknowledgment to the Home Address. However, the legacy Home Agent can not resolve Neighbor Discovery Cache for the Home Address and can not send it to the link, because the sender (i.e. Mobile Router) is not at the home link. In such case, the sender (i.e. Mobile Router) can not receive the Binding Acknowledgment at the visiting network. If the Mobile Router can not receive any Binding Acknowledgment after sending multiple Binding Updates with an IPv4 Care-of Address sub-option, it stop IPv4 Care-of Address Registration. Note that, Mobile Router basically does not send such Binding Updates to legacy Home Agent because of extended Home Agent Address Discovery mechanism described in Section 5.1.

When a Home Agent processes a Binding Update successfully, it setup IPv4 forwarding according to the Flag field of IPv4 Care-of Address sub-option. There are several types of tunnel such as GRE tunnel, Generic Encapsulation tunnel, IPsec tunnel, UDP-IPv4 tunnel for NAPT. When IPsec tunnel is selected, the Home Agent establishes Security Association with the Mobile Router. When UDP tunnel flag is set, the Home Agent creates UDP-IPv4 tunnel with the specified port number in the IPv4 Care-of Address sub-option. Mobile Router also setup IPv4 forwarding after accepting a Binding Acknowledgment with success status code. The procedure to setup IPv4 forwarding is same as Home Agent.

5.3 Applicability to Mobile IPv6

Our mechanism can be applied to Mobile IPv6 as well. However, Mobile IPv6 uses Proxy Neighbor Discovery to intercept packets at the Home Agent. Therefore, after de-registering the regular binding cache entry, the Home Agent still defends the Home Address to intercept packets meant for the Home Address by Proxy Neighbor Discovery. Once the Home Agent intercept packets by Proxy Neighbor Discovery, the Home Agent forwards packets to Mobile Node's IPv4 Care-of Address by IPv4 forwarding.

For the Correspondent Node, the Mobile Node de-registers its binding cache by sending a Binding Update via Home Agent. The Mobile Node tunnels the Binding Update to Home Agent IPv4 address by IPv4 forwarding and the Home Agent deliver the Binding Update to each Correspondent Node. It means route optimization can not be used while the Mobile Node locates in IPv4 network.

6 Evaluation

6.1 Solution Flexibility

Our solution does not assume any special network infrastructures for IPv4 network support on the basic NEMO protocol. This is very important for mobile computing, because movements of Mobile Routers are not expectable and are widely covered on the Internet. Service providers of the basic NEMO protocol extends its home agents and served Mobile Routers to have IPv4 and IPv6 dual stack.

Our solution also supports various kinds of tunnel mechanism between a Mobile Router and a Home

Agent. Depending on services, a Mobile Router can change its tunnel method dynamically.

6.2 Tunnel Overhead

We evaluate how tunnel processing causes additional overhead. Figure 4 shows the experimental network. The Mobile Network Node (MNN) sends ICMP echo requests to the home agent (HA) with message size either 16 or 1500 byte. Between the Mobile Router (MR) and HA, there is a router. The router becomes a tunnel server to provide IPv6 capability to MR when MR does not support our solution. In our solution, the router acts just as a router. The network topology is same for two experimentations. The Round Trip Times (RTT) between MNN, MR and HA are shown in Figure 4. We use IPv4-IPv6 bi-directional tunnel between MR and HA for our proposal and use IPv4-IPv6-IPv6 bi-directional double tunnel for the operation without our scheme. It indicates that additional overhead is caused by an additional IPv6 header of the basic NEMO tunnel.

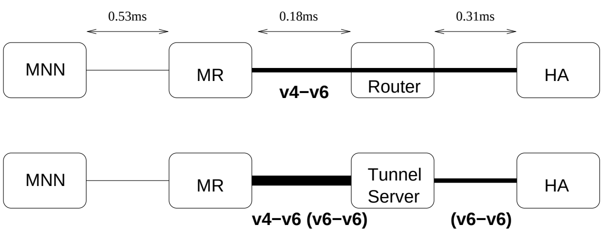

Figure 4: Experimental Network

We measured RTT between MNN and HA. The result is shown in Table 5 and Table 6. Regardless of message size, RTT is obviously decreased when our scheme is applied. Our solution decrease single tunnel overhead by de-registering binding and creating IPv4-IPv4 tunnel directly between MR and HA. When message size is greater than Maximum Transfer Unit (MTU), fragmentation is occurred and causes extra RTT. Without our proposal, HA only recursively searches both IPv6 binding and IPv4 binding to create double tunnel headers. On the other hand, HA just looks for IPv4 binding of MR when our scheme is applied.

