M.Sc. Engg.Thesis

A Route Optimization Scheme for Nested Network Mobility

by

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Submitted to

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in partial fulfillment of the requirement for the degree of
Master of Science in Engineering in
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DEPARTMENT OF COMPUTER SCIENCE AND ENGINEEING
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The thesis "**A Route Optimization Scheme for Nested Network Mobility**" submitted by Mohammad Mukhtaruzzaman, Roll No. 040805038P, Session April 2008 to the Department of Computer Science and Engineering, Bangladesh University of Engineering and Technology, has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Master of Science in Engineering (Computer Science and Engineering) and approved as to its style and contents. Examination held on May 21, 2011.

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Declaration

I, hereby, declare that the results presented in this thesis is the outcome of the investigation performed by me under the supervision of Dr. Md. Humayun Kabir, Associate Professor, Department of Computer Science and Engineering, Bangladesh University of Engineering and Technology, Dhaka. I also declare that no part of this thesis and therefore has been or is being submitted elsewhere for the award of any degree or diploma.

Mohammad Mukhtaruzzaman

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Abstract

A mobile network is a network whose link to the Internet varies with time. Network Mobility (NEMO) basic support protocol maintains the connectivity when Mobile Router (MR) of a mobile network changes its point of attachment to the Internet by establishing a bidirectional tunnel between the MR and the Home Agent (HA). A packet from a Correspondent Node (CN) traverses through the tunnel to reach the mobile network. Nesting occurs in NEMO when a MR's new attachment point is in another mobile network that has also moved away from its home link. The level of tunneling increases as the level of nesting increases. Multiple levels of tunneling in nested NEMO adds multiple legs to a non-optimized routing path that the IP packets have to traverse in order to reach the final destination. As per our study, an efficient route optimization technique in NEMO, particularly in nested NEMO, is still a research challenge. In this research, we propose a route optimization scheme for nested NEMO. We use two Care-of Addresses for each MR, as well as two types of entries, such as fixed and visiting, in the routing table in each MR. Our route optimization scheme completely removes the tunnels from the nested NEMO in a single step using only one binding update message irrespective of the number of levels in the nest. Our route optimization scheme, will also work for non-nested NEMO.

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List of Abbreviations

AODV	- Ad hoc On-demand Distance Vector
AR	- Access Router
BGP	- Border Gateway Protocol
BU	- Binding Update
CR	- Correspondent Router
CN	- Correspondent Node
CoA	- Care-of Address
COR	- Cross-Over Router
CUIP	- Cellular Universal IP
DESMERO	- Delay Sensitive Mechanism to Establish Route Optimization
DHCP	- Dynamic Host Control Protocol
DSR	- Synamic Source Routing
EMIP	- Extended Mobile IP
FAR	- Foreign Access Router
HA	- Home Agent
HAR	- Home Access Router
HIP	- Host Identity Protocol
HoA	- Home Address
IEEE	- Institute of Electrical & Electronics Engineers
IETF	- Internet Engineering Task Force
IP	- Internet Protocol version 4
IPv4	- Internet Protocol version 4
IPv6	- Internet Protocol version 6
LFN	- Local Fixed Node
LMA	- Local Mobility Anchor
MA	- Mapping Agent
MANET	- Mobile Ad hoc Network
MIP	- Mobile IP
MIPv4	- Mobile IP version 4
MIPv6	- Mobile IP version 6
MH	- Mobile Host

MIRON	- MIPv6 RO for NEMO
MN	- Mobile Node
MNN	- Mobile Network Node
MNP	- Mobile Network Prefix
MR	- Mobile Router
NBSP	- NEMO Basic Support Protocol
NCO	- Nested Care-of address Option
NEMO	- NEtwork MObility
NERON	- NEst RO for NEMO
NEMO WG	- NEtwork MObility Working Group
OLSR	- Optimized Link State Routing
ONEMO	- Optimzed NEMO
ORC	- Optimized Route Cache
P2P	- Peer-to-Peer
PCH	- Path Control Header
PD	- Prefix Delegation
QoS	- Quality of Service
S-RO	- Simple Route Optimization
RA	- Router Advertisement
RAO	- Router Alert Option
RBU	- Recursive Binding Update
RFC	- Request For Comment
RO	- Route Optimization
ROTIO	- Route Optimization using TIO
RRH	- Reverse Routing Header
TCP	- Transmission Control Protocol
TIO	- Tree Information Option
TLMR	- Top Level Mobile Router
TOS	- Type of Service
VMN	- Visiting Mobile Node
WINMO	- Wide-area IP Network MObility
xTIO	- Extended Tree Information Option

Chapter 1

Introduction

1.1 Background

Internet is evolving towards a true ubiquitous network, accessible anytime and from anywhere. In particular, the demand for Internet access in mobile platforms such as planes, trains, cars and ships is constantly increasing. With mobility support, an IP node is capable of changing its point of attachment to the network and still remains seamlessly reachable by other IP nodes in the Internet. A mobile node may be either a mobile host or a mobile router.

Host mobility enables the mobile hosts to move within the mobile wireless network regardless of its home location address. The mobile hosts are identified by its home address regardless of its current location. When a mobile host is away from its home location it is associated with a care-of-address. The care-of-address provides the information about the current location of the node. When an IP packet is transferred to a mobile host's home address that packet will be routed to the care-of-address. The mechanism for binding the home address with the care-of-address of the mobile hosts at their home agent enables them to remain seamlessly reachable by each other. Mobile IPv4 [1] supports host mobility, however, suffers from suboptimal routing path problems and ingress filtering by the border routers. Mobile IPv6 (MIP) [2] has been proposed to provide better support for host mobility overcoming the problems faced in Mobile IPv4.

In several scenarios, demands for mobility are not restricted to a single host anymore. Network Mobility (NEMO) becomes increasingly important to support the movement of a mobile network consisting of several mobile nodes where nodes move together as a group, as in a plane, train, car, ship etc. NEMO allows a whole network to move with all of its nodes (all hosts and all routers) from one access router to another access router. NEMO also makes all the nodes in the moved network seemingly accessible.

To support network mobility, the IETF NEMO working group proposed the NEMO basic support protocol (NBSP) [3] extending host mobility support protocol, MIPv6. NBSP is the current *de facto* standard for NEMO which enables Mobile Network Nodes (MNNs) to move together as a mobile network with a delegated router called the Mobile Router

(MR). NEMO also allows different MRs from different home networks to join each other in an ad hoc manner and form a nested NEMO.

In the NEMO [4], each MR is primarily designated to be connected to a particular network, known as its home network. MR is then given a permanent IP address called its home address (HoA). MR's HoA remains unchanged regardless of its attachment point in the Internet. When the NEMO is away from home, packets addressed to the nodes of the NEMO are still routed to the home network and a Home Agent (HA), a router in the MR's home network, takes care of all the data traffic of the MR. When the NEMO is in a foreign network, it is getting attached with a Foreign Access Router (FAR). MR acquires an address from the foreign network, called the Care-of Address (CoA). MR then sends a Binding Update (BU) message to its HA to map the CoA with its HoA.

After a successful completion of binding process, a bi-directional tunnel is setup between MR and its HA. All future packets will be intercepted by the HA and then encapsulated with an extra IPv6 header whose destination address is the MR's CoA. The packets are now transferred to the mobile node (MN) in NEMO through the MR-HA tunnel. The MR receives the encapsulated packet in its CoA, removes the outer IPv6 header, and delivers the original packet to MN.

However, there are two main problems in NEMO basic support system, which are reported in the research work [5]. One is sub-optimal routing or pin-ball routing and the other one is multiple encapsulations, which may cause delayed packet delivery. The root cause of the route sub-optimality problem is the requirement of a bi-directional tunnel to be setup between an MR and its HA.

In nested-NEMO, there are several MRs that form a tree or nest. Each MR adds one level of tunnel and the last level of tunneling occurs between the root-MR and its HA. Here, root-MR is the top MR in the MR tree. The addition of multiple level of tunnelings for multiple level of nestings in nested NEMO worsens the route sub-optimality problem.

In this research, we propose a new scheme for nested NEMO to solve the tunneling problem. In this scheme, we propose to use two CoAs, local-CoA and root-CoA, for each MR. Here, the local-CoA of a MR will be its own CoA while the root-CoA of a MR will be the CoA of the root MR in the nest. We also propose to use two types of entries in the routing table in each MR: Fixed and Visiting. Fixed part of the routing table will have the entries for the networks that are homed at the MR. Visiting part of the routing table will have the entries for the networks that are temporarily attached with the mobile routers in the sub tree rooted by the MR. Proposed scheme will completely remove the tunneling from nested NEMO in a single step using only one binding update message. This proposed route optimization scheme will also work for non-nested NEMO. A non-nested NEMO is in fact a special case of nested-NEMO, where the root-MR is the only MR in the tree.

1.2 Research Objective

The primary aims of this study is to find a solution to the suboptimal routing and the packet overhead problems caused by NEMO Basic Support protocol, while considering the different principles of route optimization.

Existing proposals on route optimization have different definitions and models based on the target scenarios and problems. Therefore, the degree of optimization varies and as a result the path is still suboptimal in some configurations. Furthermore, as a tradeoff of the optimal path, severe signaling and packet overhead is caused at mobile routers.

As our solution to these problems, a concept for route optimization is proposed which offers sufficient optimal path for nested mobile networks with minimum overhead. We define the requirements of route optimization through analysis of different proposals, and we design and implement a solution to evaluate the effectiveness of our proposal.

1.3 Thesis Overview

The remaining Chapters of the thesis are organized as follows. In Chapter 2, Network Mobility is described in detail, along with an overview of the NEMO Basic Support protocol and the problems of the NEMO Basic Support protocol, as well as the issues surrounding route optimization. Chapter 3 covers the research works related in this field and motivations behind this research work. Chapter 4 explains and evaluates the proposed mechanism. Chapter 5 compares our work with other related research works. Finally, Chapter 6 concludes our research findings.

Chapter 2

Network Mobility

As Internet access becomes more and more ubiquitous, demand for mobility is constantly increasing. Nowadays, vehicles like cars, trains, plains etc. contain many sensor devices and built-in computers which move together and require accessing Internet seemingly as shown in Figure 2.1. In order to satisfy such demands, the IETF [18] has standardized NEMO Basic Support Protocol (NBSP) [3], to provide continuous network connectivity to a group of hosts moving together.

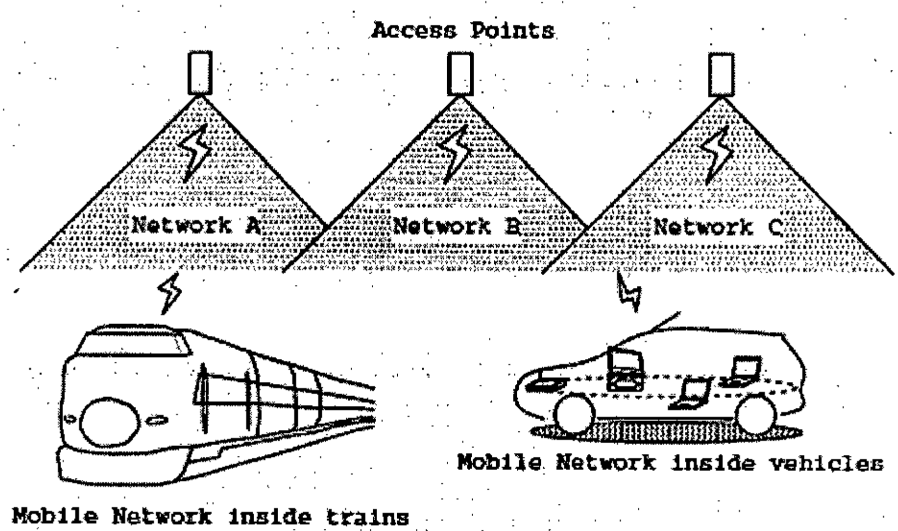


Figure 2.1: Mobile Network inside Vehicles

NEMO is primarily based on Internet Protocols (IP) and Mobile IP. For this reason, we first describe all the versions of IP (IPv4 and IPv6) and Mobile IP (MIPv4 and MIPv6). Finally, we shed lights on NEMO Basic Support protocol, which is based on Mobile IPv6 mechanisms, and Nested NEMO.

2.1 Internet Protocol (IP)

The Internet Protocol (IP) [27] is the network layer protocol in TCP/IP [30] protocol stack, which is used to send data from one computer to another computer through the Internet. Each computer (known as a host) on the Internet has at least one IP address that uniquely identifies it from all other computers on the Internet. An application data is first divided into some packets called IP packets. Each IP packet has its source and destionation IP addresses in its header. This header is called the IP header of a packet. An IP packet is then passed onto the network. If the destination host resides in the same network, the IP packet reaches the destination host directly. A typical IP network has been shown in Figure 2.2.

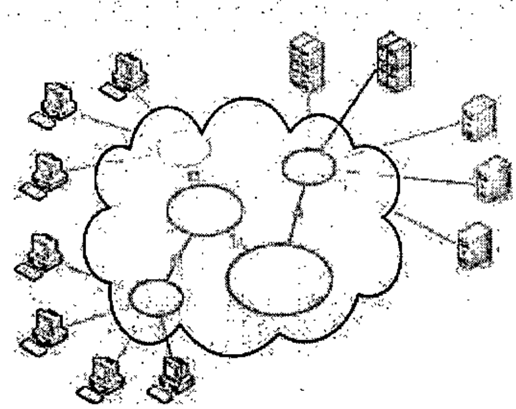


Figure 2.2: A typical IP network

Each network connects itself to the Interner through one or more routers, which are known as the gateways to all the hosts in the network. If the destination host of an IP packet is outside the network, the packet is intercepted by the router. An IP packet can reach the destination host via mutliple networks, i.e., via multiple routers. There might be multiple such paths from one host to another host through the Internet. Router helps the IP packet to go through the best path. Each router in the Internet mainatins a routing table to keep track of the best path towards a destination. The routers read the destination IP address and succesively forward the packet to the next router on the best path. The last router on the path finally passes the IP packet to the destination host.

IP is a connectionless protocol, which means that there is no continuing connection between the end points that are communicating. Each packet that travels through the Internet is treated as an independent unit of data without any relation to any other unit of data. Because a message is divided into a number of IP packets, each packet can, if necessary, be sent by a different route across the Internet. Packets can arrive in a different order than the order that was used to send them. The Internet Protocol just delivers them. It's up to another protocol, the Transmission Control Protocol (TCP), the connection-oriented protocol that keeps track of the packet sequence in a message to put them back in the right order.

2.2 IPv4 and IPv6

The Internet Protocol has two versions that are actively used in today's Internet. These are IP version 4 (IPv4) and IP version 6 (IPv6).

2.2.1 IPv4

The Internet Protocol Version 4 (IPv4) is defined by IETF in RFC 791 [27]. IPv4 has proven to be robust, easily implemented, and interoperable. However, initial design of IPv4 did not anticipate the growth of internet and created many issues. Security requirements and routing flexibility were not defined properly in IPv4 [28]. Many applications available today that need additional features like as Quality of Service (QoS) [29]. The main limitations of IPv4 are given below.

