Route Optimization based on ND-Proxy for Mobile Nodes in IPv6 Mobile Networks

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***Abstract*— This paper specifies a mechanism for enabling mobile nodes in IPv6 mobile network to perform route optimization. The route optimization is possible because mobile router provides the prefix of its care-of address for its mobile nodes by playing the role of ND-Proxy. Through binding updates associated with the network prefix of an access network, the mobile nodes can perform route optimization.**

I. Introduction

Lateley, the demand and necessity of network mobility (NEMO) [1] is increasing along with those of host mobility based on Mobile IPv6 [2]. The purpose of network mobility is to guarantee the continuity of the sessions of fixed or mobile nodes within mobile networks, such as car, bus, subway train, airplane and submarine. IETF NEMO working group has been performing the standardization of network mobility support [3]. The current solution is based on bi-directional tunnel between home agent (HA) and mobile router (MR) [1]. The basic support protocol of NEMO enables mobile network node (MNN) and correspondent node (CN) to communicate through the bi-directional tunnel. Data exchange between MNN and CN is performed not via optimal routing path, but via the non-optimal path including bi-directional tunnel. MR's HA intercepts all of packets destined to the MNNs and tunnels them to the MR. Also, the MNNs' outbound packets are tunneled in order to pass ingress filtering [1], [2]. This mechanism is very simple but it gives up a powerful feature of Mobile IPv6, route optimization (RO) without ingress filtering. In addition, when the mobile network has multiple nested mobile routers, packet delay between MNN and CN becomes longer because of dog-legged routing and also packet size becomes bigger due to extra IPv6 header attached to packet per level of nesting [4]. In order to deal with this route problem in NEMO, some drafts related to RO have been published as Internet-Draft [4]–[6].

When we think over the applicability of NEMO in our daily life, we can forecast that network mobility service will be provided in vehicles, such as bus, subway train and airplane, because most passengers in such vehicles will have hand-held PC or PDA as mobile node rather than fixed node in near future. Therefore, it is necessary to provide route optimization for such mobile nodes. This paper suggests a way of optimizing the routes between MNs and CNs, independently of the level of nesting and without the extra IPv6 header. The route optimization mechanism is based on the proxying function of mobile router, which informs mobile nodes within mobile network of the access network prefix to make a care-of address (CoA) passing ingress filtering, and also relays packets between access router and mobile node. This proxying for RO is performed through IPv6 Neighbor Discovery (ND), which is called ND-Proxy.

The remainder of the paper is organized as follows. In Section II, related work is presented. Section III explains the concept of the multilink subnet and ND-Proxy. In Section IV, the mechanism of route optimization is presented on the basis of ND-Proxy in detail. In Section V, we analyze the route optimization of our scheme. Finally, in Section VI, we conclude the paper with future research work.

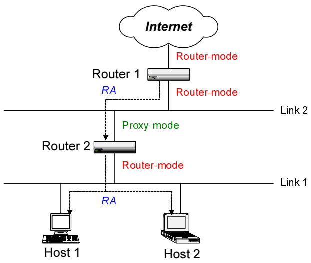
II. Related Work

A. Route Optimization based on Prefix Delegation

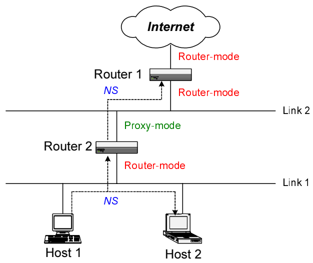
Mobile router gets a prefix from an access router using Prefix Delegation protocol and advertises the delegated prefix into its subnet [6]. Each mobile node makes its care-of address from the prefix and performs binding update. MNs behind of MR can communicate with CNs via optimized route and MR saves processing power by reducing the amount of extra header process of packets which must be encapsulated. This mechanism is suitable for a large, hierarchical and stable mobile network, such as train or airplane because it takes some time to configure and update new CoA by prefix delegation protocol. Therefore, the limitation is that it needs a prefix delegator within every access network and the additional delay of prefix delegation for route optimization.

B. Route Optimization based on IPv6 Reverse Routing Header

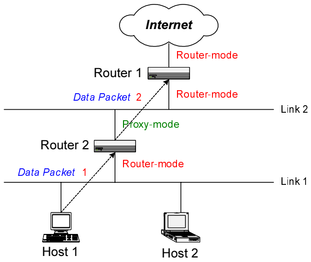
In order to enable nested mobile networks, NEMO basic support protocol involves the overhead of nested tunnels between the mobile routers and their home agents. This proposal allows the building of a nested Mobile Network avoiding the nested tunnel overhead [4]. This is accomplished by using a new routing header, called the reverse routing header, and by overlaying a layer 3 tree topology on the evolving mobile network.