There is only single flow between MNN and HA in this experimentation. However, HA will server hundreds of MRs at the same time and tunnel overhead affects heavily to network performance. Thus, our proposal is important to serve MRs visiting to IPv4 only network.

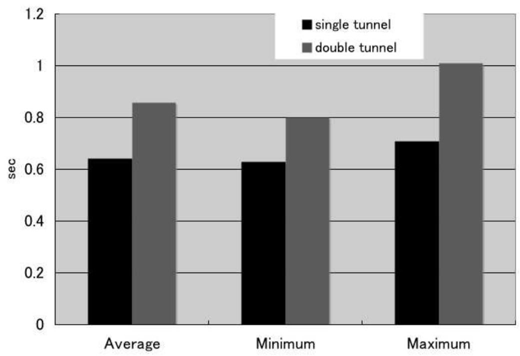

Figure 5: Comparison of RTT (16 byte) when either single or double tunnel is used (STD: 0.01 for single tunnel, 0.033 for double tunnel)
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7 Conclusion

This paper proposes a new mechanism to support IPv4 network on the basic NEMO protocol. The basic NEMO protocol is designed only for IPv6 network and is not assumed that Mobile Routers move to IPv4 access networks. However, IPv4 and IPv6 are coexisted on the current Internet. There are mechanisms to allow Mobile Routers to move to

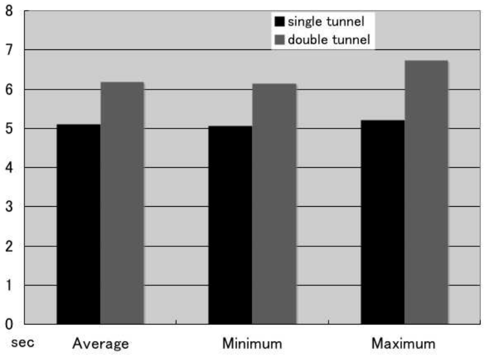

Figure 6: Comparison of RTT (1500 byte) when either single or double tunnel is used (STD: 0.018 for single tunnel, 0.058 for double tunnel)
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IPv4 access network with IPv4 transition mechanism such as ISATAP. But most of these mechanisms are based on IPv4-IPv6 tunnel technology. The basic NEMO protocol always requires IPv6-IPv6 bi-directional tunnel between a Mobile Router and a Home Agent while the Mobile Router is away from home. Additional tunnel overhead is not negligible on the basic NEMO protocol as described in Section 6. Thus, we propose IPv4 Care-of address registration scheme for the basic NEMO protocol. It supports various kinds of tunnel method between a Mobile Router and a Home Agent. It also supports movement to NAT/PAT IPv4 access network. Even when a Mobile Router visits to IPv4 only network, it can maintain IPv6 connectivity with minimal tunnel overhead.

References

[1] S. Deering and R. Hinden. Internet Protocol, Version 6 (ipv6) Specification. Request for Comments (Draft Standard) 2460, Internet Engineering Task Force, December 1998.

[2] V. Devarapalli, R. Wakikawa, A. Petrescu, and P. Thubert. Nemo Basic Support Protocol (work in progress). Internet Draft (draft-ietf-nemo-basic-support-03), Internet Engineering Task Force, June 2004.

[3] S. Hanks, T. Li, D. Farinacci, and P. Traina. Generic Routing Encapsulation (GRE). Request for Comments (Informational) 1701, Internet Engineering Task Force, October 1994.

[4] D. Johnson, C. Perkins, and J. Arkko. Mobility support in IPv6. Request for Comments (Proposed Standard) 3775, Internet Engineering Task Force, June 2004.

[5] S. Kent and R. Atkinson. IP Encapsulating Security Payload (ESP). Request for Comments (Proposed Standard) 2406, Internet Engineering Task Force, November 1998.

[6] S. Kent and R. Atkinson. Security Architecture for the Internet Protocol. Request for Comments (Proposed Standard) 2401, Internet Engineering Task Force, November 1998.

[7] J. Postel. Internet Protocol. Request for Comments (Standard) 791, Internet Engineering Task Force, September 1981.

[8] W. Simpson. IP in IP Tunneling. Request for Comments (Informational) 1853, Internet Engineering Task Force, October 1995.

[9] T. Soliman and G. Tsirtsis. Dual Stack Mobile IPv6 (work in progress). Internet Draft (draft-soliman-v4v6-mipv4-00.txt), Internet Engineering Task Force, August 2003.

[10] P. Thubert, P. Molteni, and P. Wetterwald. IPv4 traversal for MIPv6 based Mobile Routers (work in progress). Internet Draft (draft-thubert-nemo-ipv4-traversal-01.txt), Internet Engineering Task Force, May 2003.