• **Scarcity of IPv4 Addresses**: The IPv4 addressing system uses 32-bit address space. This 32-bit address space is further classified in A, B, and C classes. 32-bit address space allows maximum 4,294,967,296 IPv4 addresses, but the previous and current IPv4 address allocation practices limit the number of available public IPv4 addresses. Many addresses which are allocated to different organizations were not used and this created scarcity of IPv4 addresses.

• **Security Related Issues**: Communication over a public medium such as the Internet requires cryptographic services that protect the data from being viewed or modified in transit. Although a standard now exists for providing security for IPv4 packets, known as Internet Protocol security or IPSec. But IPSec is not built-in and optional in IPv4. Many IPSec implementations are proprietary.

• **Quality of service (QoS)**: Though IPv4 has Type of Service (TOS) field in its header, most implementations of TCP/IP as well as nearly all hardware that uses TCP/IP ignore this field and handles all the packets with the same priority. Payload identification is not possible when the IPv4 packet payload is encrypted. IPv4 Option headers, if implemented, are processed by every router in the path, resulting in the slowdown of the routing process and making it undesirable to implement optional features.

2.2.2 IPv6

The Internet Engineering Task Force (IETF) has developed a suite of protocols and standards known as IP version 6 (IPv6) [20] that successfully solved the growth problems as well as dealt with the long-term growth issues such as security, auto-configuration, real-time services, and transition [31]. IPv6 is designed to have minimal impact on upper- and lower-layer protocols and to avoid the random addition of new features. IPv6 has solved many problems of IPv4 and is superior to IPv4 in many aspects which are described below.

• **Large address space**: IPv4 has 32 bit (4-byte) address space, but IPv6 has 128-bit (16-byte) address space. The very large IPv6 address space supports a total of 2^{128} (3.4×10^{38}) addresses. This large address space allows a better, systematic, hierarchical allocation of addresses and efficient route aggregation.

• **New Packet Format and Header:** IPv6 specifies a new packet format that helps to minimize packet header processing by routers. This is achieved by moving both nonessential and optional fields to extension headers that are placed after the IPv6 header.

• **Integrated Internet Protocol Security (IPSec)**: Internet Protocol Security (IPSec) is a set of Internet standards that uses cryptographic security services to provide Confidentiality, Authentication, Data integrity. The support for IPSec was optional in IPv4. IPSec is an integral part of the base protocol suite in IPv6 and this support is mandatory in IPv6.

• **Extensibility:** The features of IPv6 can be extended by adding extension headers after IPv6 header. The size of IPv6 extension headers is constrained only by the size of the IPv6 packet, unlike 40 bytes of options of IPv4.

2.3 Mobile IPv4

Mobile IPv4 [1] is a protocol to ensure movement transparency to IPv4. Below is the terminology defined in the MIPv4 specification.

2.3.1 Terminology

Mobile Network Node (MNN)

A host with capabilities to move between different access networks, while keeping movement transparency to its upper layers and protocols.

Home Network

An MN usually resides when it is not moved to other networks.

Home Agent (HA)

A router which assists the movement of an MN, resides in home network.

Correspondent Node (CN)

A node in the Internet wishes to communicate with an MN.

Home Address (HoA)

An unchanging address allocated to an MN.

Care-of Address (CoA)

An address which is acquired by an MN on the visiting link.

Binding Update (BU)

A message is sent by the MN to its HA in order to inform the CoA.

2.3.2 Protocol Overview

Mobile IPv4 (MIPv4) [1] is the protocol by which Internet nodes can achieve seamless mobility. In MIPv4, a mobile node has a permanent home address (HoA) registered on a home network. When the mobile node is not on its home network, it notifies a router at the home network called the home agent (HA) to forward packets to its new acquired address called care-of address (CoA) at the foreign network. When the mobile node is on its home network, it sends and receives packets directly at its home address.

The MIPv4 protocol allows the Mobile Node (MN) to retain its HoA regardless of their point of attachment to the network. While the MN is roaming from one network to another network its CoA is changed. In this way, the CoA correctly identifies the mobile node's new point of attachment with respect to the network topology. In Mobile IPv4 the CoA management is achieved by an entity called Foreign Agent (FA). FA is a router located in the foreign network and configured to receive and forward the packets that are destined to the MN when the MN has a CoA from FA.

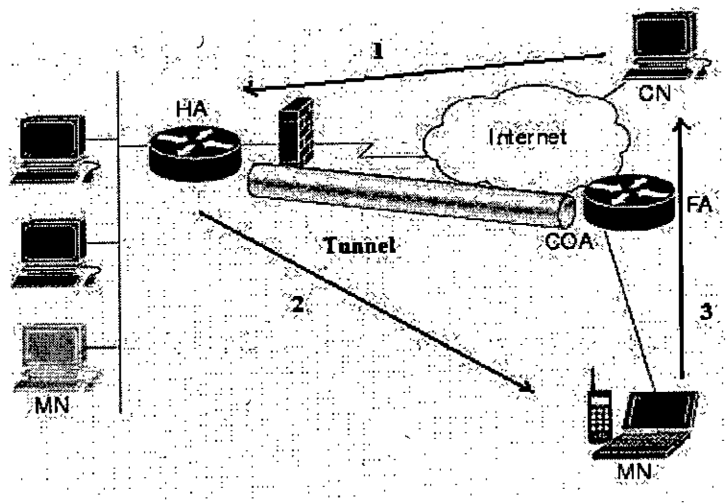


Figure 2.3: Architecture of Mobile IPv4

After getting attached with a foreign network MN obtains a new CoA from corresponding FA. This new CoA is registered with the HA by sending a binding update (BU) message. In this way, HA knows the current CoA of a MN in the current foreign network. Packets from a Correspondent Node (CN) destined to the MN is first intercepted by the HA. In order to deliver the packets from the home network to the MN's CoA, HA tunnels the packet to the FA, i.e., HA encapsulates the packet with HA as the source address and the FA as the destination address. After receiving an encapsulated packet, the FA decapsulates it to get the original packet and forwards it to the MN in its current CoA. MIPv4 packets from a CN to an MN must go through MN's HA and this creates a triangular routing path as shown in Figure 2.3. This triangular routing adds extra delay in packet delivery.

2.4 Mobile IPv6

Mobile IPv6 [2] is a protocol to ensure movement transparency to a single host. Terminologies used in MIPv6 are very much common with MIPv4 described in Section 2.3.1.

2.4.1 Protocol Overview

Mobile IPv6 allows MN to move around between different links on the Internet while being reachable regardless of its attachment point. Without Mobile IPv6, established sessions are terminated and the nodes become unreachable after a handoff.

Mobile IPv6 provides a HoA to each MN, allocated from the home link of its HA. When the MN is connected to the home link, it is reachable through this address. When the MN is away from home, it becomes reachable via a CoA configured with the prefix advertised on the foreign link. Since IP addresses must be topologically correct, the MN uses this CoA while away from home. A packet destined to the HoA of a MN is first routed to its HA and the HA forwards the packet to the CoA. MN can thus maintain reachability with a unique address even after movements. Figure 2.4 shows the overview of Mobile IPv6.

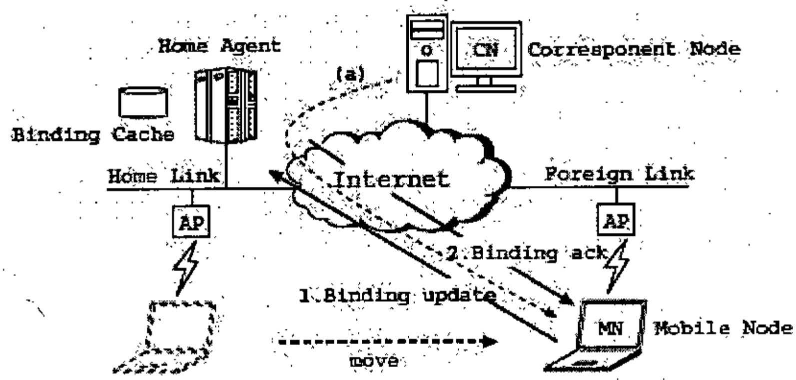


Figure 2.4: Overview of Mobile IPv6

A MN registers a binding between its HoA and CoA with a HA to have packets forwarded by HA accordingly. Whenever the MN moves to a different access network, it informs the HA of its new CoA configured on the link by sending a BU message (1 in Figure 2.4). When the HA receives this message, it returns a Binding Acknowledgement (Binding Ack) to indicate the status of the registration (2 in Figure 2.4). If successful, the HA forwards packets from the CN to this CoA (a in Figure 2.4). Packets from the MN are tunneled [19] to its HA, where the HA forwards the packet to the CN.

2.4.2 Binding Cache Management

A HA must maintain a database to manage the MN that it is serving. This database is called the Binding Cache. An example of the entry in the Binding Cache is shown in Table 2.1.

HoA	CoA	Lifetime
2001:2::2	2001:1::EU164	600

Table 2.1: Entry in the Binding Cache

Each CoA is bound to an unchanging HoA. A lifetime value is also maintained to delete entries when expired. The entries however are not limited to those mentioned in Table 2.1.

2.4.3 Route Optimization Mechanism in Mobile IPv6

Since packets are forwarded via the HA, the path can become suboptimal depending on the location of the MN, the CN and the HA. Such suboptimal path is not preferred because it brings problems such as packet delay, waste of network resources, and causes heavy load at the HA. As a solution to this problem, Mobile IPv6 introduced a mechanism known as route optimization to provide a direct path between the MN and CN. Figure 2.5 shows the details of this mechanism.

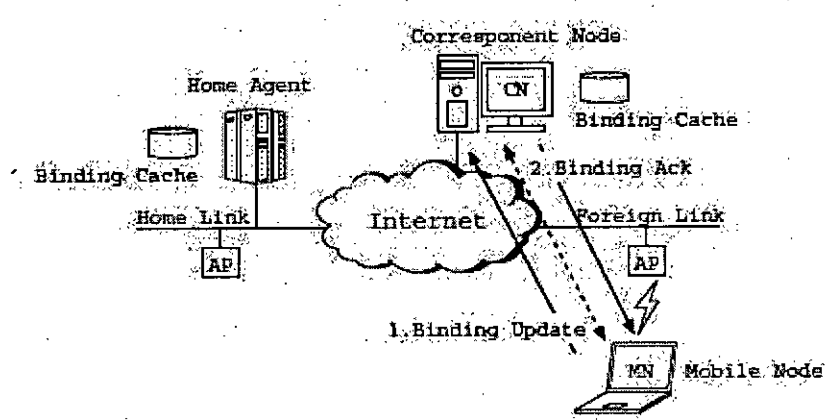


Figure 2.5: Route Optimization in Mobile IPv6

When the MN receives a packet forwarded from its HA, it triggers to perform route optimization with the CN. MN first proceeds with the Return Routability Procedure defined in the specification [2] and then sends a BU message to the CN (1 in Figure 2.5). The Return Routability Procedure enables the CN to obtain some reasonable assurance that the MN is in fact addressable at its claimed CoA as well as at its HoA. Only with this assurance, the CN is able to accept BU message from the mobile node which would then instruct the CN to direct that mobile node's data traffic to its claimed CoA. When the CN receives the BU message, it returns a Binding Ack to the MN (2 in Figure 2.5). After a successful establishment of the binding between MN and CN, packets are forwarded directly using the optimal path with the newly defined mobility headers and routing headers. The CN must have the correspondent capabilities such as management of the Binding Cache to perform route optimization.

2.5 Network Mobility

The NEMO Basic Support protocol is a solution to provide network mobility support in IPv6 [20]. The protocol is currently being standardized at the NEtwork MObility Working Group (NEMO WG) of IETF. The WG is taking a step wise approach to standardize the basic functions needed to achieve network mobility. The protocol is designed based on the experiences gained from standardization of Mobile IPv6, and therefore many of the functionalities are extensions of Mobile IPv6.

2.5.1 Terminology

Below is the terminology used in network mobility and defined in Network Mobility Support Terminology [4] and Mobility Related Terminology [21]. Some of the terminologies used are the same with those of MIPv4 and MIPv6 described in Section 2.3.1 and therefore are omitted in this section.

Mobile Network (NEMO)

A set of hosts and routers which moves as an entity, between different attachment points in the Internet.

Mobile Router (MR)

The router within a NEMO that connects the associated network to the Internet.

Mobile Network Node (MNN)

A host which is attached with the MR.

Access Router (AR)

A router through which the MR connects the mobile network to the Internet.

Home Access Router (HAR)

In the home link, an MR is attached with a Home Access Router (HAR) to connect itself to the Internet.

Foreign Access Router (FAR)

A router through which the MR connects the mobile network to the Internet after moving to a foreign link.

Home Agent (HA)

A NEMO entity that resides in the HAR to work on behalf of an MR while it is away from the home network. HA in NEMO is different from the HA in both MIPv4 and MIPv6. HA in MIPv4 and MIPv6, works on behalf of a mobile node, whereas, HA in NEMO works on behalf of a mobile router.

Nested Mobile Network

A state in which a MR attaches itself to another mobile network in a hierarchical fashion.

Local Fixed Node (LFN)

These nodes do not move with respect to the mobile network.

Local Mobile Node (LMN)

These nodes usually reside in the mobile network but can move to other networks.

Visiting Mobile Node (VMN)

These nodes belong to another network but are currently attached to the mobile network.

2.6 NEMO Basic Support

In Basic NEMO, a packet from a CN always reaches the HAR first. If the MR is in the home link, its HAR forwards the packet to the MR normally so that the MR can route the packet to the destination MNN.

An MR can move from its home network to a foreign network along with all the hosts associated with it. When a NEMO is away from its home network, an MR acquires a temporary address from its FAR which is called Care-of Address (CoA). A Binding Update (BU) message is then sent by the MR to its HA in order to inform it the new CoA. The HA maps the new CoA with MR's HoA. If an MR is in the foreign link when a packet comes from a CN, corresponding HAR cannot forward the packet to the MR normally. In this situation, the packet is intercepted by the HA of the MR. The HA then forwards the packet to the new CoA using an IP tunnel between the HA and the MR. The HA encapsulates the packet with HA address as the source address and the MR's CoA as the destination address. Then, the HA sends the encapsulated packet to MR's CoA through the HA-MR tunnel. Figure 2.6 shows the structure of NEMO basic support protocol.