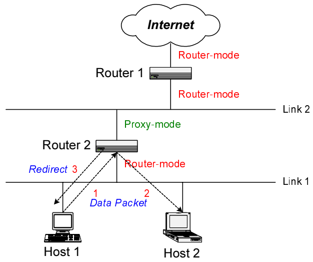
(a) Router Advertisement over Multilink Subnet



(b) Duplicate Address Detection within Multilink Subnet



(c) Delivery of Data Packet from Host 1 to Router 1



(d) Redirect into New Next-hop Node

Fig. 1. Neighbor Discovery in Multilink Subnet

III. Multilink Subnet and ND-Proxy

We define a Multilink Subnet (MS) as a collection of independent links, connected by routers, but sharing a common subnet prefix. This might be used, for example, in a home network where a router connects a wired and a wireless link together to form a single subnet [7]. The routers that consist of this multilink subnet is defined as Multilink Subnet Router (MSR). MSR should play the role of proxying ND messages as ND-Proxy, which performs both proxying and relaying for all nodes on its router-mode interfaces except proxy-mode interfaces among its network interfaces. ND-Proxy processes ND messages through router-mode interface and performs ND proxying through proxy-mode one [7], [8].

A. Multilink Subnet Model

The multilink subnet can be managed with two models according to the way of handling the subnet prefix for the multilink subnet; (a) Off-link model, and (b) On-link model.

1) Off-link Model: If the MSR sets the A (autonomous address-configuration) flag on, and the L (on-link) flag off in Prefix Information option of Router Advertisement (RA) message, then hosts on the link will attempt stateless address configuration in the given prefix, but will not treat the prefix as being on-link [7]–[9]. As a result, ND is effectively disabled and packets to new destinations always go to the router first, which will then either forward them if the destination is off-link, or redirect them if the destination is on-link.

2) On-link Model: If the MSR sets both the A and the L flags on in Prefix Information option of RA message, then hosts on the link will perform stateless address configuration and ND as usual [7]–[9]. However, since Neighbor Solicitation (NS) messages from existing hosts are sent to link-scoped solicited-node multicast address [10], they will never reach nodes on other links within the subnet. Instead, MSRs must be able to relay such NS messages to other links of their proxy-mode interfaces.

B. Neighbor Discovery in Multilink Subnet

Fig. 1 shows the ND operation in multilink subnet. Router 1 advertises a multilink subnet prefix through RA messages like Fig. 1 (a). Router 2 relays the RA message received at its proxy-mode interface into its another router-mode interface attached to Link 1. Like Fig. 1 (b), Host 1 performs DAD procedure for its new address made from the advertised prefix. In order that the address is checked in the multilink subnet, the NS message for DAD is relayed into another link, Link 1 by Router 2. When the timer for DAD in Host 1 expires and no solicited Neighbor Advertisement (NA) message is delivered to it, it considers that there is no duplicate address within the multilink subnet and configures the address as preferred address [9].

The way of delivering data packet is different according to multilink subnet model. For example, let's see the case where Host 1 sends its data packet to Router 1 in off-link model. Let's assume that Host 1 has no neighbor information for Router 1, such as Router 1's link-layer address in its neighbor and destination caches. Because the prefix of destination node, Router 1 is not on-link, Host 1 sends its data packet to its default router as next-hop, Router 2 can forward the packet to destination node, Router 1 through neighbor discovery of address resolution like Fig. 1 (c) [8]. During the delivery of data packet, Router 1 and Router 2 install the route toward Host 1 [8]; that is, Router 2 installs Host 1's IPv6 address and link-layer address in its destination cache and neighbor cache, respectively, and Router 1 installs Router 2's IPv6 address and link-layer address as next-hop toward Host 1 in its destination cache and neighbor cache, respectively, too. There happens the redirect of next-hop like Fig. 1 (d) in off-link model. Let's see the case where Host 1 sends data packets to Host 2. Because the prefix of Host 2 is not on-link, Host 1 sends its data packet to next-hop, Router 2. Because Router 2 knows that Host 1 and Host 2 are on the same link, Link 1, Router 2 relays Host 1's data packet to Host 2 and then sends a redirect message informing Host 1 of Host 2's existing on the same link, which contains Host 2's link-layer address. After receiving the redirect message, Host 1 verifies the reachability of Host 2 through Neighbor Unreachability Detection (NUD) and then sends next data packet directly to Host 2 [8].

