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A Survey on Various Route Optimization Techniques in Network Mobility

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Abstract

The growing use of IP devices in portable applications has created the demand for mobility support for entire networks of IP devices. Network Mobility solves this problem by extending Mobile IP. The protocol is an extension of Mobile IPv6 and allows session continuity for every node in the mobile network as the network moves. The Mobile Router, which connects the network to the Internet, runs the Network Mobility Basic Support protocol with its Home Agent. The protocol is designed so that network mobility is transparent to the nodes inside the mobile network. This paper targets to analyze network mobility issues and requirements. The aim is to explore the idea of route optimization in Network mobility. We classify the schemes established on the basic method for route optimization, and equal the schemes based on protocol overhead, such as header overhead, amount of signaling, and memory requirements. After discussing the need of route optimization in Network mobility, different solutions provided so far are discussed and analyzed. Lastly the performance of the classes of different schemes has to be estimated under norms such as available bandwidth, topology of the mobile network and mobility type. All these issues are explained to provide a future scope of studies in this field.

Keywords: mobile IPv6, route optimization, NEMO basic support protocol, nested NEMO

1 Introduction

As wireless networking products and services proliferate, users expect to be connected to the Internet from "anywhere" at "anytime". These devices moving with the user together constitute a Personal Area Network or PAN, and are an example of a small scale mobile network. Access networks deployed on public transportations such as ships, trains, buses and aircrafts are examples of mobile networks at a larger scale. The Mobile IP Working Group within the Internet Engineering Task Force (IETF) has proposed the Mobile IP protocol [9, 16] to support host mobility in IP-based networks. Mobile IP aims at maintaining Internet connectivity while a host is moving. To achieve this, it needs two addresses: 1) a home address (HoA) which is a fixed address (identifier) and 2) a care-of address (CoA) which is a locator. By registering its location with the home agent (HA) on the home link, a mobile host can communicate with corresponding nodes (CNs) as it moves about. Experiments [8] have shown that MIPv6 is unable to deliver packets to nodes inside the mobile network. The Home Agent (HA) is unable to encapsulate packets, destined for the mobile network nodes, to the mobile network because for the HA, the tunnel is a host specific tunnel rather than a network specific tunnel. So the HA is only able to see the MR at the other end of the tunnel, and the nodes behind the MR seem invisible.

This type of scenario is ok for a single node but a group of nodes in a single moving entity (i.e., a bus or a train) may also need to be connected to the Internet. Standard groups therefore progress the research and standardization for 'mobility support'. Network Mobility (NEMO) proposed by IETF, is an extension to mobile IPv6 which focuses on the condition where the entire network moves The Network mobility (NEMO) protocol is a way of managing the mobility of an entire network, viewed as a single unit, which changes its point of attachment to the Internet [7]. Such a network will include one or more mobile routers (MRs) that connect it to the global Internet. Basically, an MR has two interfaces; egress and ingress. An MR can access the Internet through the egress interface and detect movements

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(by listening for router advertisement messages) and registers its location (by sending binding update messages) using the egress interface i.e. this interface gives accessibility with the HA of the MR. The MR also provides accessibility to its own mobile network nodes (MNNs), which are attached to its ingress interface, that has its own network prefix.

The complex scenarios of a mobile network brought along problems which were previously unknown in the node mobility concept, which led to the creation of the IETF's NEMO (Network Mobility) Working Group. One of the tasks [6] of this working group is to come up with a protocol, as an extension to Mobile IPv6 [9], which deals with network mobility and its unique problems. The solution which they came up with was known as NEMO Basic Support Protocol (NBS) [5]. This solution though provided improved network mobility support compared with MIPv6, but it still had performance limitations, especially in regards to route optimization. Route optimization implies improving the end-to-end path of packet flow between communicating nodes which directly affects quality of service (QoS). Several proposals have been forwarded each of which claims to rectify NBS's sub-optimal routing and provide a complete solution.

A mobile network can have a hierarchical structure, e.g., a mobile network within another mobile network. This situation is referred to as a nested mobile network. For example, a personal digital assistant and a mobile phone might be organized together to form a user's personal area network (PAN). A PAN may travel a vehicle, which also contains a mobile network of larger scale. Figure 3 illustrates a simple nested mobile network. Initially, MR1, MR2, MR3, and VMN are attached to their own home links. After MR3 moves to a foreign link [MR3 is attached to the access router (AR)], MR2 is connected to MR3. Then, MR1 is connected to MR2. The VMN now moves under MR1. Figure 3 is a snapshot at this moment. Note that the subnet of MR3 is also the foreign link of MR2. The same relation applies between MR2 and MR1 and between MR1 and VMN. Here, MR3 is the top-level mobile router (TLMR) of the nested mobile network and is deemed to be the gateway to the whole nested mobile network. From the perspective of the VMN MR1 is the closest MR. When a CN wants to send a packet to the VMN in the nested mobile network, the current NEMO protocol requires the packet to visit all the HAs (starting from HA_VMN, then HA1, HA2, and HA3). Note that HAn is the HA of MRn. As the degree of nesting increases, the packets destined for an VMN in a nested mobile network will suffer more and more inefficient routing. This is the so-called pinball routing problem, which will be detailed later in this paper. To route IP packets efficiently in such complicated networking environments, the current NEMO basic support protocol should be extended [20, 24].

In addition to routing inefficiency, other criteria are important in designing a route optimization scheme for nested mobile networks. The concept of network mobility was introduced to reduce the signaling overheads of a number of hosts moving as a group. The NEMO basic support protocol uses a bidirectional tunnel between the HA and the MR to keep MNNs from sending all their location registrations simultaneously when the MR changes its point of attachment. This characteristic is called mobility transparency, which is a very desirable feature for the route optimization scheme. Another characteristic is location privacy. The information about the location of a node (e.g., its CoA) is a matter of privacy, and ideally should not be disclosed to a non administrative domain (e.g., a CN). However, the location privacy is not mandatory, since the mobile IPv6 (optimized MIPv6) protocol already permits a binding update to the CN for the route optimization. Besides mobility transparency and location privacy, intra-NEMO route optimization and handoff disruption can be important metrics. Usually, the route to be optimized is taken to be the path between the MNN and the CN, which is outside the nested mobile network. As peer-to-peer applications proliferate, communication inside a mobile network must also be considered. In addition to all these considerations, the handoff disruption time should be minimized.

In this paper, we survey the state-of-the-art in mechanisms for supporting network mobility. We first motivate the problem, identify its characteristics, and illustrate why existing solutions do not suffice. We next identify the solution design requirements, and then review some of the solutions proposed in the literature.

The rest of the paper is divided as follows. Section 2 explains NEMO issues including NBS. Section 3 provides the need for route optimization. Section 6 describes different existing route optimization approaches. In the succeeding Section 7 we evaluate the performances of various RO schemes on the basis of different metrics. Section 8 focuses on the issues and future work. Section 9 states a conclusion.

2 Network Mobility Issues

Network mobility (NEMO) is an extension protocol to Mobile IPv6. Network mobility is provided to a group of network by the usage of Mobile Router (MR) and Home Agent (HA). The seamless Internet connection is provided to the users without any interruption even when the MR changes its point of attachment to the network. NEMO services are provided to the passengers who are carrying mobile devices such as palm, laptop and etc on board. Those devices would like to connect to the Internet. Those devices can connect to the MR which is located in the NEMO BUS as well. MR will connect to the access router AR 1 at time A by establishing a tunnel between HA and MR. After few minutes, NEMO BUS has arrived at another location. At this time B, MR will connect to the access router AR 2. The connection from the users to the MR is seamless and transparent to the passengers. We assume that AR 1 is also the service provider for the NEMO BUS Internet service. In other words, the AR 1, HA, MR and NEMO BUS sit in the same network. Therefore, in order to achieve seamless connectivity as described above, MR will first get an IP address from access router AR 2 when attached to the network under AR 2. This IP address will be the care of address (CoA).MR will then send a binding update to its HA and a tunnel will be established. Any packets destined to the mobile network must be forwarded to the MR through this tunnel.