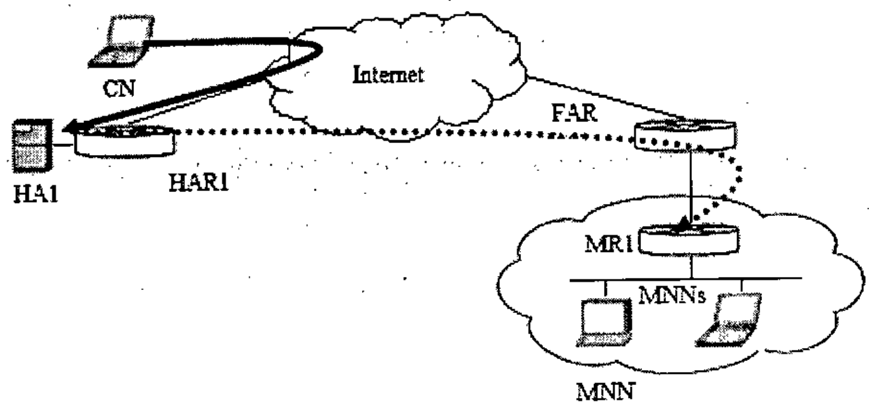


Figure 2.6: NEMO Basic Support Protocol

After receiving the encapsulated packet from the HA, the MR decapsulates it to get the original packet from the CN back. The MR routes the original packet to the destination MNN. Now, every packet coming to the MR from the CN is tunneled by the HA of MR as shown in Figure 2.7.

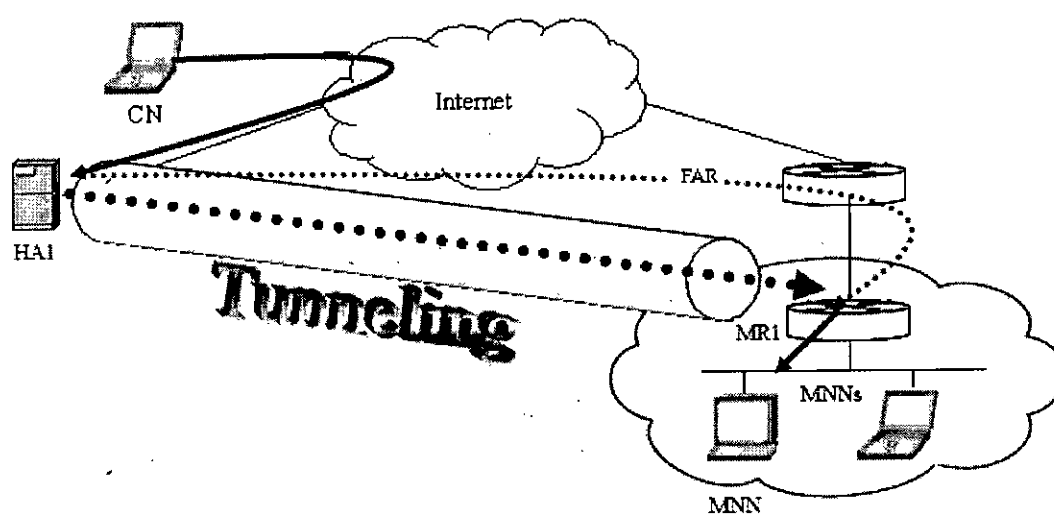


Figure 2.7: Tunneling in NEMO basic support protocol

2.7 Nested NEMO

NEMO Basic support also supports nesting of the MRs. In nested NEMO, several MRs join together in a hierarchical manner and form a tree or nest. Here, top level MR works as the root of the tree and is called the root-MR. In order to describe how tunneling and encapsulation occur in nested-NEMO let's consider a second mobile router MR2 and its home access router HAR2. If MR2 moves from HAR2 and gets access through MR1, nesting occurs. MR2 acquires a care-of-address CoA2 from MR1 and sends a BU message to its home agent HA2 informing this CoA2. CoA2 of MR2 is associated with MR1 and default location of MR1 is HAR1. HA2 now assumes that MR2 is now associated with HAR1.

When a CN sends a packet to an MNN of MR2, HA2 first receives it (1 in Figure 2.8). Since MR2 moves to CoA2, HA2 encapsulates the packet with HA2 address as the source address and CoA2 as the destination address. HA2 forwards the encapsulated packet by creating a bidirectional tunnel between HA2 and MR2. As CoA2 is an address accessed from MR1 (of HAR1), the encapsulated packet is taking a route towards HAR1 (2 in Figure 2.8).

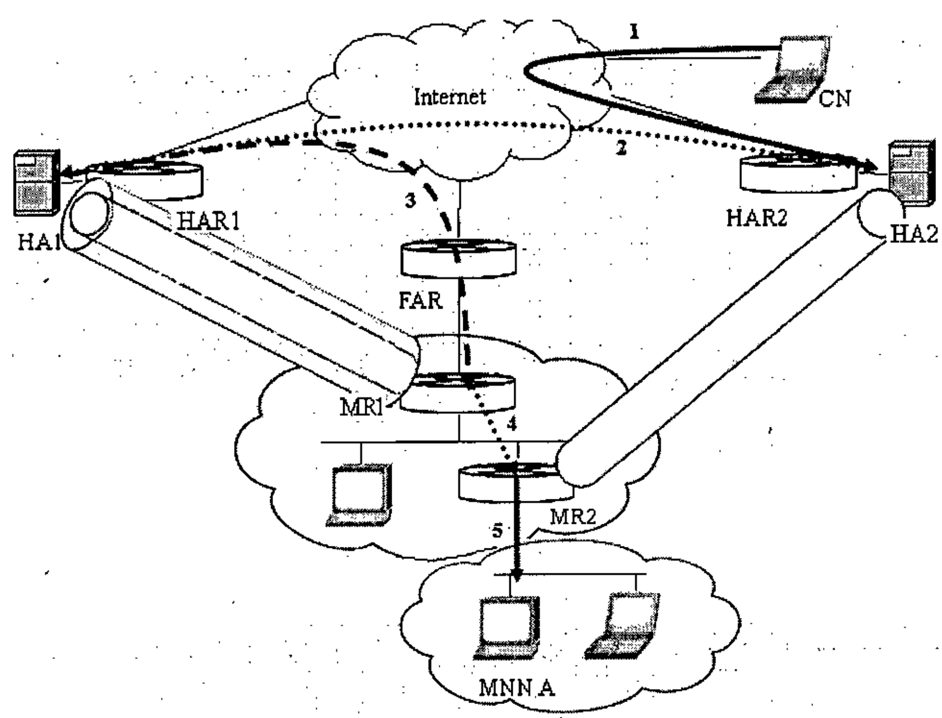


Figure 2.8: Two level tunneling in two level nested NEMO

HA1 receives the encapsulated packet through HAR1. Since MR1 has also moved to CoA1, HA1 encapsulates the packet again and forwards it to CoA1 by creating a second level tunnel between HA1 and MR1 (3 in Figure 2.8). Above two level tunneling and encapsulations have been demonstrated in Figure 2.8 and 2.9 respectively.

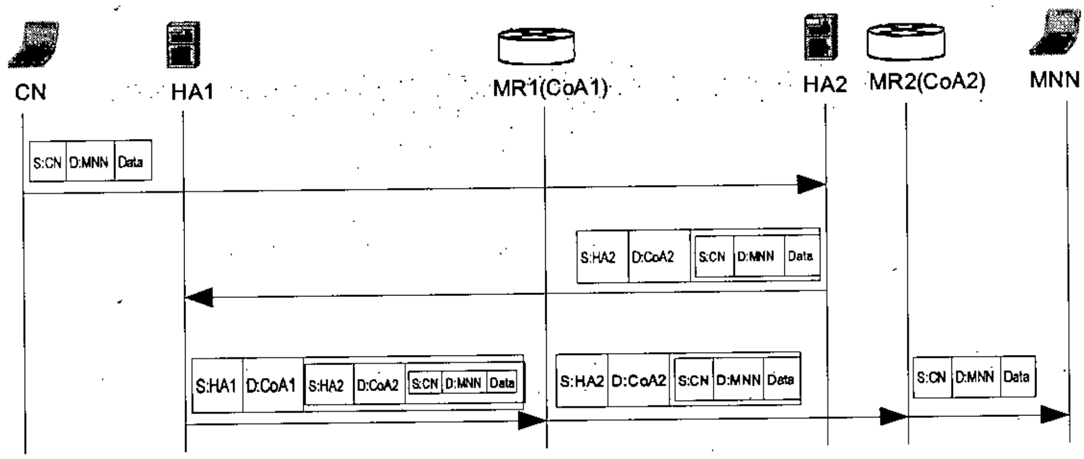


Figure 2.9: Operation of basic-NEMO for two level nested NEMO

MR1 receives the packet at CoA1 and decapsulates the second level encapsulation and forwards the packet, still with the first level encapsulation, to CoA2 (4 in Figure 2.8). MR2 receives the forwarded packet at CoA2 and decapsulates the first level encapsulation in order to get the original packet sent by CN back and routes the original packet to the destination MNN (5 in Figure 2.8).

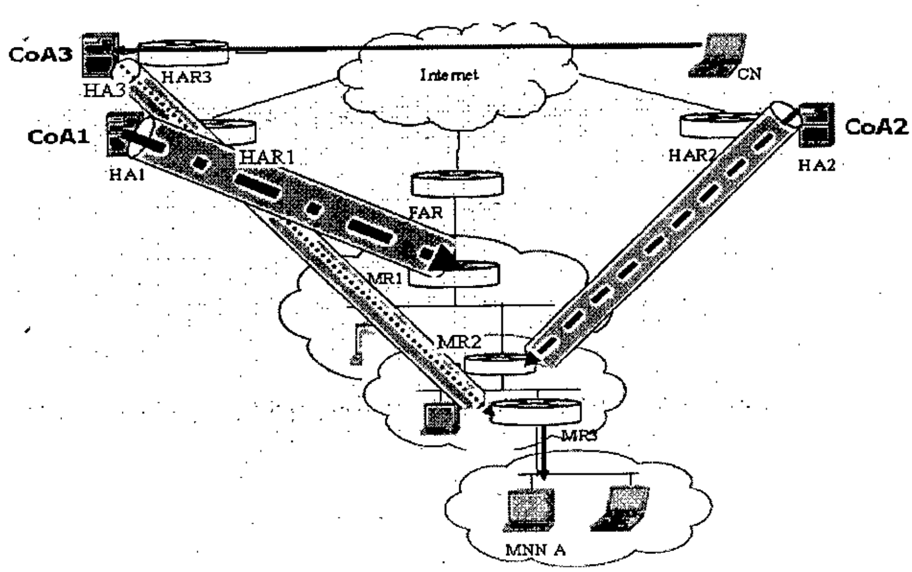


Figure 2.10: Three level tunneling in three level nested NEMO

Two level tunneling occurs in two level nesting. Now, if a third mobile router MR3 arrives from HAR3 and gets associated with MR2, situation worsens, three level of tunneling occurs which has been presented in Figure 2.10.

If a CN sends a packet to an MNN associated with MR3, the packet traverses 7 route segments as shown in Figure 2.11 before reaching the MNN.

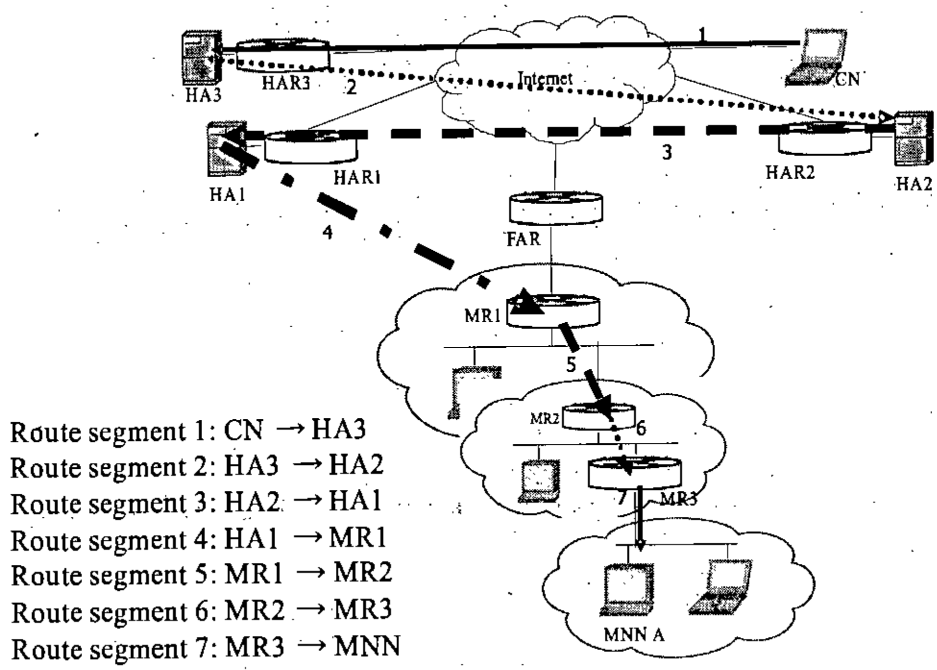


Figure 2.11: Pin ball routing in nested NEMO

Thus, for three level of tunneling the packet traverses 2*3+1 route segments. Similarly, if the CN were also behind three level tunnels, the packet needs to traverse 2*(3+3)+1 route segments. In general, 2(N + M) + 1 route segments will be traversed by a packet in a nested NEMO if both the MNN and the CN are behind N and M level tunnels respectively.

In NEMO basic support, every packet from a CN is tunneled by every HA in the hierarchy. Tunneling creates sub-optimal routing or pin ball routing. This route sub-optimality problem worsens as the number of nesting level grows. As an effect of tunneling, network throughput decreases, end-to-end network delay increases, and the network overhead increases.

Multiple encapsulations in nested NEMO also cause delayed packet delivery dividing the original encapsulated packet into multiple packets if the packet size of the original encapsulated packet is beyond the link-MTU. When a HA manages several MRs, the HA of the MR will be overloaded by MNN's packets when many MNNs exist. Susceptibility to link failure and the instability of network connection are also indirect consequences of route sub-optimality. For these reasons route optimization is important in nested NEMO.

2.8 Summary

In this Chapter, we have discussed the Internet Protocol along with its most popular versions IPv4 and IPv6. We have covered the limitations of IPv4 and relative superiority of IPv6 over IPv4. Both IPv4 and IPv6 provide host mobility support through MIPv4 and MIPv6 respectively. We have presented the NEMO basic support protocol, an extension from MIPv6, to support network mobility. We have described NEMO and nested NEMO in details with examples and their limitations. We saw that the sub-optimal routing is applied due to tunneling/encapsulation in basic-NEMO. To overcome these limitations, many research works have been conducted. In the next chapter, we will discuss those research works.

Chapter 3

Related Works

Route optimization is one of the major challenges in both nested and non-nested NEMO. Figure 2.11 in Chapter 2 gives an example of this problem. Currently route optimization schemes in NEMO have been discussed at the NEMO working group in the IETF and at various conferences. Some of the research works have also been discussed in survey paper [71] and [72]. In recent years, numerous solutions have been proposed to tackle route sub-optimality in NEMO networks. Many solutions only focus on non-nested NEMO. Examples of these schemes include the optimized route cache management protocol (ORC) [6] and the Global HA to HA protocol [7]. This Chapter, however, deals with schemes specifically for enhancing the nested NEMO scenario.