Next, let's see the case where Host 1 sends its data packet to Router 1 in on-link model. Because the prefix of Router 1's address is on-link prefix, Host 1 performs neighbor discovery of the address resolution for Router 1's link-layer address by itself. Host 1's NS message for ND is relayed to another link, Link 2 by Router 2. The NS message finally arrives at Router 1. Because the target address of the NS message matches Router 1's address, Router 1 responds to the NS message with an NA message containing the information of its link-layer address. The NA message is sent to Router 2 and it is finally relayed to Hoast 1 via Router 2. Now, in Host 1's destination

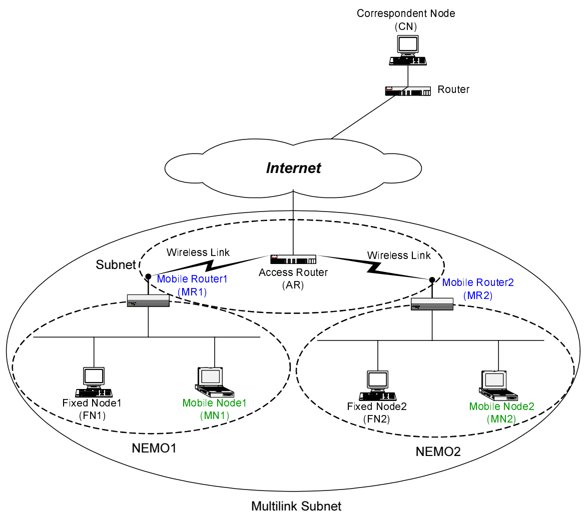


Fig. 2. Multilink Subnet for Route Optimization

cache, the next-hop address toward Router 1 is configured as Router 2's address. Like Fig. 1 (c), Host 1 can send its data packets to Router 1 via Router 2.

IV. ND-Proxy based Route Optimization for Mobile Nodes

This route optimization is possible by a mobile router performing ND-Proxy, which makes a care-of address (CoA) with the prefix advertised by access router and relays the prefix of access network into the whole mobile network. Fig. 2 shows a multilink subnet consisting of one subnet and two mobile networks (i.e., NEMO1 and NEMO2) [7]. Each mobile node can make its new CoA with router advertisement message including access network prefix and perform the return routability and binding update procedure with its correspondent node for route optimization. As ND-Proxy, the mobile router performs neighbor discovery for the sake of the mobile nodes within its mobile network.

Like this, access network and mobile network are configured into a multilink subnet through mobile router that performs ND-Proxy. Fig. 3 shows an example of the route optimization (RO) through a multilink subnet comprised of four links from Link 1 to Link 4. Three mobile routers, MR1 through MR3, relay the prefix information of access network (AR1_P) that was sent by an access router, AR1 as proxy-mode and relay the prefix information to its subnet as router-mode like in Section III.B [7]. The mobile nodes, MN1 and MN2, within the mobile network controlled by MR1 can perform route optimization with the prefix information relayed by its mobile router, MR1. Also, MN3 can optimize the route through MR2. MN4 and MN5 can perform route optimization through MR2 and MR3, too.

A. Mobile Router Extension - Process of Prefix Information Option for RO

Mobile router must perform the role of ND-Proxy and relay the prefix information that is received from an access router.

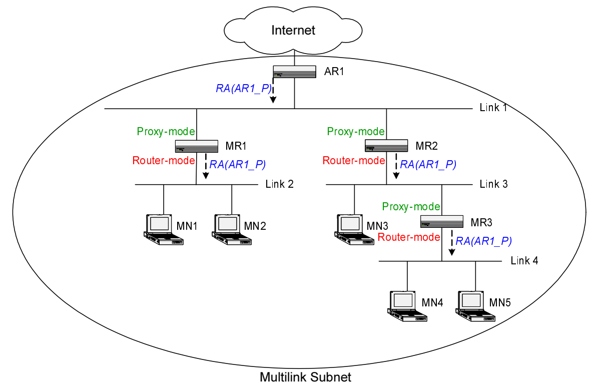


Fig. 3. ND-Proxy based Route Optimization

Before mobile router advertises the prefix information through Router Advertisement (RA) message, it must set O (route-optimization) flag indicating that this prefix can be used for route optimization of mobile nodes, which are either local mobile nodes or visiting mobile nodes within the mobile network.

If a mobile node within a mobile network receives the new prefix information option through RA message and can recognize this option, it may prefer this new prefix information option to the normal prefix information option that contains the mobile network prefix assigned by the mobile router's home network. By performing binding update with the prefix of the access network, the mobile node can optimize the routes between its correspondent nodes and itself.