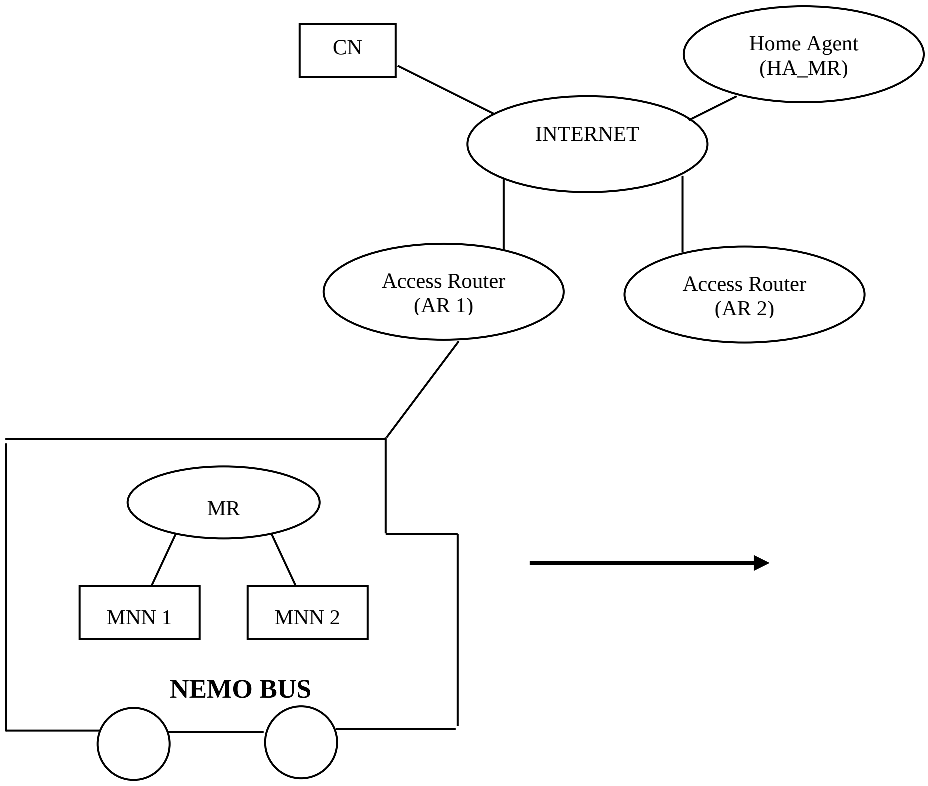

Figure 1: An overview of NEMO

2.1 NEMO Operation

NEMO allows a MR to manage the mobility of the nodes inside a mobile network which are known as mobile network nodes (MNNs) with the help of a fixed mobility anchor point, home agent (HA). When an MR is in its home network, it is connected directly to its HA, so that all traffic to and from the mobile network is delivered via the HA and the MR. The mobile network is connected to the Internet via an IP-IP tunnel between the MR and the HA when the MR is away from home. When an MR moves to a new network, it obtains a care-of-address (CoA) and sends a binding update (BU) to its HA. The BU binds the new CoA of the MR with its permanent address (home address). The HA then sends a binding acknowledgement (BA) to inform the MR of the status of the update. A tunnel is then established between the CoA of the MR and the address of the HA. The MR and its HA then deliver all traffic between the mobile network and the Internet via this tunnel. This overlay routing hides the mobility of the MR from the CNs and also from the MNNs. Thus, the MNNs do not need any mobility management capabilities to take advantage of the mobile Internet access. An MNN, which is not capable of managing its own mobility, is known as a local fixed node (LFN). However, a mobile device managing its own mobility may enter a mobile network, treating it as a foreign network in which case the MNN is known as an VMN. An example of this is a passenger with a MIPv6 capable mobile device entering a train with a mobile network. In this case, the MIPv6 capable VMN will send a BU to its own HA (HA_VMN) informing it to deliver all traffic to its new CoA using IPv6 tunneling. This results in two nested levels of mobility management since a MR manages the mobility of the mobile network. However, the VMN can use MIPv6 RO to communicate more directly with CNs bypassing the HA_VMN using its CoA from the mobile network prefix.

2.2 NEMO Basic Support Protocol

Mobile IPv6 deals with host mobility protocols, NEMO Basic Support protocol (NBS) deals with the concept of a group of nodes moving around in the Internet as a unit. This unit is called a mobile network. One or more MRs handle communications to and from the mobile network. The nodes inside the mobile network are called mobile network nodes (MNNs). The node with which a MNN communicates is called a Correspondent Node (CN). MNNs can belong to the mobile network e.g. local fixed nodes (LFNs) or they can belong to another home link and visit the mobile network e.g. visiting mobile nodes (VMNs). An LFN belongs to subnet of MR and cannot change point of attachment whereas VMNs are temporarily attached to subnet of MR by obtaining its CoA. These VMNs can either be single MIPv6 enabled nodes or a MR with other nodes behind it. When a mobile network acts as an access network and allows visiting nodes to attach to it, the network is called a nested network. If the foreign node happens to be a MR, with nodes behind it, its network would be called a sub-NEMO and it would be attaching itself to a parent-NEMO.

An MR along with its mobile network is initially at its home i.e. it is being served by its Home agent (HA). An MR has a unique IP address called its home address. The HA has a registry of the MR's home address. The HA also takes care of the packets that are destined for MRs when the MR is away from its home link 13.

When the MR moves to another network from its home network (foreign link), the foreign link provides it with a care-of-address (CoA). The MR then binds this CoA to its home address. This binding is called a binding update (BU). The MR then sends this BU to its HA. The HA, upon receiving this BU, makes an entry for the CoA, along with the home address, in its binding cache. The HA then acknowledges the BU, by sending a Binding Acknowledgement (BA) to the MR. Upon the successful completion of this binding process, a bi-directional (MR-HA) tunnel is setup between the MR and its HA. After setup of the tunnel, all future packets addressed to the mobile network, would first be encapsulated [3] by the HA, with an extra IP header whose destination address is the CoA of the MR, and then sent through the bi-directional tunnel towards the MR at its current CoA. Packets going out from the mobile network would also be encapsulated with an IP header and sent through the bi-directional tunnel (reverse routing).

2.3 Pinball Routing Problem in NEMO

Nested mobile networks come up with the pinball routing problem. In the NEMO basic support protocol, each mobile node (MR or VMN) has its own HA. In the worst case, when a CN sends a packet to the MNN which is located at the bottom most level of the nested mobile network, the packet has to visit the HAs of all the MRs prior to reach the MNN.

Figure 4 illustrates the pinball routing problem with three degrees of nesting. First, the data going from a CN to an VMN is routed to HA_VMN. The binding cache of HA_VMN contains the information that VMN is located below MR1. So the data is tunneled to MR1’s HA (HA1). At this point, HA1 has binding information specifying that MR1 is located below MR2. So the data is encapsulated again and rerouted to MR2’s HA (HA2). HA2 tunnels the data once again and delivers it successfully to MR2. Accordingly, the original data is encapsulated four times. The MRs decapsulate the packet and forward the packet to the VMN.