3.1 CUIP

Cellular Universal IP (CUIP) [8] [9], a mobility scheme, proposes a hierarchical network architecture using universal IPv6 addressing to eliminate tunneling. The concept of universal addressing is borrowed from the traditional mobile phone communication, which allows an MNN to be addressed anywhere with a single phone number. CUIP also allows an MR as well as an MNN to be addressed and located universally by a single IPv6 address. An MR does not need to acquire a CoA when traveling to a foreign network and therefore does not need to register the CoA with the home network for its movements. Network architecture of CUIP is shown in Figure 3.1 quoted from [8].

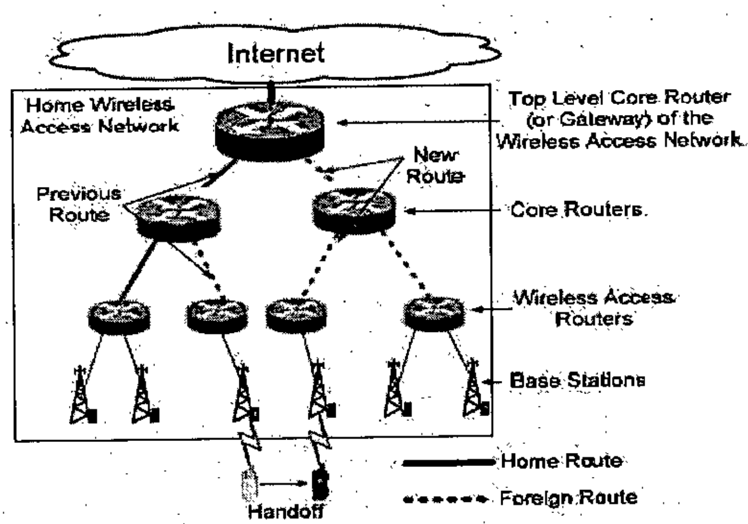


Figure 3.1: Network Architecture of CUIP

CUIP organizes all the MRs in a hierarchy. There is a root MR that first divides a network into some sub networks. Each sub network can be further divided into smaller networks. For this reason, in CUIP, the address space covered by an MR is always the subset of the address space covered by its upper level MR.

In a hierarchical network structure, all handoff scenarios must consist of exactly one cross-over router (COR) between the previous route and the new route, where the COR is defined as the router at the forking point of the two routes. After handoff, only the routers on the new route and the previous route, up to the COR of this handoff (home or new), need to be updated by CUIP. The handoff is therefore transparent to the rest of the network beyond the COR, including the Internet and the CN. The concept of COR in CUIP has been shown in Figure 3.2 quoted from [9]. In addition, the handoff is completed as soon as the new route is updated. The routers to be updated for handoff are along the data path. Therefore, signaling can be piggybacked on outgoing data packets for more efficient handoff, particularly for real-time applications with continuous stream of data packets. The signaling delay is therefore proportional to the time interval between two consecutive data packets. That is, the signaling delay scales naturally with the blackout delay requirements of the data stream.

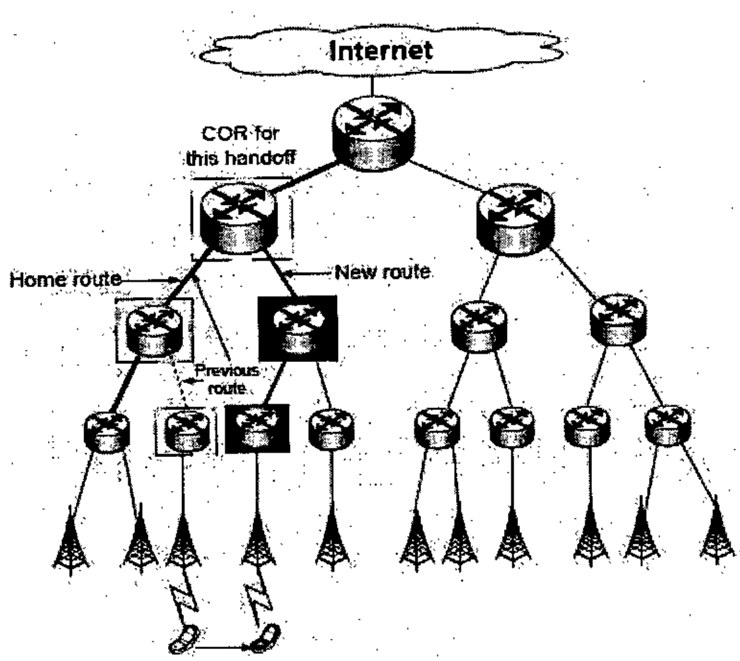


Figure 3.2: Concept of COR in CUIP

Tunneling is not required because of the use of universally unique IP address before and after the movement of an MNN or MR. Furthermore, in CUIP, the work load of the handoff operation is distributed throughout the entire network, and thus there will be no single-point-of-failure. However, CUIP is not effective in the Internet, because of its non-hierarchical architecture. A radical change is necessary in the present Internet infrastructure to make it hierarchical in order to implement CUIP, which is quite infeasible.

3.2 MANET

In Mobile Ad-hoc Network (MANET) [10], a collection of nodes, connected by wireless links, form an arbitrary, dynamic graph. Two classes of ad-hoc routing protocols have been proposed: reactive and proactive.

Reactive protocols, such as DSR [11] and AODV [12], discover and maintain routes only when they are required by using a request reply flooding cycle.

The Dynamic Source Routing protocol (DSR) is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring, without the need for any existing network infrastructure or administration. The protocol is composed of the two main mechanisms of "Route Discovery" and "Route Maintenance", which work together to allow nodes to discover and maintain routes to arbitrary destinations in the ad hoc network. All aspects of the protocol operate entirely on demand, allowing the routing packet overhead of DSR to scale automatically to only what is needed to react to changes in the routes currently in use.

The Ad hoc On-Demand Distance Vector (AODV) routing protocol is intended for use by mobile nodes in an ad hoc network. It offers quick adaptation to dynamic link conditions, low processing and memory overhead, low network utilization, and determines routes to destinations within the ad hoc network. AODV based route optimization is applied in [65].

On the other hand, proactive protocols, including OLSR [13][35], ONEMO [16], NNRO [67] and DESMERO [14] always maintain routes to each destination through periodic advertisements.

Optimized Link State Routing (OLSR) protocol for mobile ad hoc networks is an optimization of the classical link state algorithm tailored to the requirements of a mobile wireless LAN. The key concept used in the protocol is multipoint relays (MPRs). MPRs are selected nodes which forward broadcast messages during the flooding process. This technique substantially reduces the message overhead as compared to a classical flooding mechanism, where every node retransmits each message when it receives the first copy of the message. In OLSR, link state information is generated only by the nodes elected as MPRs. A second optimization is achieved by minimizing the number of control messages flooded in the network. As a third optimization, an MPR node may chose to report only links between itself and its MPR selectors. Hence, as contrary to the classic link state algorithm, partial link state information is distributed in the network. This information is then used for route calculation. OLSR provides optimal routes (in terms of number of hops). The protocol is particularly suitable for large and dense networks as the technique of MPRs works well in this context.

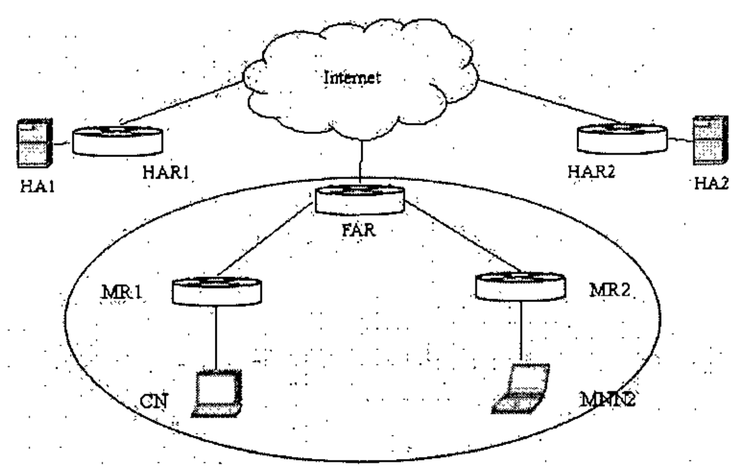


Figure 3.3: Network Architecture of OLSR Route Optimization

Ryuji Wakikawa et. al. in [15] and [16] proposed to use OLSR ad-hoc routing protocol in order to make an intelligent forwarding decision by an MR in a nested NEMO if the destination is found to be local. In this case, a route to the destination can be established through the ad-hoc network constructed by the source and the destination MRs. The use of ad-hoc network routing protocol bypasses the HA from the routing path, i.e., eliminates the tunnel between the MR and HA. Alternatively, if the destination is not local, data will be routed through the HA, where basic NEMO tunneling and encapsulation will take effect.

3.3 S-RO

In order to remove tunneling and encapsulation, network prefix binding updates (NPBU) of nested NEMO are used in research work S-RO [17]. When an MR in NEMO receives an encapsulated packet, it removes the encapsulation and sends a binding update to the original packet sender. The original sender address can be obtained from the source address of the decapsulated packet. In case of nested NEMO, a sender might be an HA of an upper level MR. In the binding update message, the MR sends its CoA in the foreign network. The sender node caches the CoA and uses it as the loose source route to deliver the future packets to the destination avoiding the tunnel. Loose source routing is used to route the internet datagram based on information supplied by the source. Functionality provided by these options can be exploited in order to perform remote network discovery, to bypass firewalls, and to achieve packet amplification for the purposes of generating denial-of-service traffic.

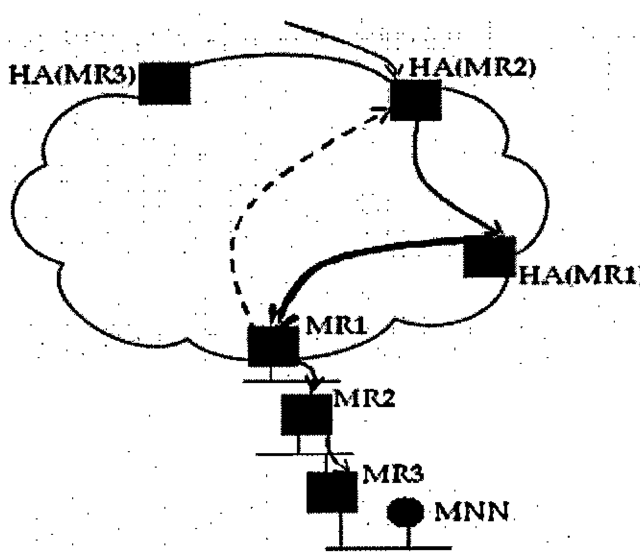


Figure 3.4: Architecture of S-RO

In loose source routing, the Routing header contains a list of one or more intermediate nodes to be visited on the way to a packet's destination. All routing headers start with a 32-bit block consisting of four 8-bit fields, followed by routing data specific to a given routing type. The source node does not place the ultimate destination address in the IPv6 header. Instead, that address is the last address listed in the Routing header, and the IPv6 header contains the destination address of the first desired router on the path. The Routing header will not be examined until the packet reaches the node identified in the IPv6 header. At that point, the IPv6 and Routing header contents are updated and the packet is forwarded. The update consists of placing the next address to be visited in the IPv6 header and decrementing the Segmentations Left field in the Routing header.

In a nested NEMO, a CN obtains the CoA of each intermediate MR in the nest successively after repeating the above mentioned steps. The number of repetitions depends on the number of levels in the nest. Finally, CN sends packets to the destination in the foreign network using all the CoAs as the loose source route avoiding multi level tunneling and encapsulation. However, too many BU message transmissions are needed in this scheme to avoid all the levels of tunneling and encapsulations. And too many CoAs are needed to be used as the loose source routes after removing the tunnels. This increases the packet header size significantly.

Like S-RO, Path Control Header (PCH) is used in [62], where the CoA of the MR is inserted into packets by the corresponding HA when a packet travels from an MNN to a CN. After passing through all the HAs, the header of the packet contains the CoAs of all MRs in the hierarchy. Path control is achieved by a specific router. They propose to use a specific router in the CN side that can be an access router or any router through which CN connects to the Internet. This router may be called correspondent router (CR). CN will not involve in route optimization process. CR will cache all the CoAs. When CN sends packet to an MNN, packet will be intercepted by the CR and CR will insert the CoAs into the packet header. Then the CR will create a tunnel between CR-MR. Here MR is the top MR. Therefore, all the HAs are bypassed in this scheme. Instead of HA-MR tunnel, this scheme uses CR-MR tunnel that is optimized compare to HA-MR tunnel.

In xMIPv6 [63], MRs send BUs containing CoAs of MRs above it to their corresponding HAs. An MR obtains CoAs of MRs above it from the MR to which it is attached through router advertisement (RA). They introduce a new nested care-of address option (NCO) in the packet header during RA. NCO is used to carry sequence of MR's CoAs in the header. Except additional NCO option in packet header in this scheme, optimization process and packet routing are exactly the same as S-RO.

3.4 ROTIO

To get optimized route in nested mobile networks, Tree Information Option (TIO) [41] is used in research work named Route Optimization using Tree Information Option (ROTIO) in [26]. TIO is based on Neighbor Discovery protocol for IPv6 [40]. IPv6 nodes on the same link use Neighbor Discovery to discover each other's presence, to determine each other's link-layer addresses, to find routers, and to maintain reach-ability information about the paths to the active neighbors.

In a nested mobile network, multiple MRs form a tree like structure in which the top MR is called the top-level mobile router (TLMR). Regular router advertisement (RA) message are sent from each MR in the tree. RA message contains TIO option and xTIO sub-option as shown in Figure 3.5 quoted from [26]. When an MR forwards RA message, it appends its CoA in the xTIO sub-option. If an MR receives an RA message without the xTIO option, the MR (which is the TLMR) detects that it is positioned at the top level of the entire mobile network and inserts the TIO option with its HoA into the TreeID field. If an MR receives the RA message with this TIO option, the MR can deduce that it is not the TLMR. Each MR appends its CoA into the xTIO option and propagates the RA message downwards. By listening to this RA message, MRs can maintain an MR list, that stores the list of CoAs of all the ancestor MRs (for the TLMR, its HoA is stored).