B. Neighbor Discovery Extension

In order to support this route optimization, ND implementation in MR and MN must be extended to process the prefix information option for RO and that in Local Fixed Node (LFN) within mobile network, which has no mechanism for Mobile IPv6, need no change.

1) RO Prefix Information Option Format: The mechanism of this paper needs a new O (route-optimization) flag within prefix information option for route optimization [8], [9]. When this flag is set on, it indicates that the prefix included in the option can be used by mobile nodes within a mobile network for the route optimization. Fig. 4 shows the format of the modified prefix information option, RO Prefix Information option and Table I describes important fields.

The RO Prefix Information option provides a mobile node with the network prefix of access network and allows it to autoconfigure its new CoA through stateless address autoconfiguration and to perform binding update. The prefix information option appears in RA message and must be silently ignored for other messages. L (on-link) flag may be either 0 or 1. Namely, this route optimization can be either on-link or off-link model of Section III.A. A (autonomous address-configuration) flag must be set on, indicating IPv6 stateless address autoconfiguration.

2) Neighbor Solicitation (NS) Message Format: NS message must be extended for DAD of the address based on

```
 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     | Prefix Length |L|A|O|Reserved1|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Valid Lifetime                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Preferred Lifetime                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Reserved2                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                            Prefix                             +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Fig. 4. RO Prefix Information Option Format

TABLE I

RO PREFIX INFORMATION OPTION FIELDS

Field	Description
Type	Message type. The same as Prefix Information option.
O-flag	Route-Optimization flag. When set indicates that this prefix can be used for the route optimization of mobile nodes within NEMO.
Prefix	Prefix of access network where the NEMO is attached directly.