The problem becomes more complicated as the level of nesting increases and the routing distances between HAs become longer. Two levels of nested NEMOs can easily occur if there is a PAN in a vehicle, and three levels if there is, say, a PAN in a car on a ship. However, by including a multihop relay between NEMOs, a topology with four or more nested levels become plausible. A multihop relay occurs when a NEMO is attached indirectly to the access network via neighboring NEMOs. This is a severe level of nesting which will greatly exacerbate the pinball routing problem. To illustrate the effect of routing distances, consider the following scenario: There is a PAN in an airplane on an international flight. The home network of the PAN is in Korea and the home network of the airplane is in America. If someone sends data to a PDA in the PAN, the data has first to go to the HA of the PAN in Korea, and then to the HA of the airplane network in America. After visiting the HA of the airplane, the data finally arrives at the MR of the airplane network, which may be located in yet another country. If the data has real-time characteristics, the resulting delay and jitter may not be tolerable.

2.4 Some Facts about NEMO

When looking at the NEMO protocol, two basic facts can be observed. First, the mobile router needs to provide mobility function to its serving network. That means the mobile router does not have to stop its function as a mobile router, when it moves under another mobile router. The object of the mobile router is to support connectivity to the nodes under its network when that network moves to new access router. Mobile router needs to provide mobility service to non-mobile router or devices, but it does not have to provide mobility Original lPv6 Packet service to other mobile router. The subordinate mobile router only needs to provide mobility function to its connected non-mobile router or devices.

Second fact is that only the top-level mobile router need to perform handover, when it moves to new access router. If all the subordinate-level mobile routers in the mobile network perform handover, then the packets need only to go to the pertaining home agent i.e. if the CN wants to communicate with the node under MR3 the MR3 will register the CoA from AR in HA3. The packet will go to HA3 and be tunneled to MR3 under AR. If the subordinate mobile router also performs handover when moving to new access router, then there is no benefit of NEMO basic support protocol because the advantage of mobility transparency gets lost. The greatest advantage of NEMO basic protocol is that only the top-level mobile router performs handover while moving to another network while all other subordinate-level mobile routers need not be aware of the movement. Also, there may be different layer 2 access technologies that the top-level MR can not provide to nested subordinate-level MR. For example, the AR may not provide access technology that the MR3 can provide to MR2. Therefore, nested mobile network is indispensable.

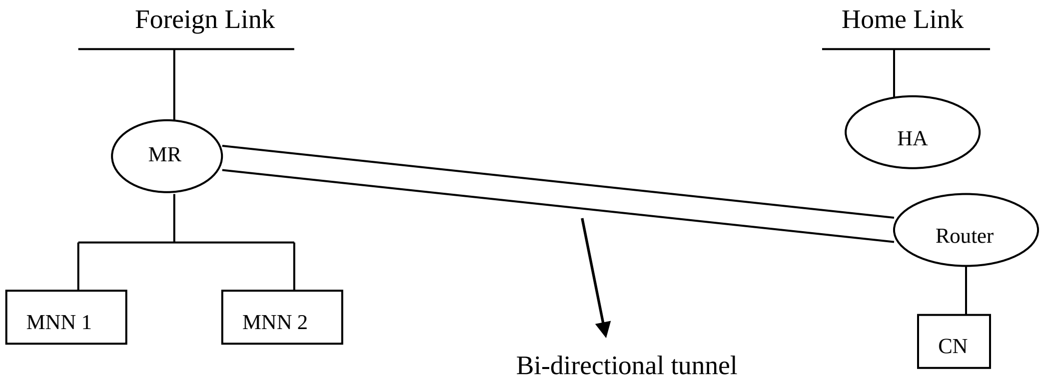

Figure 2: Non-nested NEMO

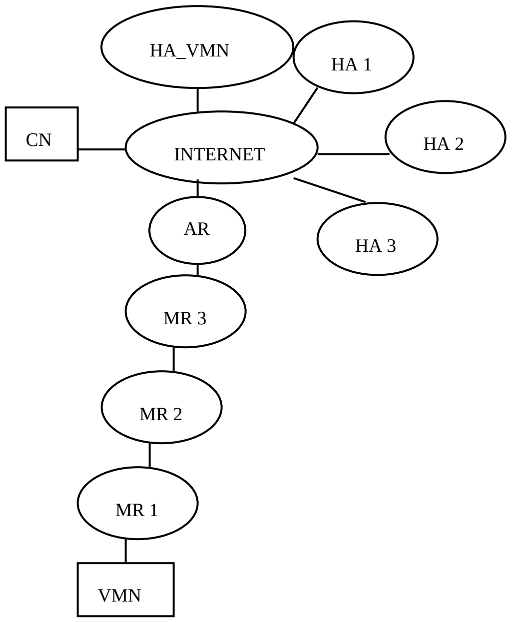

Figure 3: Nested mobile network

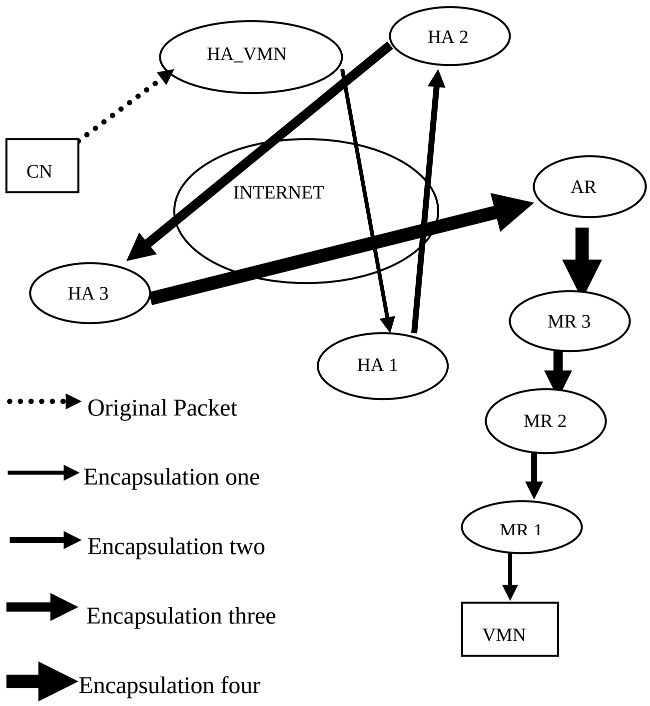

Figure 4: Packet routing in NBS (pinball routing)

3 The Need for Route Optimization

The deployment of NEMO Basic Support Protocol incurs operational limitations and overheads, which can be alleviated by a set of NEMO Route optimization techniques. A route optimization scheme for NEMO Basic Support Protocol would refer to improvement of end-to-end path of packet flow between a mobile network node (MNN) and Correspondent Node (CN). Some of the problems associated with NEMO Basic Support and the reasons for a route optimization are as follows:

- According to NBS, all packets traveling between the MR and the CN must pass through the bi-directional tunnel between HA and MR and this problem is magnified when degree of nesting increases. This may lead to a longer route and packet delay. This also affects the quality of service (QoS). Also a longer route puts extra processing load on the routing infrastructure, and the probability of failure at a certain link would also be greater.
- Each time a packet goes through the bi-directional tunnel an additional IPv6 header is added (encapsulation). This increases packet size and reduces overall bandwidth efficiency. Also if the packet size goes beyond the maximum transmission unit (MTU) limit on a link it has to be fragmented, which can add to packet delay. Encapsulation also increases processing overhead and packet delay.
- All traffic originating from the mobile network goes through a single link i.e. the home link. This can cause congestion. The failure of this single link would mean all communication to and from the mobile network would cease.
- Security policies prohibit MR from tunneling traffic originating from MNNs towards the home link due to risk of security breach in the home link by rogue visitors [10,17], who might forward malicious packets through the bi-directional tunnel.
- In a nested network if two MNNs wish to communicate (intra NEMO scenario), their packets have to pass through all the upstream MRs and their corresponding HAs. This increases packet delay and packet size. In another scenario, if a HA is nested inside its mobile network, a stalemate [21] occurs. The MR cannot find its HA in the internet and a bi-directional tunnel cannot be setup.