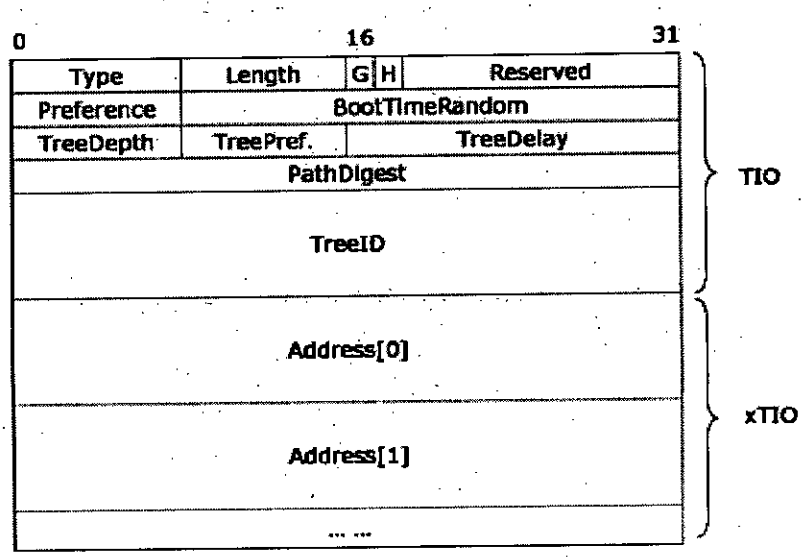


Figure 3.5: Tree Information Option and xTIO sub-option

In ROTIO scheme, each MR in the nested mobile network sends two BU messages: one to the MR's HA and the other to the TLMR. The first BU message contains the TLMR's HoA. MR's HA receives the BU message from the MR and maps MR's HoA with the TLMR's HoA. The second BU message contains routing information between the issuing MR and the TLMR. This BU message contains the HoA and the CoA of MR, and the list of all the MR's CoA between the TLMR and issuing MR. TLMR maps the list of all the MR's CoA with the HoA of the issuing MR.

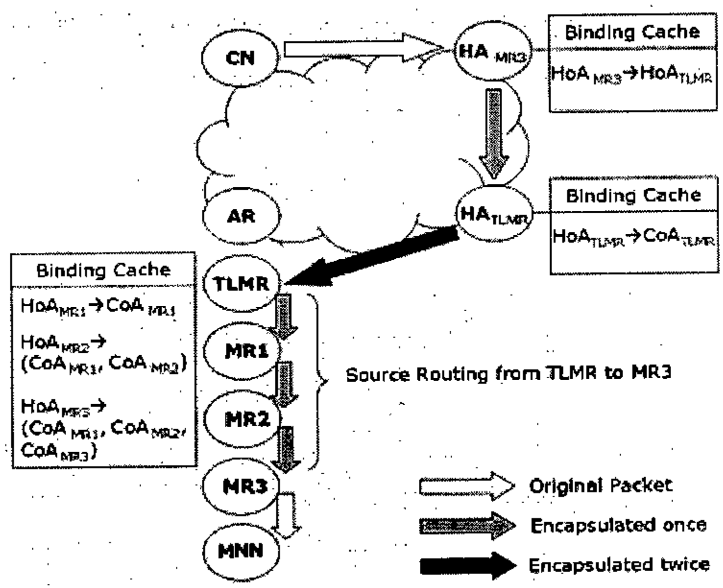


Figure 3.6: Routing a packet from CN to MNN in ROTIO

Packet transmission in ROTIO scheme has been shown in Figure 3.6 quoted from [26]. A CN sends a packet destined for an MNN of MR3. Packet is received by MR3's HA. MR3's HA encapsulates the packet with itself as a source address and TLMR's HA as the destination address and forwards the packet by creating a tunnel between MR3's HA and TLMR's HA. TLMR's HA will receive an encapsulated packet and will encapsulate the packet again with itself as the source address and TLMR's CoA as the destination address. TLMR's HA will forward the packet to the TLMR by creating a second tunnel between TLMR's HoA and TLMR's CoA. TLMR will receive the double encapsulated packet from its HA in its foreign link. It will decapsulate the second encapsulation and will forward the single encapsulated packet towards MR3 using the list of the CoAs of MRs in the tree as source routing. MR3 will receive an encapsulated packet, it will decapsulate the packet and will forward the original packet to the MNN. Therefore, a packet from a CN only needs to visit two transit nodes (the HA of the MR and the TLMR). If the level of nesting increases, number of tunneling/encapsulation isn't increasing. Only two level of tunneling exists, regardless the number of nesting levels in the mobile networks.

ROTIO scheme seems similar to our scheme, however, in this scheme, MR sends two BU messages; one to the MR's HA and other to the TLMR's HA where our scheme sends only one BU message to its HA. Because of two CoAs, ROTIO needs to create two tunnels by the MR's HA and TLMR's HA, whereas our scheme doesn't require any tunneling by any HA. In ROTIO, router advertisement is necessary, which is not allowed in basic-NEMO.

For higher nesting levels ROTIO scheme has higher header overhead that consumes more bandwidth which is scarce in wireless environment. Moreover, it can't eliminate the tunnels completely.

3.5 R-BU

Recursive Binding Update (R-BU) [22] scheme is proposed to search Binding Cache and send Binding Update messages recursively to offer an optimal path. The solution enables Mobile IPv6 hosts to perform route optimization in nested mobile networks. However, it has a drawback, constructing the optimal route requires multiple Binding Updates where the number increasing as the level of the nesting increases.

3.6 RRH

The Reverse Routing Header (RRH) [23][32] provides route optimization support for nested mobile networks, however, it can sometimes be suboptimal when the correspondent node is also nested. For example, if both end nodes are located behind two distinct nests, the path includes two HA which can still cause crucial delay in packets.

3.7 PD

The Prefix Delegation (PD) [24] [34] is proposed as a solution to enable Mobile IPv6 hosts to perform its route optimization when attached behind MRs. The use of PD is also proposed by [25], [33] and [36]. Prefix of the foreign network is delegated inside the mobile network. Mobile IPv6 Route Optimization for NEMO (MIRON) [37][44] was proposed to provide mobility support to a mobile node in nested case based on MIPv6. NERON [38] and EMIP [39] were also proposed based on MIRON. Some variations of PD are also used in [42][43][46] and [47].

In these approaches, each MR in a nested mobile network is delegated a Mobile Network Prefix (MNP) from the AR using DHCP Prefix Delegation [45]. Each MR also auto-configures its CoA from this delegated prefix. In this way, the CoAs are all formed from an aggregated address space starting from the AR. This is used to eliminate the multiple tunnels caused by nesting of mobile nodes. A MNN with MIPv6 functionality may also auto-configure its CoA from this delegated prefix, and use standard MIPv6 mechanisms to bind its HoA to this CoA.

Delegation approach is simple but exerts additional load on the infrastructure due to higher signaling. How to efficiently assign a subset of MNP to child MR could be an issue because MNNs may dynamically join and leave with an unpredictable pattern. In addition, a change in the point of attachment of the top MR will also require every nested MR (and possibly Visiting Mobile Nodes) to change their CoA and delegated prefixes. These will cause a burst of BU messages.

However, in order for the MIPv6 enabled nodes to perform their route optimization, not only the MRs but also the access routers must support the PD protocols. As it is impossible to replace all existing access routers, the solution is hard to deploy.

3.8 Hierarchical

MR/MNN joins in foreign link in a hierarchical manner in [49][50] and form a tree like structure like ROTIO and ONEMO discussed in Section 3.4 and Section 3.2. These are not hierarchical network, but joins in hierarchical manner in foreign link. In the hierarchical class, a packet rather than traveling through all the HAs, reaches the foreign network either from MNN's HA (first HA) or traveling only through the HA of the MNN and TLMR. Unlike delegation-based approach, an MR does not send its CoA to CNs. MR sends TLMR's CoA or HoA to HA. CNs use MNN's HoA to send packets to an MNN.

Packets, sent by a CN to an MNN, reach MNN's HA that tunnels the packets to TLMR's CoA or HoA. Packets, tunneled to CoA, directly reach the foreign network, where as packets, tunneled to HoA, reach TLMR's HA that tunnels packets to TLMR. On reaching TLMR, packets are routed to MNN by successive MRs that maintain a list of CoA of MRs mapping with HoA of MNN.

The schemes in this class mainly differ from in the use of TLMR's CoA or HoA for tunneling, techniques to convey TLMR's address to MRs, and routing of packets inside mobile network resulting in differences in signaling, memory requirement and degree of RO. Moreover, depending on the use of HoA or CoA of the TLMR, the number of tunnels used for communication differs among the schemes; the number of tunnels affects the degree of RO and header overhead. These schemes have the disadvantage of packets going through one or two tunnels, resulting in near optimal route and header overhead.

RO for nested mobile network in local mobility domain using local mobility anchors or LRO [48] uses a prefix that is advertised to all MRs through extended RA. MRs obtain CoA from the prefix, and send BU to its HA. Another BU is sent to Local Mobility Anchor (LMA) containing entries such as CoA, HoA, MRs home prefix and address of HA; therefore, LMA performs location management along with HA. A packet, sent from CN to Local Fixed Node (LFN), reaches LFN's HA that tunnels the packet to MR. The packet reaches the LMA that forwards the packet to MR through intermediate MRs and routers that already have all the MR's CoAs and HoAs. Therefore, the scheme can provide a near optimal way but involves one tunneling in all cases.

In the research works [49], [50] and [66] like ONEMO, MRs obtain the prefix of the foreign network through extended RA, and send the prefix (through BU) to the Mapping Agent (MAs) which acts (e.g. performs location management) like the HA. MAs intercept the packets that are sent by CN to MNN, replace the prefix of the destination address with the prefix of the foreign network, and forward the packets to the MNN. Unlike other schemes in this class, packets reach TLMR through MA (therefore, near optimal route). TLMR forwards the packet inside the mobile network after restoring the prefix of the destination address to MNN's prefix. The scheme requires increased signaling to update all MAs. Similar approach is used in research works RIPng [51] [53], HMNR[52], ROAD[55] and HMSRO [56] [54] and require a single tunnel only. Moreover, memory requirement is high due to TLMR's tracking of all the MNN's prefix to forward packets inside the mobile network.

Optimization using Prefix Information Option (ROPIO) is proposed by [58], TLMR's prefix and CoA are advertised (using PIO) to nested MRs. Nested MRs send one BU message containing its CoA to TLMR, and another containing TLMR'S CoA to HA. Thus, HA and TLMR in combination keeps track of MR's location. Packets sent from CN reaches HA that tunnels packets to TLMR. TLMR decapsulates and tunnels the packet to the nested MR.

In Hierarchical Mobile Network Binding (HMNB) [57], MRs send TLMR's HoA (instead of CoA) to respective HAs. Thus, MRs don't need to send any BU when the TLMR changes network, resulting in less signaling. Disadvantage of this scheme is packets traversal through two tunnels. The scheme in [59] proposes similar approach with one additional tunneling.

3.9 Host Identity Protocol

Host Identity Protocol (HIP) [60] supports mobility for hosts, and is used for NEMO in the scheme proposed by [61]. In HIP, each host uses a unique address at upper layers, and location changes are managed transparently at HIP or lower layers. At the start of communication in HIP, hosts (one may be an MNN) establish a key that is used for location update. Basic principle of HIP-based NEMO is the use of the key to authorize MR to perform location update on behalf of MNNs. Authorization takes place when an MNN joins the mobile network; in nested NEMO, authorization is performed at various levels and requires high signaling and high memory. Major disadvantages of this scheme are difficulty in wide deployment due to the requirement of HIP in hosts,

3.10 Wide-Area IP Network Mobility

Wide-Area IP Network Mobility (WINMO) [68] uses Border Gateway Protocol (BGP) [64] for network mobility, where the AR, upon attachment of a mobile network, initiates a BGP update announcing the prefix of the mobile network in the Internet. But this may result large routing tables and large number of update messages because of the movement of a large number of mobile networks.

3.11 Multiple HA-based RO

Multiple P2P connected HA-based RO [69] proposes deploying multiple HAs that know each other's information using P2P [70]. A mobile network has a home HA; but can register with any HA to meet certain performance criteria such as a limit for round trip time. To find a closer HA, an MR sends a special BU to its home HA that responds with a list of HAs closer to current location of the mobile network in terms of the performance criteria. MR selects an HA, obtains a HoA, and registers with the selected HA. After registration, HA initiates a BGP update among routers within the network to install the mapping of HoA to CoA. These routers tunnel the packet to the mobile networks.

3.12 Summary

In this Chapter, We have presented several route optimization techniques for nested NEMO such as CUIP, local ad-hoc routing based optimization, S-RO, ROTIO. Many other variants of route optimization schemes, such as RRH, PD, PCH, BGP, hierarchical etc. have also been presented. Some of them provide route optimization for simple NEMO only and some works can provide partial route optimization for nested NEMO. Some proposals are limited to intra domain routing only or not applicable to a regular non-hierarchical network. Some of them need to transmit too many BU messages or packet transmissions before getting optimal route and increase header overhead. For this reason, a globally efficient route optimization technique, which will be able to eliminate tunneling, in NEMO and nested NEMO, applicable to hierarchical/non-hierarchical network, effective for both intra and inter domain routing, and requiring minimum number of packet transmissions to provide optimize route, is still a research issue. In the next chapter, we will present such a route optimization technique.

Chapter 4

Proposed Route Optimization Scheme for nested-NEMO

4.1 Introduction

In this Chapter, we will present our proposed Route Optimization scheme. We will describe the network architecture of the scheme in Section 4.2 for NEMO and nested-NEMO. In Section 4.3, we will describe our proposed optimization technique with routing table structure, optimization signaling and packet flow in detail.

4.2 Network Architecture

In our proposed scheme, we assume a NEMO like the basic-NEMO comprised of some mobile nodes or MNNs and a mobile router or MR. Like the basic-NEMO, our NEMO gets access to the Internet through the MR and a home access router or HAR when it resides in its home location. MR gets a home address or HoA from its HAR. An MNN in our NEMO is accessible from the Internet through its MR's HoA. Our NEMO can move from its home network to a foreign network as a whole with its MR and all of its associated MNNs. When it is moved to a foreign network MR connects all of its MNNs to the Internet through a foreign access router or FAR. MR gets a care-of address or CoA from the FAR in the foreign network. Like basic-NEMO, our NEMO uses a HA in its HAR and updates its MR's new CoA in the foreign network to this HA by a binding update or BU message. HA maps the CoA of the MR with its HoA. Like basic-NEMO, the first packet from CN reaches MNN through a tunnel between HA and MR. However, the rest of the packets from CN reach MR directly due to our route optimization mechanism. MR forwards these packets to the MNN. Figure 4.1 shows the network architecture of our simple-NEMO.

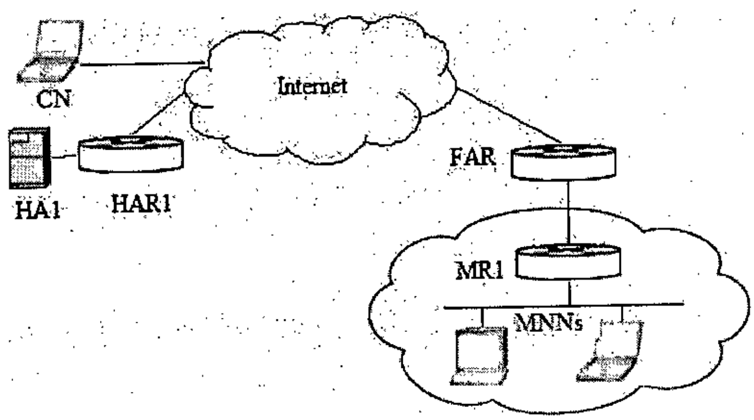


Figure 4.1: Network architecture of proposed scheme for a simple-NEMO

Like regular nested-NEMO, we assume an MR can attach with another MR and form a nested-NEMO. Like regular nested-NEMO, bottom-MR in our nested-NEMO gets access to the Internet through the top MR. Moreover, we assign the top-MR to work as the root-MR for this MR-tree. We use the CoA of this top or root MR as the root-CoA for all other MRs under it. All the intermediate as well as the bottom-MR get a CoA from its immediate upper level MR in the foreign network. They also get the root-CoA from the upper level MR. Unlike the regular nested-NEMO, the bottom-MR in our scheme sends the root-CoA instead of its regular CoA in the foreign network to its HA by a BU message. The HA of each MR under a root-MR maps the root-CoA instead of the regular CoA with the HoA of the MR. All the lower level MRs pass their associated network addresses to the upper level MR. In regular nested-NEMO, each MR only knows its directly attached network addresses. However, each MR in our scheme knows its own network addresses as well as the network addresses associated with all other MRs under it.