```
 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      |     Code      |          Checksum             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|M|                           Reserved                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                       Target IPv6 Address                     +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Options ...
+-+-+-+-+-+-+-+-+-+-+-+-
```

Fig. 5. Extended Neighbor Solicitation Message Format

TABLE II

EXTENDED NEIGHBOR SOLICITATION MESSAGE FIELDS

Field	Description
Type	Message type. The same as Neighbor Solicitation (NS) message.
Code	Code for this message type. The same as NS message.
M-flag	Multi-hop flag. When set indicates that this NS message should be relayed to the other subnet links.

RO prefix to be performed in the whole mobile network, not just within a link. Therefore, there is a need to discriminate between the normal NS message and extended NS message for route optimization [8]. Fig. 5 shows the format of the modified NS message and Table II describes important fields. M (multi-hop) flag indicates that the NS message can be relayed to other links if necessary.

C. Procedure of Route Optimization

1) Generation of a new CoA: Whenever a mobile node first receives RA message containing RO prefix information option that includes a new network prefix of access network, it makes a new CoA.

2) DAD for the new CoA: The mobile node performs DAD for the new CoA through the extended NS message. The NS message of DAD for the new address is disseminated by mobile routers, acting as ND-Proxy, in the entire mobile network where the mobile node is placed [7]. Each mobile router memorizes the DAD for returning NA message to the originator or relayer of the extended NS message for a while.

If there is no NA returned after DAD timeout, the mobile node configures the address as its new CoA in its network interface.

Notice that the DAD for the link-local addresses and global addresses based on mobile network prefix assigned by home network is performed through normal NS message only within a link and the DAD for the global addresses based on access network prefix is performed through extended NS message within the whole multilink subnet, which is relayed by ND-Proxies.

3) Return Routability and Binding Update: After configuring the new CoA, the mobile node performs the return routability and binding update procedure of Mobile IPv6 [2].

4) Delivery of Data Packets: After binding update, the data packets of correspondent nodes toward the mobile node are delivered to the access network to which the mobile network containing the mobile node is attached via optimal paths.

When the access router of the access network receives the data packets and there is no neighbor information for the mobile node, it multicasts normal NS message for address resolution to the solicited-node multicast address of the destination's IPv6 address in order to find out the link-layer address of the destination node. The mobile router, knowing the link-layer address of the destination, responds to the NS message by returning its own link-layer address with a unicast NA message to the source address of the NS message as ND-Proxy, which has known the destination's IPv6 address and link-layer address while forwarding its data packets along with neighbor discovery related to the destination node like in Section III.B.

When the access router knows the link-layer address of next-hop toward the destination like in Section III.B, it forwards the IPv6 data packets to the next-hop mobile router corresponding to the link-layer address. The mobile router relays the packets to next-hop toward the destination mobile node. Finally, the packets arrive at the destination node. Like this, in the case where the destination node is placed in multi-level mobile network, the packets may be relayed to the destination node by more than one mobile router according to the route information in each mobile router's destination and neighbor caches.

5) Movement of Mobile Router: When MR moves into another access network and detects its movement by movement detection algorithm [2], it performs binding update with its HA with a new CoA based on the new access network prefix, and then relays the prefix for RO into its other router-mode interfaces. This allows the mobile routers and nodes to perform route optimization based on the new access network prefix. When MR returns to its home network, it deregisters with its HA and advertises RA message that contains RO Prefix Information option for the previous access network prefix with Valid Lifetime and Preferred Lifetime set to zeroes and O flag

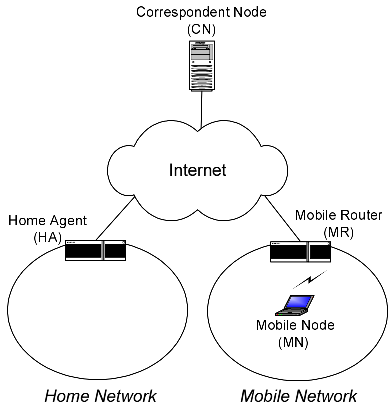


Fig. 6. Network Topology

TABLE III
PARAMETERS FOR DELAY ANALYSIS

Parameter	Description
TD_{bt}	Transmission Delay through the Bi-directional Tunnel between HA and MR
TD_{ro}	Transmission Delay through the Route Optimization between MN and CN
h	Hop count between MN and MR
d	Hop count between HA and MR, namely the tunnel distance (i.e., the distance between Foreign Network to Home Network)
m_1	Hop count between CN and HA
m_2	Hop count between CN and MR
α	One-way delay in a link of one hop
$Diff$	$TD_{bt} - TD_{ro}$

set on, and Prefix Information option for MR's mobile network prefix. This RA message allows the mobile routers and nodes below the MR explicitly to release their current CoA and to use MR's mobile network prefix in order to configure their address according to Mobile IPv6 protocol [2].

V. ANALYSIS OF ROUTE OPTIMIZATION

Fig. 6 shows the network topology for the analysis of the transmission delay between mobile node (MN) and correspondent node (CN). Table III shows the parameters for the analysis of the delay for data transmission needed between mobile node and correspondent node. With these parameters, we can calculate and compare the transmission delays through both the bi-directional tunnel and route optimization. The former delay is presented as TD_{bt} and the latter one as TD_{ro} like Table III. The following shows the procedure of the calculation. First of all, we assume that one-way delay in every link of one hop is constant, α.

$$TD_{bt} = (m_1 + d + h) \cdot \alpha \tag{1}$$

$$TD_{ro} = (m_2 + h) \cdot \alpha \tag{2}$$

With (1) and (2), we can get the delay difference, $Diff$, between these two mechanisms as follows:

$$\begin{aligned} Diff &= TD_{bt} - TD_{ro} \\ &= ((m_1 - m_2) + d) \cdot \alpha \end{aligned} \tag{3}$$

Because $m_1 - m_2$ is bounded and d contributes most to $Diff$, $Diff$ increases in proportion to $d \cdot \alpha$ like (3) and (4). Namely, the difference of transmission delays increases in proportion to the distance of bi-directional tunnel.

$$Diff \propto d \cdot \alpha \tag{4}$$

Therefore, because the longer the tunnel distance becomes, the more the transmission delay can increase, mobile nodes can opitimize the route via which data packets are delivered on the basis of the access network prefix provided by mobile router as ND-Proxy. As security consideration, the route optimization proposed in this paper does not add any other security problems to the NEMO or Mobile IPv6 [1], [2]. However, because our mechanism has to perform DAD in the whole nobile network, the delay due to this DAD can decrease the benefit of our route optimization in the case where the mobile network is deep multi-level. We need to enhance the current DAD mechanism to operate faster. For DNS, service important to IP networking, we can optimize DNS name resolution by allowing mobile nodes to use a local recursive DNS server within mobile network [5], [11].

VI. CONCLUSION

In this paper, we suggest a new mechanism for optimizing data path between a mobile node and correspondent nodes in IPv6 mobile networks. Because this route optimization mechanism is based on Neighbor Discovery Proxy, mobile node can get the information of access network prefix and make its new care-of address to communicate with its correspondent nodes via optimized data path. As future work, we will compare our mechanism with others through network simulation, such as OMNet++ [12], and improve our scheme more efficiently [4]–[6].

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