4 Issues in Route Optimization

There are several issues [15] that were raised in addition to header overhead and Intra RO those issues are given below.

- Signaling

When a mobile network moves, only the MR to which the movement is visible needs to perform signaling with its HA. Signaling packets competes with data packets for bandwidth not only inside the mobile network but also in the Internet.

- Memory requirement

The schemes have to maintain various state information, regarding the route and CN-MNN pairs. Example: small sensors and PDAs.

- Degree of RO

In an effort to trade off issues, such as signaling, some schemes allow one or two levels of tunneling or some non-optimality in the route between a CN and an MNN.

- Header overhead

Header overhead is the additional information that is put into the header for RO. Header overhead consumes bandwidth and increases chance of fragmentation.

- Deploy-ability

Changes in mobility entities are tolerable because they are going to be introduced in the existing infrastructure if NEMO support is required. Changes in functionalities in hosts and routers in the existing infrastructure may not be easily applicable resulting in concern about deploy-ability issue.

- Location management

Location management is tracking the location of an MNN to ensure reach ability and session continuity. In NEMO BSP and some RO schemes, location management is performed by HA.

- Location transparency

In NEMO BSP, MNNs except MRs and CNs are transparent.

5 Route Optimization Schemes

There are several RO schemes have been proposed to resolve the issues in RO. Based on approach used, the various RO schemes that have been proposed can be generally classified as:

- Delegation
- Hierarchical
- Source Routing
- Border Gateway Protocol (BGP)-assisted

A. Delegation Schemes

In these schemes, prefix of the foreign network is delegated inside the mobile network. MCNs contain CoAs from the prefix and send BUs to respective HAs and CNs. So, any packet from CN, addressed to CoA, reached the foreign network without going through HAs.

B. Hierarchical Schemes

In the hierarchical class, a packet, rather than traveling through all HAs, reaches the foreign network either from MNNs HA (first HA) or traveling only through HA of MNN and TLMR. Unlike delegation-based approach, an MR does not send its CoA to CNs. Rather; an MR sends TLMRs CoA or HoA to HA. CNs use MNNs HoA to send packets to an MNN. Packets, sent by CN to MNN, reach MNNs HA that tunnels the packets to TLMRs CoA or HoA. Packets, tunneled to CoA, directly reach the foreign network, whereas packets, tunneled to HoA, reach TLMRs HA that tunnels packets to TLMR. On reaching TLMR, packets are routed to MNN by MRs that maintains a routing table containing the mapping of MNNs prefix to next hop MR.

C. Source Routing Schemes

In this Schemes, RO is achieved by sending the CoAs of MRs to the CN which, like source routing, inserts the CoAs in the packet header to reflect the nesting structure of the MRs. This however, results in increased header overhead. Packets from the CN reach TLMR in an optimal route (without going through HAs); routing within the mobile network is done using the CoAs in the packet header. Memory requirement for rout- ing entries is low because each MR needs to keep track of only the attached MRs as next hop. Schemes in this class notify CN about the CoAs of MRs in various ways that will be detailed in the descriptions of the schemes. Notification of CoAs to CNs sacrifices location transparency and increases signaling. Methods of notifying the CN result in differences in signaling and overheads. Moreover, the schemes also have different memory requirement for routing packets inside the mobile network.

D. Border Gateway Protocol (BGP)-assisted Schemes

The schemes in this class rely on BGP [18] for mobility management. When the mobile network moves, BGP routers are updated to make necessary changes in the routing tables by making forwarding entries for the prefix of the mobile network. Information regarding the change of route of the mobile network is signaled to few routers that exchange the information with peers using existing routing protocols in the Internet. Therefore, routers contain routing entries to route packets to the mobile network irrespective of its location, and are responsible for location management. Schemes in this class mainly differ in the number of external BGP updates generated, and incurring other overheads for managing Intra RO.

6 Route Optimization Scenarios and Proposed Solutions

There are many Route Optimization techniques that have been proposed. The techniques can be classified as the following.

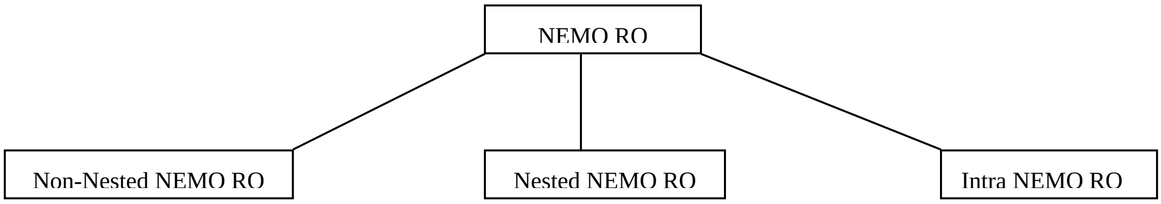

Figure 5: Classification of NEMO route optimization

A. Non-Nested NEMO Route Optimization:

Non-Nested NEMO Route Optimization deals with optimizing the route between MNN and CN. This kind of optimization technique does not involve nested networks or VMNs. The MR locates a correspondent router (CR), topologically close to the CN and establishes a bi-directional (MR-CR) tunnel with it. This is done by binding the CoA of the MR with its HA, and sending this BU to the CR. Traffic between the MNN and CN would now be forwarded through the tunnel, by-passing the HA. Traffic originating from the CN with the mobile network as its destination, is intercepted by the CR and tunneled down the (MR-CR) tunnel. If the CN is a MNN and the CR is the MR for its mobile network, the MR sets up a tunnel with the CR by means of a BU and thus packets between the MNN and CN would now be forwarded through this tunnel, forgoing the respective HAs. This kind of optimization works best where the CR is topologically closer to the CN than the HA.

Optimized Route Cache Management Protocol (ORC) [22, 23] provides a similar solution. ORC maintains an association between the prefix of the mobile network and its current CoA. This association is called a Binding Route (BR) and is kept in the caches of Interior Gateway Protocol (IGP) routers, also known as ORC routers. Packets with the mobile network as the destination address are intercepted by these ORC routers and forwarded to the mobile network via the BR. ORC provides network transparency which is an essential part of NEMO Basic Protocol, through the assignment of a unique subnet prefix to the mobile network. Also ORC is implemented on the existing routing infrastructure, which gives it scalability. The performance of the ORC scheme depends on the vicinity of the ORC router to the CN. This scheme would only provide optimal routing if ORC routers are available on CN's network. This scheme also requires significant support from the network infrastructure.

Another solution could be using the ***Prefix Scope Binding Update Protocol (PSBU)*** [8] from MIPv6. Under this, the CN keeps two bindings for a MR. One for the MR's home address (dealing with host mobility) and another for the mobile network prefix. The problem with this is that the MR has to send BUs to all the CNs, with which the mobile network is communicating. These BUs increase as the number of CNs increase. This adds to the processing load of the MR. Also since each CN manages two binding cache entries (home address and mobile network prefix) for each MR, an increase in the number of MRs would mean a double increase in the binding management cost of the CN. Putting all the CNs in a multicast group to which the MR sends a single BU, thus reducing the signaling overhead, could solve this. But there might be some security issues involved in this and performance depends on the multicast protocol used.

Mobile Router Tunneling Protocol [11] describes a solution where a permanent tunnel between the HA and the MR is maintained. This solution has a problem of creating a possible bottleneck since all the packets are routed through the HA. As the number of nodes inside the mobile network increase so does the processing load on the HA.

A proposal by Na et al. [13] lets the HA, while sending a packet to a CN, piggy back extra information on the packet. This extra information called the ***Path Control Header (PCH)*** specifies the CoA of the MR. A CR can catch this PCH containing packet and initiate a route optimization tunnel between the CR and the MR. The CR does this by sending a binding request to the MR. A BU and a binding acknowledgment then complete the procedure.