In a regular nested-NEMO, packets from CN reach an MNN associated with the bottom MR through multiple tunnels between multiple HA and MR pairs. Unlike regular nested-NEMO, the first packet from CN reaches the same MNN through only one tunnel between a HA and root-MR. After route optimization, the packets from CN directly reach root-MR and root-MR forwards the packets to the MNN. The typical network architecture of a nested-NEMO assumed in our scheme is shown in Figure 4.2.

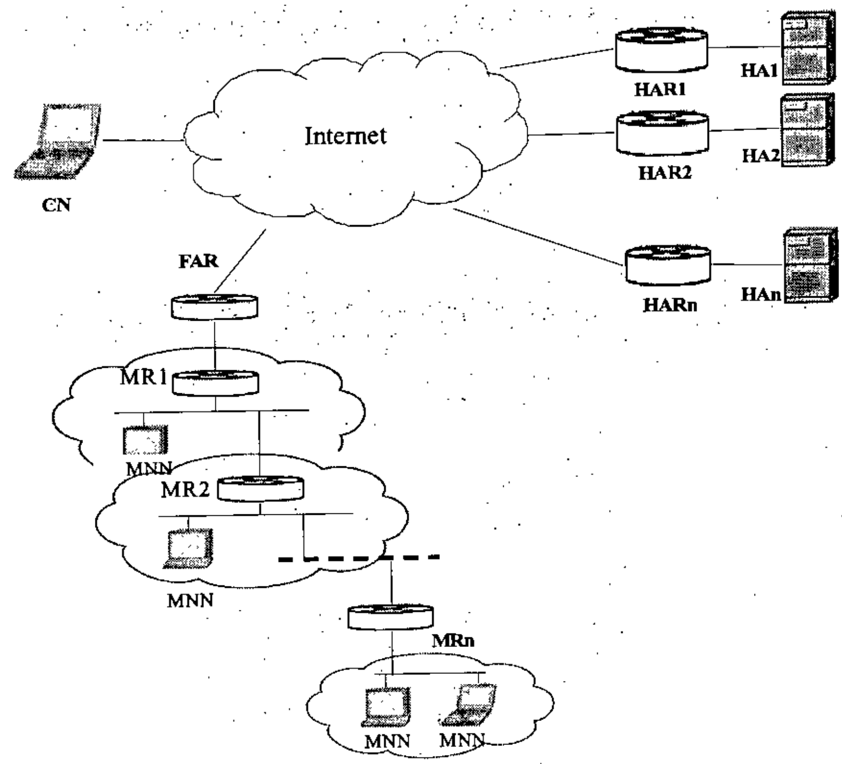
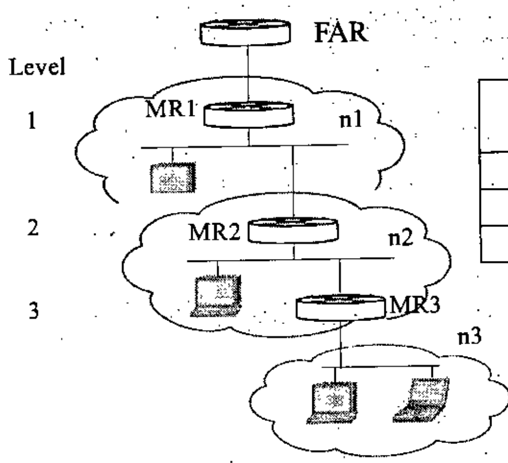


Figure 4.2: Network architecture of proposed scheme for a nested-NEMO

4.3 Optimization Technique

In this research work, we propose a new route optimization scheme for nested-NEMO to solve the tunneling problem easily. In this scheme, we propose to use two CoAs, local-CoA and root-CoA, for each MR. Here, the local-CoA of an MR will be its own CoA while the root-CoA of an MR will be the CoA of the root-MR in the nest. Like basic NEMO, we use the top MR in the nest as the root-MR. For the root-MR these root-CoA and local-CoA will be same. When an MR is getting attached to a higher level MR, we propose the higher level MR to pass the root-CoA to the newly attached MR and the attached MR to pass all of its associated network addresses to the upper level MR.

Figure 4.3(b) shows the root-CoA and local-CoA of MR1, MR2 and MR3 of Figure 4.3(a). Figure 4.3(c) shows the corresponding networks that are homed at the MRs in the MR tree.



(a)

Mobile Router	root-CoA	local-CoA
MR1	MR1's CoA	MR1's CoA
MR2	MR1's CoA	MR2's CoA
MR3	MR1's CoA	MR3's CoA

(b)

Mobile Router	Associated networks
MR1	n1
MR2	n2
MR3	n3

(c)

Figure 4.3: (a) A three level MR tree, (b) root-CoA and local-CoA addresses, (c) Associated network addresses

We also propose to use two types of entries in the routing table in each MR: Fixed and Visiting. Fixed part of the routing table will have the entries for the networks that are homed at the MR. Visiting part of the routing table will have the entries for the networks that are temporarily attached with all the mobile routers in the sub tree rooted by the MR.

Routing Parts	**Destination Networks**	**Forwarding Interface/Network**
Fixed	n1	n1
	.....	.....
	.....	.....
Visiting	n2	MR2's CoA
	n3	MR2's CoA

(a) MR1's (root-MR) Routing Table

Routing Parts	**Destination Networks**	**Forwarding Interfaces/Networks**
Fixed	n2	n2
	....	....
	....	....
Visiting	n3	MR3's CoA

(b) MR2's Routing Table

Routing Parts	Destination Networks	Forwarding Interfaces/Networks
Fixed	n3	n3
	....	....
	....	....
Visiting		

(c) MR3's Routing Table

Figure 4.4: Sample Routing Tables of MRs of Figure 4.3

If an MR learns about temporarily attached network addresses from a lower level MR, we propose the MR to enter these network addresses mapping to the local-CoA of the corresponding lower level MR in the visiting part of its routing table and pass these temporarily attached network addresses to its higher level MR and this process to continue successively up to the root-MR. In this way, the root-MR will eventually learn about all the associated and visiting network addresses in the MR tree and update its routing table as shown in Figure 4.4. All the MRs will also learn the root-CoA. Once the attachment process is complete, we propose each MR to send a binding update message to its corresponding HA. We propose the binding update message to pass the root-CoA information to HA instead of local-CoA information as shown in Figure 4.5.

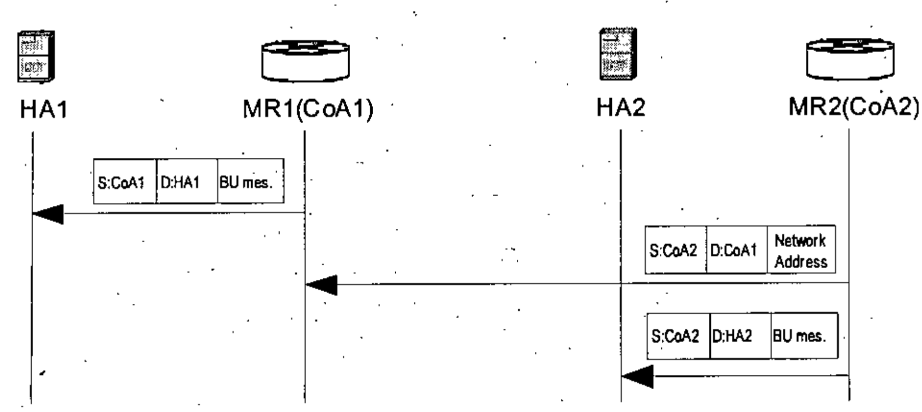


Figure 4.5: Route optimization signaling for a two level nested NEMO

In our scheme, when a CN wants to communicate with any MNN associated with a lower level MR, like regular NEMO, the first packet will reach the HA of that lower level MR. The HA of the lower level MR will encapsulate the incoming packet. However, unlike regular NEMO, it will forward the packet to the root-CoA instead of its local-CoA. After receiving the encapsulated packet the root-MR will first decapsulate the packet and forward the decapsulated packet down the tree using corresponding local-CoA. The root-MR will get the local-CoA associated with the destination of the decapsulated packet from the visiting part of its routing table. At the same time, the root MR will send a binding update message to the CN in order to pass root-CoA information to the CN. Above packet transmissions have been shown in Figure 4.6.

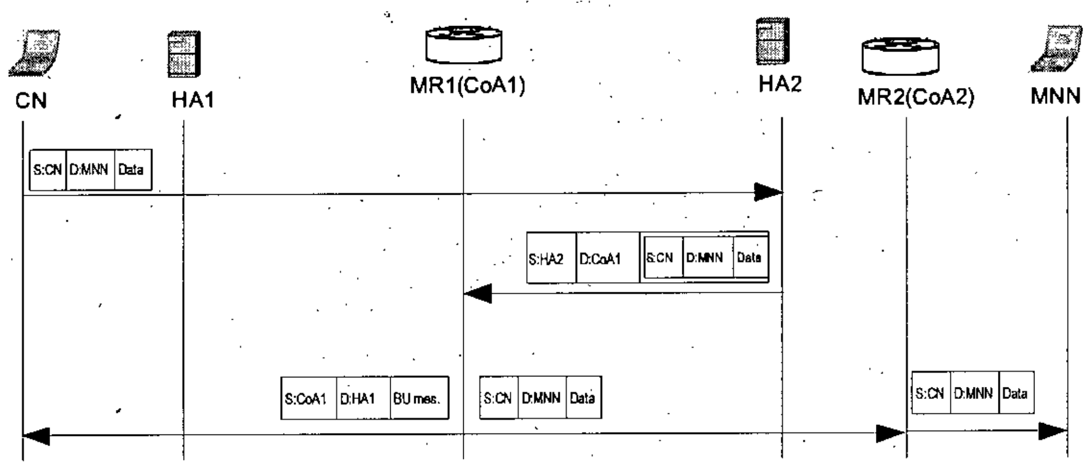


Figure 4.6: First packet flow of a two level nested NEMO

We propose the CN to send successive packets to the destination using the root-CoA as the loose source route. Each successive MR in the tree will forward the packet to its lower level MR by using the associated local-CoA from the visiting part of its routing table. Finally, the last MR or the MR of the destination MNN will receive the packet and will deliver it to the MNN. These optimized packet transmissions process have been shown in Figure 4.7.

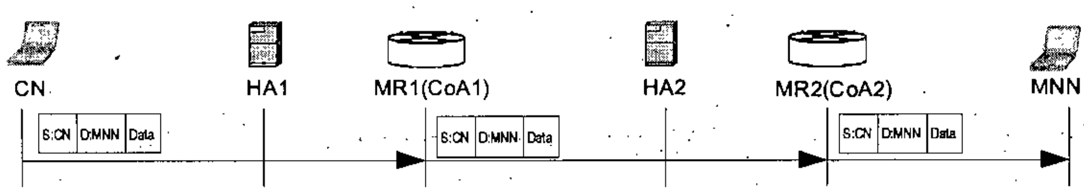


Figure 4.7: Path flow for a two level nested NEMO

Thus, applying the proposed scheme, tunneling can be completely removed from the nested NEMO in a single step using only one binding update message. This proposed route optimization scheme will also work for non-nested NEMO. A non-nested NEMO is in fact a special case of nested NEMO, where the root-MR is the only MR in the tree.

4.4 Summary

We have presented our route optimization scheme for nested NEMO in this chapter. We have discussed the routing table structure and packet signaling in different steps during route optimization. We evaluate the scheme in the next chapter with a case study of three level nested NEMO. We will also provide the proof of the scheme by mathematical induction.

Chapter 5

Evaluation of Proposed Route Optimization Scheme

5.1 Introduction

In this Chapter, we evaluate our Route Optimization scheme. In Section 5.2, we will describe a case study to show that the proposed solution solves the tunneling problem and provides an optimized route in nested NEMO. We will also proof the technique by mathematical induction. In Section 5.3, we will compare our presented route optimization technique with few other research works to show the greatness of our scheme.

5.2 Case Study

We first proof the effectiveness of our route optimization scheme using a three level nested NEMO. In this scenario, let a mobile router, MR1, moved from its home access router, HAR1, to a foreign access router, FAR. MR1 acquired a care-of-address, CoA1, from FAR and sent a BU message to its home agent, HA1, informing this CoA1. So, HA1 became aware of the movement of MR1 as well as CoA1 of MR1.

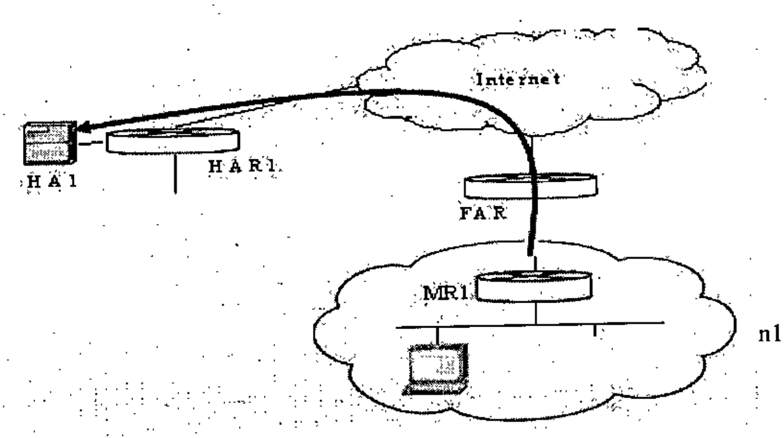


Figure 5.1: Movement of MR1 from HAR1 to FAR

Let another mobile router, MR2, moved from its home access router, HAR2, and gets attached with MR1, i.e., a two level nesting occurred. MR2 acquires two CoA from MR1. One is the root-CoA that is the care-of-address of MR1, i.e., CoA1, and the other one is the local-CoA that is MR2's own care-of-address from MR1, i.e., CoA2. MR2 passes its associated network addresses (n2 in Figure 5.2) to MR1. MR1 maps MR2's associated addresses with the CoA2 in its visiting part of routing table. Also, MR2 sends a BU message to its home agent HA2 informing the CoA1.