B. Nested NEMO Route Optimization:

Nested Mobility deals with the scenario where a MIPv6 enabled node, whose home network prefix is different from the mobile network prefix i.e. its home link is not the same as that of the mobile network, comes and attaches itself to the MR. This can be a single MIPv6 enable host or it can be a MR. The attaching MR can also have nodes behind it, thus forming a sub-NEMO inside a parent-NEMO.

Basically, this type of Route Optimization deals with 2 issues:

i) Decreasing the number of Home Agents on the path,

ii) Decreasing the number of tunnels.

There are various existing Route Optimization schemes which consider the aforementioned 2 issues.

A solution, which utilizes the route optimization mechanism of MIPv6, proposes an ***Access Router Option (ARO)*** [14] to this mechanism. In this approach, the home agents of the MRs collect binding information from upper level MRs one by one and deduce the optimal route recursively. This approach is simple and needs minimum changes in the existing NEMO basic support protocol. However, since the route is optimized step by step, the process needs a long convergence time, which is proportional to the degree of nesting. In ARO, the whole binding cache in the HA has to be searched recursively to find the optimal path to the MNN and the number of recursive steps for each packet is proportional to its degree of nesting. Furthermore, since the CN also participates in the route optimization mechanism, location privacy is not guaranteed.

Fast_RO is a technique which, unlike other RO techniques does consider the environment where the levels of nesting are changed continuously. If a group with partial levels of nesting in a nested mobile network moves to another mobile network, the Top Level MR (TLMR) is changed, the route optimization is not achieved or the communication is disrupted. For example, if users use a public transport system and transfer to another vehicle, the levels of nesting and TLMR are changed. In this environment, the user also wants to receive services such as real-time services or multimedia streaming without interruption. Thus, we need fast routing and route optimization after the handoff in which the TLMR is changed. After the TLMR is changed, the proposed scheme also has a constant convergence time during route optimization and supports seamless mobility to the users as well. Figure 6 shows the registration procedure when a VMN enters into the mobile network. Firstly, the addresses of nodes within the MAP domain are assigned hierarchically using a subnet Identifier. If the VMN enters into a mobile network, the VMN generates an initial CoA (ICoA) based on MR1 prefix. The VMN then performs binding-updates to the VMN's HA. The VMN sends a binding update message including the VMN's CoA and the HA sends a binding-acknowledgment message to the VMN. If the registration process is completed, the VMN is able to receive the packets through the HA without the registration to the MAP. After registration of VMN, the CN sends the packets whose destination address is the VMN's HoA (HA_VMN) in order to send a packet to the VMN. The VMN's HA intercepts the packets and checks its own binding-cache entry and tunnels them to the VMN's ICoA. Thus, packet is encapsulated only once. In the proposed scheme, the route optimization is achieved by a process in which the packet passes through the HA of the VMN (HA_VMN). The CN does not participate in the route optimization process of the proposed scheme to prevent the binding-update storm problem after the handoff. Therefore, even though a CN starts to communicate with a VMN of a mobile network, the CN does not require an extra process.

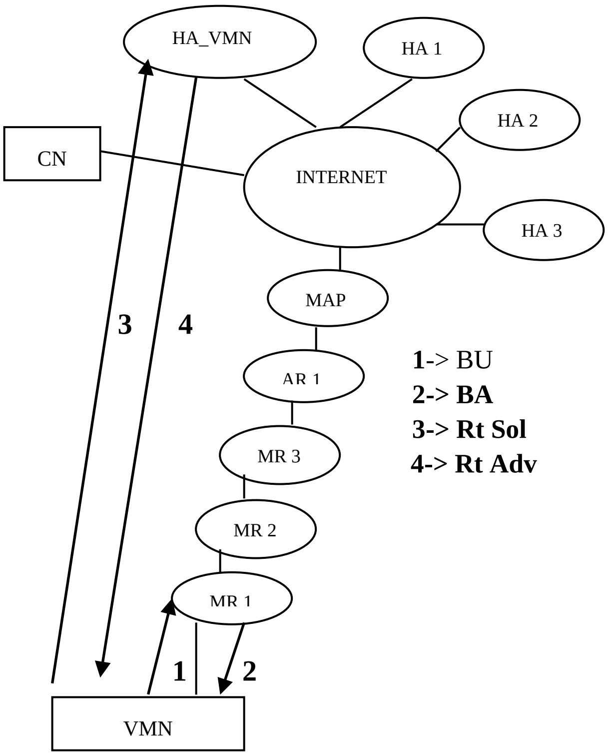

Figure 6: VMN enters mobile network (Registration)

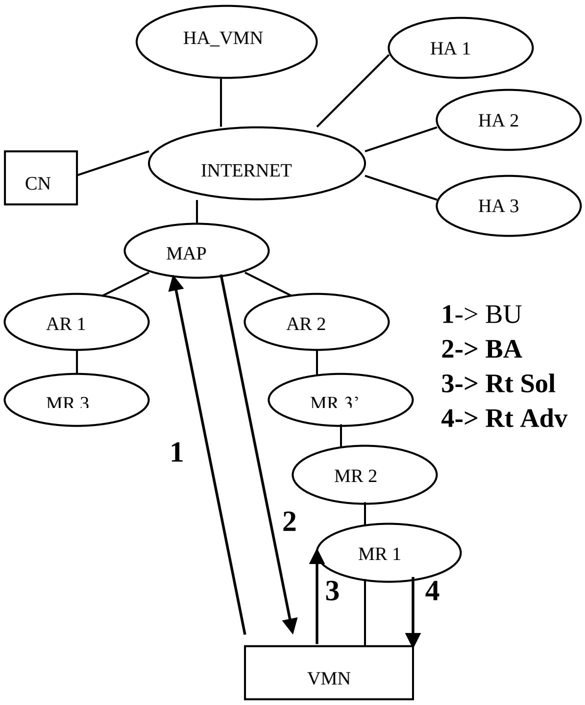

Figure 7: Handoff, TLMR is changed

Figure 7 illustrates the scenario where handoff occurs i.e. the TLMR is changed. After the handoff, hierarchical addresses are assigned to MR2, MR1 and VMN using the router solicitation (Rt Sol) and router advertisement (Rt Adv) messages. The VMN then registers the new CoA (NCoA) to the MAP using a binding-update (BU) and binding-ACK (BA) messages. The MAP stores the NCoA and ICoA in the binding cache and performs a proxy neighbor advertisement on behalf of VMN. This is due to the fact that the VMN's HA(HA_VMN) does not know whether the handoff occurs and the packets are still forwarded to the VMN's ICoA. After this, the MAP intercepts the packets destined to the VMN's ICoA and tunnels them to the VMN's NCoA. Following this, the route optimization is completed as VMN registers the NCoA only to MAP. In this way, although the handoff occurs where the TLMR is changed, the proposed scheme enables communication between a CN and VMN as well as the seamless handoff.

Ad hoc On Demand Vector (AODV) based RO is based on Ad hoc On Demand Vector (AODV) routing protocol which is reactive in nature and tense to offer quick adaption to dynamic link conditions, low processing and memory overhead, low network utilization, and determines unicast routes to destinations within the ad hoc network

[4]. By implementing AODV, we are having the advantages such as routes need not be included in packet headers and nodes maintain routing tables containing entries only for routes in active use. As NEMO apparently appears quite similar with the mobile ad hoc network, the adaption of AODV into NEMO can benefit NEMO with those advantages as stated. Adapting AODV in NEMO leads to optimization of route in 2 ways:

Optimized Route in Intra NEMO **:** First, Intra-NEMO here is a scenario where there exist a nested NEMO networks. In this context, it will be the MRs and mobile nodes which are located behind the AR. As illustrated in Figure 7, when a mobile network with MR C as the MR joins the network, MR C will need to get a CoA from MR B network. MR C will then need to send a BU to HA C to inform HA C about its current point of attachment. This process is described in NEMO. Now comes the use of AODV routing protocol to NEMO. As the MR C going to send a BU to HA C, MR C is the source node and HA C is the destination node. Meanwhile, MR B, MR A and the Access Router (AR) have become the intermediate nodes. MR C will now initialize a route discovery phase by broadcasting a RREQ message. The RREQ message will be traversed accordingly until it reaches the destination HA C or any of the intermediate nodes that has a current and valid route to the destination HA C. Each intermediate node will then get a RREP message from the predecessor nodes accordingly until the RREP message is received by the source node. Upon the successful route discovery, the BU will then be sent to the HA C. Each mobile router has its own routing table constructed. Each intermediate nodes will have a valid route to HA C and each intermediate nodes will also keep an entry of route in their routing table. For example, MR B will have MR A to AR and to HA C in its routing table. The full path of HA C to reach MR C will be registered at HA C. Since every MR has the information on each other, route optimization inside the nested NEMO can be achieved easily. For a scenario where a laptop (VMN_C) under MR C mobile network wish to send a packet to the laptop (VMN_B) inside MR B mobile network, all the MR C need to do is to check a valid route entry in its own routing table for destination MR B. This route initialization phase is not triggered by this event but already being setup during the time when MR C would like to send a BU to HA C. From these procedures, the nested NEMO can handle the traffic themselves without routing through the access router and find their HA respectively to have the packet sent. The nodes inside the mobile network can communicate directly through the link between their mobile routers. This will greatly reduced the packet overhead issues and also the sub optimal problem faced in NEMO.

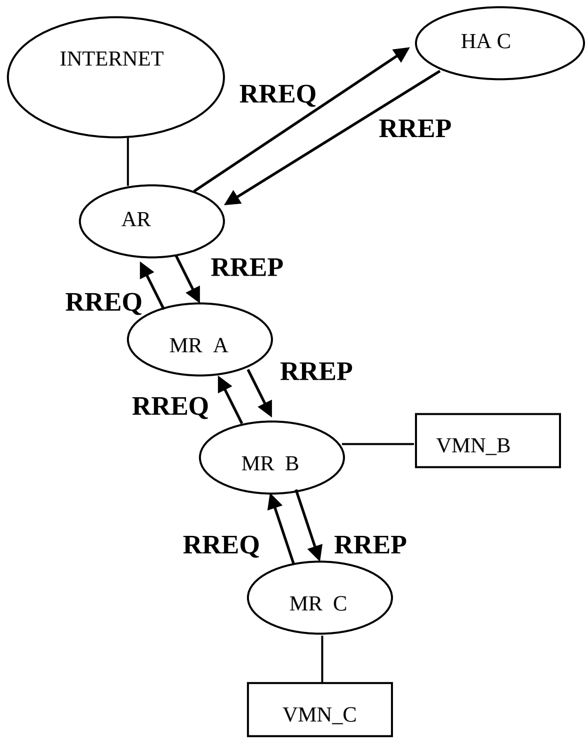

Figure 8: AODV in nested NEMO

Optimized Route in Inter NEMO: As shown in Figure 8, the route from HA C to MR C or any MR that is located behind the access router (AR) has been fully discovered. Therefore, the communication of any corresponding node with any nodes inside the network is optimized. When a corresponding node is attached to the internet, suppose it would like to send a packet to the laptop (VMN_C) which is attached to MR C. The corresponding node will forward the packet to the laptop's home network which is the HA C. With the routing entry to reach MR C stored earlier, the packet will be forwarded directly to the access router (AR) and accordingly until it reaches MR C. The packet sent from the corresponding node only visits HA C but not HA B, HA A. Thus with the elimination of pinball routing, number of encapsulations is minimized to only one. If CN wants to send a packet to VMN_C, it will be first forwarded to HA C. Since, HA C has the full route defined in its routing table to reach MR C, it encapsulates the packet with CoA of MR C and forward to next hop which is the AR. The AR has the entry of next hop MR A, MR A has the entry of MR B, and MR B of MR C. MR C now decapsulates the packet and forwards it to VMN_C.

Route Optimization using Tree Information Option (ROTIO) [2] considers LFN instead of VMN where each MR in the nested mobile network sends two binding updates (BUs): one to its home agent (Normal BU) and the other to the TLMR (Local BU). The Normal BU contains the TLMR’s home address, while the Local BU contains routing information between the issuing MR and the TLMR. Now, a packet from a correspondent node (CN) only needs to visit two transit nodes (the home agents of the MR and the TLMR), regardless of the degree of nesting. Moreover, the ROTIO scheme provides location privacy and mobility transparency. We also extend ROTIO to perform routing between two mobile network nodes inside the same nested mobile network more efficiently and to substantially reduce the disruption when a mobile network hands off.

Figure 9 illustrates forward route optimization. A packet sent from the CN toward the LFN is routed to the closest MR’s HA. Since IMR3’s HA already has the binding information that IMR3 (the closest MR to the LFN) is located below the TLMR, the packet is encapsulated and sent to the HA of the TLMR. When the packet is delivered to the HA of the TLMR, it is encapsulated again and sent to the current location (CoA) of the TLMR. After receiving the packet, the TLMR decapsulates it and searches its binding cache to find the route to reach LFN. By searching the binding cache, the TLMR discovers that the LFN is reachable via IMR1, IMR2, and IMR3. The TLMR forwards the packet using source routing. When the packet arrives at IMR3, it decapsulates the packet and forwards it towards the LFN. There are only two levels of nested tunnels: 1) between the closest MR and its HA and 2) between the TLMR and its HA. This forward route optimization mechanism provides transparent mobility by sending BU messages only at BU intervals and location privacy is achieved by passing packets via two HAs.