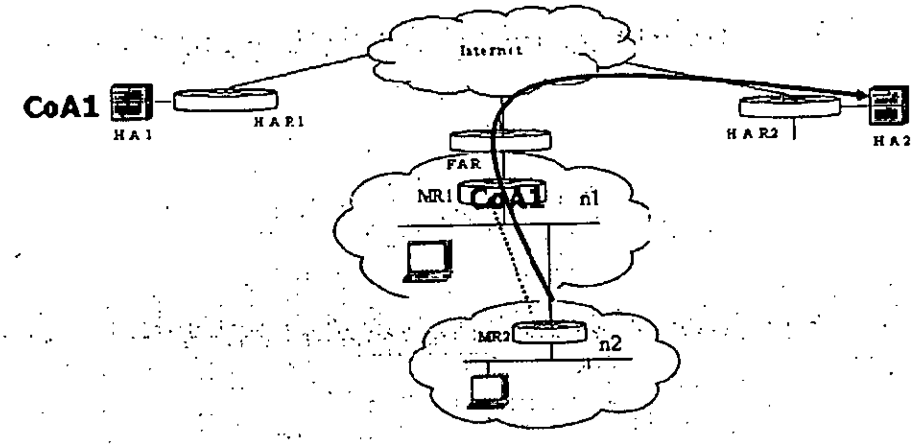
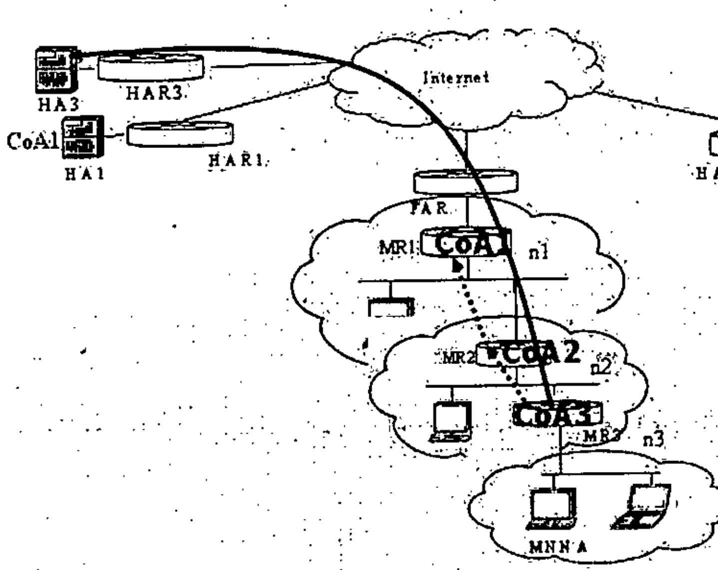


Figure 5.2: Movement of MR2 from HAR2 to MR1

Let a third mobile router, MR3, moved from its home access router, HAR3, and got attached with MR2, i.e., a three level nesting occurred. MR3 acquired two CoA from MR2. One is the root-CoA that is the care-of-address of MR1, i.e., CoA1, and the other one is the local-CoA that is MR3's own care-of-address from MR2, i.e., CoA3. MR3 passed its associated network addresses (n3) to MR2. MR2 mapped MR3's associated network addresses to CoA3 of MR3 and entered this information into the visiting part of its routing table. Successively, MR2 passed MR3's associated network addresses to MR1. MR1 mapped MR3's associated network addresses to CoA2 of MR2 and entered this information into the visiting part of its routing table. MR3 also sent a BU message to its home agent HA3 informing its root-CoA, i.e., CoA1.



(a)

Mobile Router	root-CoA	local-CoA
MR1	CoA1	CoA1
MR2	CoA1	CoA2
MR3	CoA1	CoA3

(b)

Figure 5.3: (a) Movement of MR3 from HAR3 to MR2, (b) root-CoA and local-CoA addresses of MRs

The movements of MR1, MR2, and MR3 have been shown in Figure 5.1, 5.2, and 5.3 respectively. The routing tables of MR1, MR2, and MR3 after the completion of the attachment in the foreign link have been shown in Figure 5.4.

Routing Parts	Destination Networks	Forwarding Interface/Network
Fixed	n1	n1
Visiting	n2	CoA2
	n3	CoA2

(a) MR1's (root-MR) Routing Table

Routing Parts	Destination Networks	Forwarding Interfaces/Networks
Fixed	n2	n2
Visiting	n3	CoA3

(b) MR2's Routing Table

Routing Parts	Destination Networks	Forwarding Interfaces/Networks
Fixed	n3	n3
Visiting		

(c) MR3's Routing Table

Figure 5.4: Routing Tables of MRs of Figure 5.3

Let a CN sends a packet to a mobile node, MNN A, associated with MR3. HA3 will receive the packet first. Since CoA1 is MR3's root-CoA and it is known to HA3 through the BU message, HA3 will encapsulate the packet with its own address as the source address and CoA1 as the destination address. HA3 will forward the encapsulated packet to CoA1, i.e., MR1 in the foreign network. As CoA1 is an address accessed from FAR, the encapsulated packet will take a route towards FAR. Thus a tunnel will be created between HA3 and MR1 as shown in Figure 5.5.

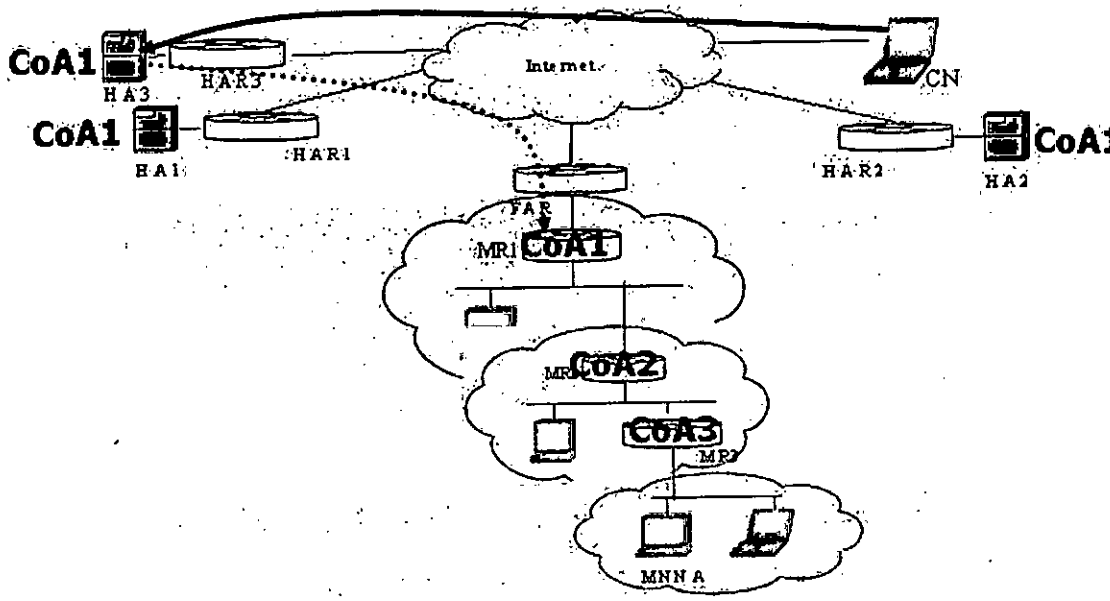


Figure 5.5: Transmission of first packet from CN

MR1 will decapsulate the received packet in order to get the original packet sent by the CN back. MR1 will forward the decapsulated packet to CoA2 of MR2 by using the information from the visiting part of its routing table. MR2 will again forward the decapsulated packet to CoA3 of MR3 by using the information from the visiting part of its routing table. MR3 will finally receive the packet and delivers it to MNN A.

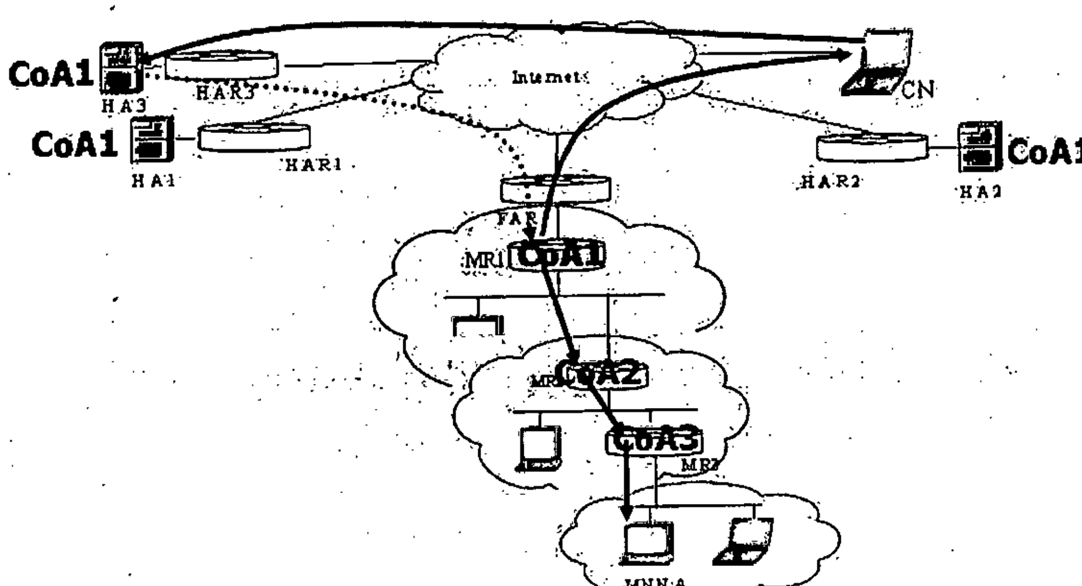


Figure 5.6: Sending of BU message from root-MR to CN

As shown in Figure 5.6, MR1 will also send a BU message to the CN informing the root-CoA, CoA1, while forwarding the decapsulated packet to MR2. After knowing about the movement of MR3 as well as it root-CoA, i.e., CoA1, the CN will send successive packets directly to CoA1, i.e., MR1, as the loose source route as shown in Figure 5.7. MR1 will forward the successive packets to MR2 and MR2 to MR3. MR3 will finally deliver these packets to MNN A.

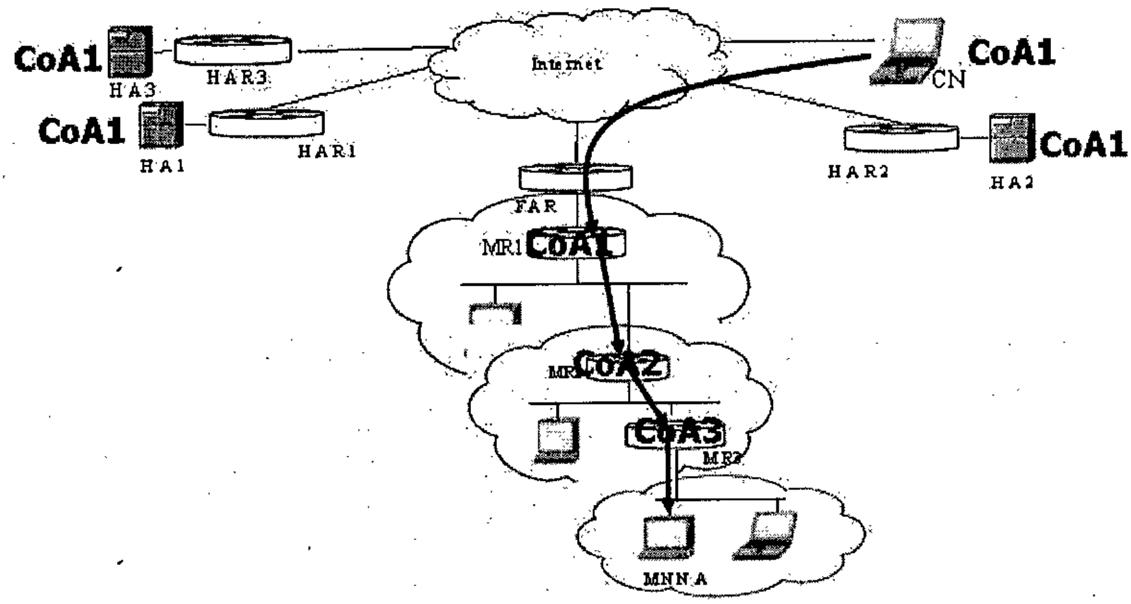


Figure 5.7: Packet transmission from CN to root-MR

We saw in Chapter 2 that for the same three level nesting in regular nested-NEMO, three level tunnels had been created to send packets from a CN to an MNN and the route taken by the packets was sub-optimal. However, our proposed route optimization scheme has eliminated all level of tunnelings and the route taken by the packets is optimal. Our scheme eliminated three level tunnels in one step and using only one BU message. Moreover, our scheme uses only one CoA as the loose source route, which keeps the packet header size small.

If we increase the number of levels in the nested NEMO our route optimization scheme will perform the same. It will remove all the levels of tunnels in one step and using only one BU message. We are giving the proofs of these claims in Lemma 1 and Lemma 2 respectively.

Lemma 1: Regardless the number of levels (n) in the nested NEMO, proposed optimization scheme removes tunneling completely (for $n>0$).

Proof: Let $P(n)$ denote the proposition that our optimization scheme removes tunneling completely with n level of nested-NEMO, i.e., $\forall n\, P(n)$ is true.

Basis: If n=1, only one MR is involved between an MNN and a CN which is working as both the root-MR and the MR of the MNN. HA of the MR gets bound with its CoA in the foreign network. When a data packet is sent from the CN, it reaches the HA and the HA forwards the packet to the MR through a single tunnel between the HA and the MR. The MR forwards the data packet to the MNN. Therefore, the packet will traverse through following route segments.

$$\text{CN} \rightarrow \text{HA} \Rightarrow \text{MR} \rightarrow \text{MNN}$$

MR optimizes the route by sending a BU message to the CN. After optimization, CN sends the data packets directly to the MR without going through any tunnel. Then, packet will follow the following route.

$$\text{CN} \rightarrow \text{MR} \rightarrow \text{MNN}$$

Therefore, tunneling is completely eliminated from the NEMO when n=1. This establishes that the P(n) is true when n=1.

If n=2, two MRs are involved between a CN and an MNN. Here, the top MR is working as the root-MR and the bottom MR is working as the MR of the MNN. When the bottom MR joins into the nested-NEMO, it sends a BU message to its HA with the root-CoA. So, when a data packet is sent from the CN, it reaches the HA of the bottom MR and the HA of the bottom MR forwards the packet to the root-MR by creating a tunnel between this HA and the root-MR. The root-MR forwards the data packet to the bottom MR using the visiting part of its routing table. Route segments will be followed by the packet are given below.

$$\text{CN} \rightarrow \text{HA (of MR)} \Rightarrow \text{root-MR} \rightarrow \text{MR} \rightarrow \text{MNN}$$

Only one tunnel exists between the root-MR and the HA of the bottom MR. In order to remove this only existing tunnel, the root-MR sends a BU message to the CN. After optimization, CN sends the data packets directly to the root-MR without any tunnel. The route of successive packets is given below.

$$\text{CN} \rightarrow \text{root-MR} \rightarrow \text{MR} \rightarrow \text{MNN}$$

Thus, tunneling is completely eliminated from the NEMO when n=2. This establishes that the P(n) is true when n=2.