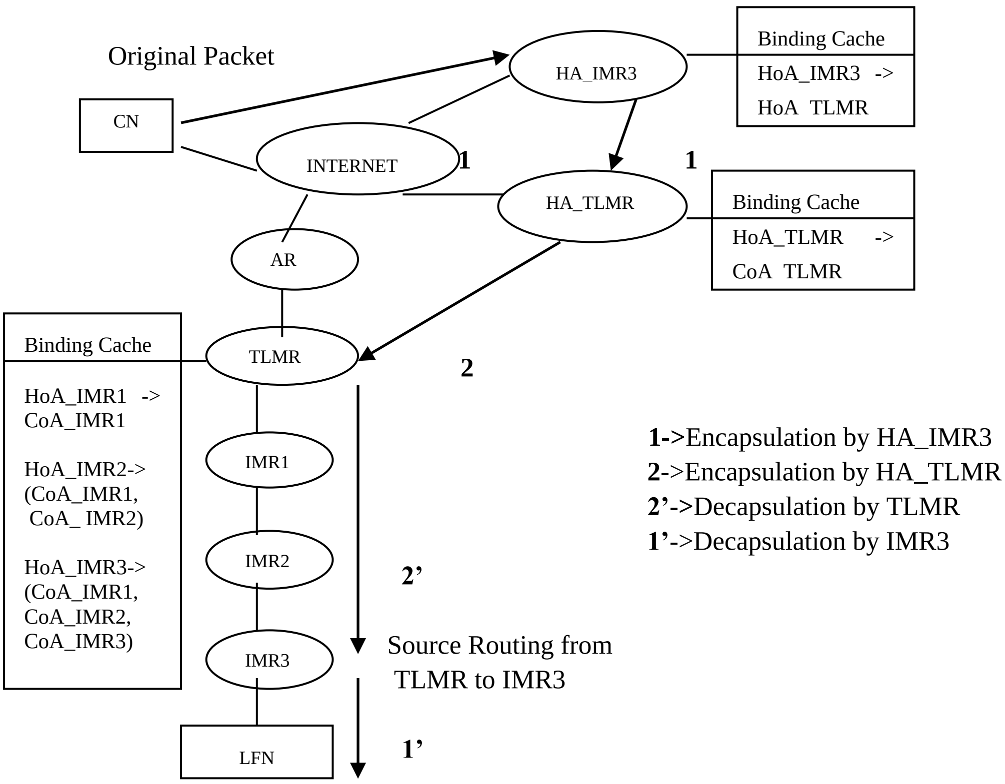

Figure 9: Forward route optimization in ROTIO

To optimize the reverse routing path, there need to be some modifications to the operation of the IMRs. As in forward route optimization, we use two-level nested tunneling: only the closest MR encapsulates the packet generated by its LFN and sends it to its HA, while the other IMRs simply relay that packet toward the TLMR. Figure 10 illustrates reverse route optimization from the LFN to the CN. When IMR2 receives a packet from the LFN, IMR2 encapsulates that packet and sends it to its HA. At this time, the source address of the outer header should be the HoA of the TLMR to protect it from ingress filtering at the HA of the TLMR. IMR1 simply relays the encapsulated packet to the TLMR, which encapsulates the packet once again and sends it to its HA. The packet is routed to the CN via the HA of the TLMR and then via the HA of IMR2.

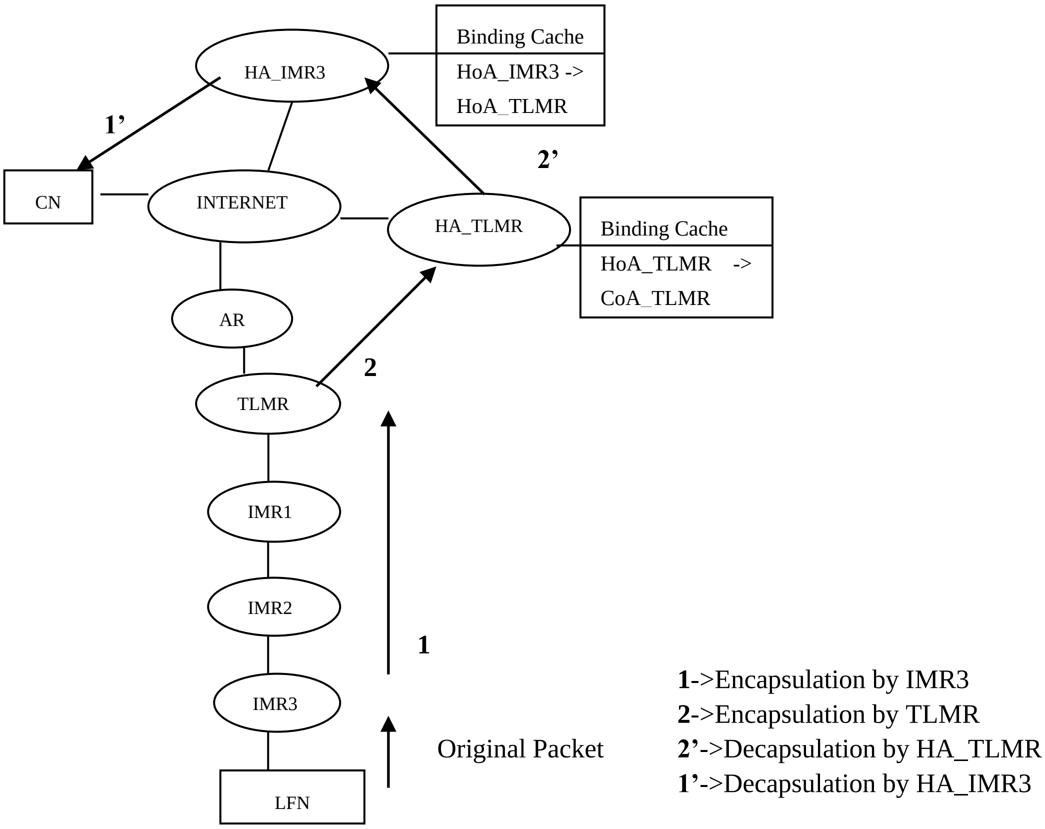

Figure 10: Reverse route optimization in ROTIO

ROTIO+ **-** an improved version of ROTIO reduces number of encapsulations from two to one. The modifications made in the ROTIO techniques are regarding the RA messages and the normal BU of IMR that is sent to the corresponding HA.

*RA messages***:** The TLMR and IMR will continue to use the TIO and xTIO option in the RA messages to MRs down the tree. However, the first address field after the TreeID will contain CoA of TLMR. The CoA of IMRs will follow it.

*Normal BU***:** The IMRs will send two BUs to the corresponding HA in the same message. The first one being the primary routing address which will be the CoA of the TLMR and the second one being the alternate routing address which will be the HoA of TLMR.

In case of forward Route Optimization, a packet sent from CN to LFN is routed to closest MR's HA (IMR3 of Figure 9).Since IMR3's HA already has the binding information that the IMR3 is located below TLMR, the packet is encapsulated and sent to the CoA of TLMR. After receiving the packet, the TLMR searches its binding cache to find the route to the LFN. By searching the binding cache the TLMR discovers that the LFN is reachable via IMR1, IMR2, and IMR3. The TLMR forwards the packet using source routing. When the packet arrives at the IMR3, it decapsulates the packet and forwards the packet towards the LFN. Thus, the number of encapsulations is reduced from two (ROTIO) to one.

The reverse route optimization also requires some modifications in the IMRs and the TLMR. There will be just one level of encapsulation at the immediate MR. Rest of the MRs including TLMR, will relay the packet up till the access router. The encapsulation in the immediate MR is preventing ingress filtering at the HA of the IMR.

C. *Intra NEMO Route Optimization:*

This is a scenario where two corresponding mobile network nodes (MNNs) are within the same nested network. According to the NBS, a packet sent from one MNN to another must leave the nested network, visit the corresponding HAs of each MRs before reaching another MNN. This increases packet size and transmission delay. Also there are chances of disruption of services when the gateway to the Internet, i.e. TLMR gets disconnected. The solution of this problem requires that the traffic between two MNNs nested within the same network should follow a direct path between them without being routed out of the mobile network. Examples include Mobility Anchor Points (MAP) [19] and ROTIO [2].

7 Performance Evaluation in NEMO RO Techniques

To evaluate the performances of various NEMO RO techniques discussed above we consider some performance metrics viz. packet size, processing time for encapsulation and decapsulation, Packet delay time, number of bytes required for storing all BU messages etc.

1) Packet Size (S): The packet size plays an important role in evaluating the performance of the RO schemes as because when original packet is encapsulated and tunneled to the CoA, an outer header is added to the original packet of size 20 bytes. Let us consider the original IP packet size to be (20+d) and depth of the deepest MR in nested network is L. Also, we assume the original IP packet size is 1400 bytes including header. The packet sizes in different schemes are shown below:

In NBS scheme, S = [(20+d)+20*(L+1)]
= 1440, for L=1
= 1460, for L=2
= 1480, for L=3 and so on.

In ROTIO scheme, S = [(20+d)+20*2] = 1440, since only two encapsulations are there irrespective of depth of nesting (at least two levels of nesting is required).

In ROTIO+ scheme, S = [(20+d)+20] = 1420,since only one encapsulation occurs irrespective of degree of nesting (at least two levels of nesting is required).

In Fast_RO scheme, S = [(20+d)+20] = 1420, since the number of encapsulation is one.

In AODV_RO scheme, S = [(20+d)+20] = 1420 and the reason is same as above.