If n=3, three MRs are involved between the CN and MNN. Here, the top MR is still the root-MR, the bottom MR is the MR of the MNN and the middle MR is an intermediate MR. When the middle and bottom MRs join into the nested NEMO, each of them sends separate BU message to its HA with the root-CoA. So, when a data packet is sent from the CN, it reaches to the HA of the bottom MR and the HA forwards the packet to the root-MR by creating a tunnel between the HA and the root-MR. The root-MR and other MRs forwards the data packet to the bottom MR using their visiting parts of the routing table and bottom MR forwards the packet to the MNN. First packet will follow the route given below.

$$\text{CN} \rightarrow \text{HA (of MR)} \Rightarrow \text{root-MR} \rightarrow \text{MR (intermediate)} \rightarrow \text{MR} \rightarrow \text{MNN}$$

So, before optimization, only one tunnel exists between the root-MR and the HA of the bottom MR. In order to remove this only existing tunnel, the root-MR sends a BU message to the CN. After optimization, CN sends the data packets directly to the root-MR without any tunnel. Successive packets will follow the following route.

$$\text{CN} \rightarrow \text{root-MR} \rightarrow \text{MR (intermediate)} \rightarrow \text{MR} \rightarrow \text{MNN}$$

Thus, tunneling is completely eliminated from the NEMO when n=3. This establishes that the P(n) is true when n=3.

Induction: Using the basis let's assume P(n) is true for any n>0. Now, we need to proof that P(n+1) is also true for any n. From the basis, we can say that the top MR is always working as the root-MR in our scheme. And the HA of each MR in the tree has a binding update about the root-MR. For this reason, when any HA receives a data packet from any CN, it forwards the packet by creating a tunnel between the HA and the root-MR. The root-MR and the other MRs forward the data packet to the destination MNN using their visiting parts of the routing table. Therefore, the first packet will traverse the following route segments.

$$\text{CN} \rightarrow \text{HA (of MR)} \Rightarrow \text{root-MR} \rightarrow \text{MRs (intermediate)} \rightarrow \text{MR} \rightarrow \text{MNN}$$

In order to remove the tunnel that exists between the root-MR and the HA of MR of the MNN, the root-MR sends a BU message to the CN irrespective of the number of levels in the tree. After receiving a BU message from the root-MR, CN sends the data packets directly to the root-MR without any tunnel. Now, routing of packets is given below.

$$\text{CN} \rightarrow \text{root-MR} \rightarrow \text{MRs (intermediate)} \rightarrow \text{MR} \rightarrow \text{MNN}$$

From the above discussion, we can say that the root-MR of nesting level n also works as the root-MR of nesting level n+1 and after sending a BU message from the root-MR, the scheme removes tunneling completely with a nesting level n+1. In other words, P(n+1) is true for any n>0. Therefore, we have proved that $\forall$ n P(n) is true.

Lemma 2: Regardless the number of levels (*n*) in the nested-NEMO, the proposed solution needs to transmit only a single BU message (for *n*>0) to get optimized route between the MNN and the CN.

Proof: Let *P(n)* denote the proposition that, in our scheme, it requires only a single BU message to transmit to get the optimized route between the MNN and the CN with n level of nestings in the nested-NEMO, i.e., $\forall$n *P(n)* is true.

Basis: If n=1 then only one MR is involved between an MNN and a CN which is working as both the root-MR and the MR of the MNN. When a data packet is sent from the CN, it reaches the MR through its HA. MR forwards the data packet to the MNN and sends a BU message to the CN in order to optimize the route from CN to MNN as shown below.

$$\text{MR} \xrightarrow{\text{BU Message}} \text{CN}$$

Therefore, only one BU message is enough to optimize the route, i.e., P(n) is true when n=1.

If n=2, two MRs are involved between the CN and MNN. The top MR is working as the root-MR and the bottom MR is working as the MR of the MNN. When a data packet is sent from the CN, it reaches the root-MR through bottom MR's HA. The root-MR forwards the data packet to the bottom MR using the visiting part of its routing table and the bottom MR forwards the data packet to the MNN. The root-MR sends a BU message to the CN in order to optimize the route from CN to MNN. Passing a BU message from root-MR to CN has been shown below.

$$\text{root-MR} \xrightarrow{\text{BU Message}} \text{CN}$$

Thus, only one BU message is sent to optimize the route, i.e., P(n) is true when n=2.

If n=3, three MRs are involved between the CN and MNN. The top MR is still working as the root-MR, the bottom MR is still working as the MR of the MNN and the middle MR is working as an intermediate MR. The visiting part of the routing table of the root-MR holds the addresses of both the middle and the bottom MR's and their associated networks. The visiting part of the routing table of the middle MR holds the addresses of the bottom MR and its associated networks. The HA of each MR knows the current address of the root-MR. When a data packet is sent from a CN, it reaches the root-MR through bottom MR's HA. The root-MR forwards the data packet to the intermediate MR using the visiting part of its routing table, intermediate MR again forwards the data packet to the bottom MR using the visiting part of its routing table and the bottom MR finally forwards the data packet to the destination MNN.

$$\text{root-MR} \xrightarrow{\text{BU Message}} \text{CN}$$

Here, only the root-MR sends a BU message to the CN in order to optimize the route from CN to MNN. Therefore, P(n) is true when n=3.

Induction: Using the basis let's assume P(n) is true for any n>0. Now, we need to proof whether P(n+1) is also true for any n. From the basis step, we can say that the top MR is always working as the root-MR in our scheme and the other MRs in the tree are getting bound with the root-MR through the visiting part of their routing table. The HA of each MR in the tree also has the entry for the root-MR. For this reason, any data packet from any CN to any MNN of any MR reaches the root-MR first and the root-MR forwards the data packet to the destination MNN using the visiting part of the routing table in root-MR and the same in other MRs on the tree. Only the root-MR irrespective of the number of levels in the tree sends only one BU message to the CN in order to achieve route optimization from MNN to CN as shown below.

$$\text{root-MR} \xrightarrow{\text{BU Message}} \text{CN}$$

From the above discussion it is obvious that the root-MR of nesting level n also works as the root-MR of nesting level n+1 and only the root-MR sends only one BU message in order to optimize the route with a nesting level n+1. In other words, P(n+1) is true for any n>0. Therefore, we have proven that $\forall n$ P(n) is true.

5.3 Comparisons

	Basic-NEMO	CUIP	ONEMO	S-RO	ROTIO	Proposed scheme
tunneling	HA↔MR	None	HA↔MR or none	None	$HA \leftrightarrow HA_{TLMR}$ $HA_{TLMR} \leftrightarrow TLMR$	none
NEMO routing	pin-ball	semi-optimal	pin-ball or optimal	optimal	pin-ball	optimal
nested NEMO routing	pin-ball	semi-optimal	pin-ball or optimal	optimal	nearly optimal (two tunnels)	optimal
encapsulation degree	number of MR level in the nest	zero	nested level or zero	zero	zero	zero
additional function with basic-NEMO	-	COR, home route	RA	RAO	TIO	none
additional information with basic-NEMO	-	network hierarchy	network address of all MR in the tree	BU from all MR, all CoAs in packet header	two BU from all MR, all CoAs in packet header	root CoA, network address of lower level MRs only

Table 5.1: Comparison of proposed scheme with other schemes

In Table 5.1, we compare our proposed route optimization scheme for nested NEMO with that of basic-NEMO [3], CUIP [9], ONEMO [16], S-RO [17], and ROTIO [26]. We compare the route optimization schemes with respect to several attributes, such as tunneling, NEMO routing, nested NEMO routing, encapsulation degree, additional functionality with basic-NEMO, and additional information with basic-NEMO. In basic-NEMO, packets are encapsulated from HA to MR when MR is in a foreign network. This is known as tunneling. In non-nested NEMO, only one MR is attached in the foreign network. The routing between this first level MR and CN is called NEMO routing. A packet from CN to a destination of an MNN of MR is routed via MR's HA. This is called pin-ball routing. A semi-optimal route is a route which is not the shortest path or where a packet needs to traverse a longer distance. In nested NEMO, where several MR form a tree like structure, a packet transmission between a CN and an MNN associated with a lower level MR in the tree goes through all the upper level MRs. This type of routing is called nested- NEMO routing. The number of encapsulations on a packet is called its degree of encapsulation. If any new function is included in the scheme which was not present in the basic-NEMO is defined as the additional functionalities with basic-NEMO. If a scheme requires to containing extra information than that of the basic-NEMO is defined as the additional information with basic-NEMO. COR is the forking point of previous attachment point and new attachment point. Network hierarchy means a hierarchical structure of MR and due to network hierarchy each MNN needs to store its home route. A home route is a route that is a permanent route from top level MR to an MNN. Router advertisement (RA) is a periodical advertisement of networks to update the network addresses associated with an MR. Router Alert Option (RAO) is applied to avoid multiple encapsulations and to support multiple headers in a packet. Top-level mobile router (TLMR) is the top-MR in the MR tree. Tree Information Option (TIO) is used to advertise the networks with TreeID (TLMR's address) and the prefix of MRs in the tree.

In basic-NEMO [3], HA to MR tunneling exists, and, due to tunneling pin-ball routing is required in NEMO and nested-NEMO. Each level of MR in the tree causes an extra level of encapsulation of the packet. Thus, packet is encapsulated several times and takes a longer or sub-optimal path.

In CUIP [9], tunneling and encapsulation is removed but it is limited to only hierarchical network. Due to the hierarchical structure of the network, a packet might require to traverse a longer distance. To provide optimize route, this scheme requires to introduce few new terminologies in network structure like COR, home route etc.

ONEMO [16] scheme is able to remove tunneling and encapsulation only within the ad-hoc network formed between MR and CN in the same foreign network. In this scheme, router advertisement is necessary which was not present in basic-NEMO. Network addresses of all MRs in the tree are required to store in order to forward packets within the same domain. However, this scheme suffers from tunneling and encapsulation problems in inter-domain networks.

S-RO [17] scheme solves the tunneling and encapsulation problems. In S-RO, a CN and an HA require to cache all CoAs of MR's in the tree. Router Alert Option (RAO) is required to eliminate multiple levels of encapsulation. This scheme requires too many BU message transmissions to achieve optimal route in a nested NEMO. Too many CoAs as the loose source route also increases the size of the packet header.

In ROTIO scheme [26], the number of tunneling is minimized to only two tunnels for multi-level nested NEMO. Therefore, this scheme can't eliminate tunneling completely. Two BU messages are sent from each MR, one to HA and the other to TLMR's HA. Router advertisement is necessary, that is not present in basic-NEMO. This scheme is based on TIO option. Therefore, to implement this scheme, all the networks are needed to support TIO option.

In our proposed scheme, CN requires to cache only the root-CoA of MR. MRs in the tree do not need to store the network addresses associated with the upper level MRs. No extra functionality is required. Moreover, only one BU message is needed to remove tunneling and encapsulation completely irrespective of the number of levels in the nested NEMO. Route optimization is also achieved in one step. Only one CoA is necessary to use as the loose source route, which keeps the packet header size small.

5.4 Summary

In this Chapter we have evaluated our scheme with a case study of three level nested NEMO. We have shown that our scheme eliminated tunneling completely from nested NEMO. The scheme requires simple mechanism and optimizes the route with a single BU message only. Compared to other schemes our scheme solves the tunneling problem efficiently. Our scheme is not limited to intra domain routing and is not limited to hierarchical network.

Chapter 6

Conclusions and Future Works

6.1 Conclusions

In this thesis, we have discussed the tunneling problem in nested-NEMO, which causes pin-ball routing and encapsulation, therefore, delay in packet transmission. Although several schemes have been proposed to solve these problems, those solutions either need extra functionalities or extra information with NEMO basic support protocol. Those solutions take multiple steps and longer time to remove tunneling and to achieve route optimization. They also need to transmit a large number of BU messages. Therefore, we propose a new route optimization technique to eliminate the tunneling completely in one step and by transmitting only one BU message irrespective of the number of levels in the nested NEMO. We made our scheme equally applicable for both hierarchical and non-hierarchical networks and effective for both intra-domain and inter-domain routing. Our scheme provides optimum route with a very simplified mechanism. It is expected that our scheme will reduce the end-to-end network delay and increases the network throughput with no additional overhead.

We have demonstrated by a case study that our route optimization scheme eliminates all the tunnels in a nested-NEMO in one step and by transmitting only one Binding Update message. We also proved that our scheme will remove all the tunnels from a nested-NEMO of any number levels n in one step and by transmitting only one message by proving related lemmas using induction technique. We compared our scheme with other route optimization schemes with respect to several attributes, such as tunneling, NEMO routing, nested NEMO routing, encapsulation degree, additional functionality with basic-NEMO, and additional information with basic-NEMO. We found that our scheme is performing well compared to other schemes with respect to many attributes.

6.2 Future Works

In this research work, we did not solve the packet drop problems due to egress and ingress filtering. Egress filtering is the control of traffic leaving a network. Firewall administrators may create a rule to let their internal network transmit any and all traffic patterns out to the Internet. Egress filtering limits this traffic flow to a reduced subset and prevents sending unwanted traffic out to the Internet. This could include leaking out private address space or stopping compromised systems attempting to communicate with remote hosts. Egress filtering can also help prevent information leaks due to wrong configuration, as well as some network mapping attempts. Finally, egress filtering can prevent internal systems from performing outbound IP spoofing attacks. Similarly, ingress filtering is the control of traffic entering a network. Ingress filtering prevents receiving unwanted traffic from the Internet. Source routing generally faces egress and ingress filtering. We have used loose source routing, for which egress and ingress filtering may become a threat. As we store lower level MR in the visiting part of the routing table of each MR, egress filtering may be overcome. But, incoming packet from the CN may suffer ingress filtering in the FAR, because, the actual destination of the packet and the forwarded packet path is not identical topologically. So, FAR may think these packets as an external attack for its network and may discard all the packets from the CN.

Besides the egress and ingress filtering, some packets might also get dropped during the hand-off. Moreover, some other parameters such as bandwidth, link speed, link stability and so forth may be considered as an element to determine the triggering of route optimization. In our future research works, we wish to investigate these issues. Finally, we certainly hope that the presented Route Optimization technique can become a new research stream, and will lead to a ubiquitous communication environment that will fit into the fourth generation wireless communication architecture.

We didn't present any simulation result in our thesis because simulating a nested NEMO is not possible in network simulators, such as ns2 [73], ns3[74], Opnet[75], Omnet[76], OMNeT++ [77], GloMoSim [78], QualNet [79], NetDisturb [80] etc., directly. We have proved that we need to send only one BU message by mathematical induction. Simulation results can definitely add strong justification of our scheme. Test bed experiments can also make our arguments stronger. In our future work, we will extend a network simulator in order to simulate our scheme. We will also experiment our scheme in a test bed in future.

Chapter 7

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