Also let us consider that the maximum transmission unit (MTU) is 1500 bytes. Thus, in NBS, packet needs to be fragmented after four encapsulations. The overall comparison is depicted in Figure 11.

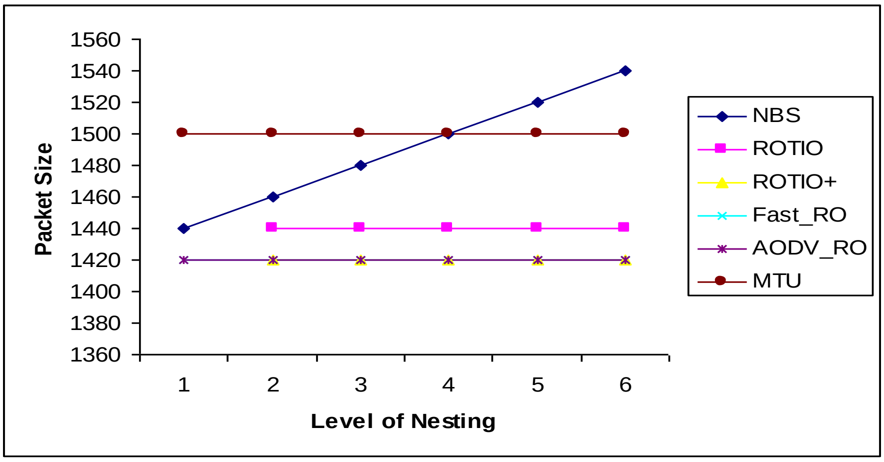

Figure 11: Comparison of packet size in different RO schemes

2) Packet Delay Time (Dt): This metric depicts the delay time for transmission of packet from one network to another. If the HAs are located at far distance, the packet has to travel a longer route which may lead to packet delay. We assume that all corresponding HAs are equi-distant and delay time between nodes within a network is negligible. Also wireless channel delay is assumed to be very small so that we can ignore it. We assume the delay time for transmitting packets from CN to a particular HA and between HAs of different network is taken to be 40 ms. Then, for different RO schemes, the delay time is given below.

NBS scheme: Dt = delay from CN to HA_VMN + delay from HA_VMN to HA_1 + delay from HA_1 to AR = 120 ms, for L=1.Accordingly, for L=2, Dt = 160 ms. For L=3, Dt = 200 ms and so on.

ROTIO scheme: Dt = 120 ms.

ROTIO+ scheme: Dt = 80 ms.

Fast_RO scheme: Dt = 80 ms and

for AODV_RO: Dt = 80 ms. This is depicted in Figure 12.

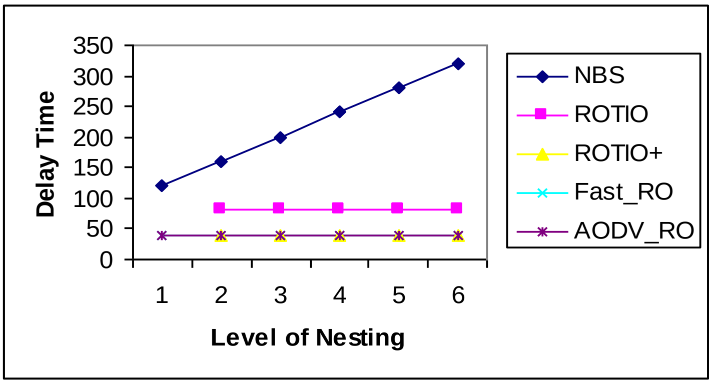

Figure 12: Comparison of packet delay time in different RO schemes

3) Processing Time (Pt): Encapsulations and corresponding decapsulation at different nodes results in increased processing time of the packet at each node the packet has to pass through. Encapsulation means adding an outer header to the original IP packet and decapsulation means removal of that particular header at a specific node. Let us consider the encapsulation processing time to be 20 ms and L be the depth of the deepest MR in the nested network. Then, the processing times are:

For NBS scheme, Pt = (L+1)*20 = 40 ms for L=1

= 60 ms for L=2 and so on.

For ROTIO scheme, Pt = 2*20 = 40 ms for a network of any depth.

For ROTIO+ scheme, Pt = 1*20 = 20 ms.

For Fast_RO scheme, Pt = 1*20 = 20 ms and

for AODV_RO scheme, Pt = 1*20 = 20 ms. Figure 13 depicts the scenario.

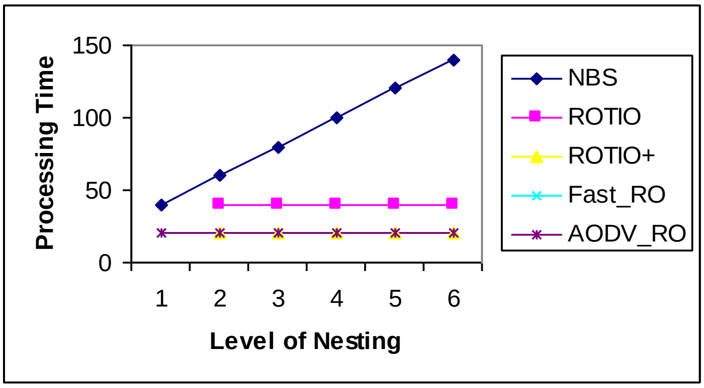

Figure 13: Comparison of processing time in different RO schemes

4) Number of bytes required for all BU messages (Cbu): Whenever an MR or an mobile node changes their location from their home network to foreign network or from one foreign network to another foreign network, they must register their current location to their corresponding HA by sending an BU message which is stored in the binding cache of the HA. The number of bytes thus stored for all BU messages should be considered as an important metric. Considering the byte size of BU messages being 1000 bytes and L being the depth of the deepest MR, we calculate the above metric for different RO schemes as below.

For NBS, Cm = 1000*(L+1) = 2000 for L=1

= 3000 for L=2 and so on.

For ROTIO, Cm = [(2*1000)*(L-1)]+1000 = 3000 for L=2
= 5000 for L=3 and so on as because each intermediate MRs send 2 BU messages and the TLMR sends only one BU.

For ROTIO+, Cm = [{(2*1000)*(L-1)}+1000*(L-1)]+1000 = 4000 for L=2
= 7000 for L=3 and so on.

For Fast_RO, Cm = (1000*L)+2*1000 = 3000 for L=1
= 4000 for L=2 and so on.

For AODV_RO, Cm = 1000*L = 1000 for L=1
= 2000 for L=2 and so on.

In this particular scheme we are ignoring the delay for route discovery before sending BU messages. The scenario is depicted in Figure 14.

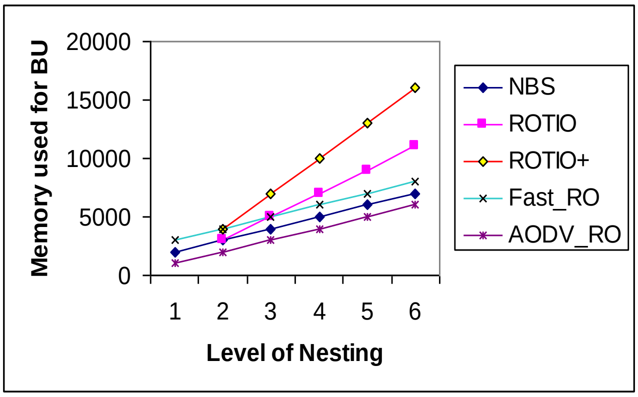

Figure 14: Comparison of memories used for BU messages in different RO schemes

8 Issues and Future Work

Route optimization schemes certainly recover from the problems of NBS but at the same time can also bring about new problems. This section looks at some of the issues that might be needed to be addressed in route optimization schemes. These issues are required to be addressed in near future to make NEMO beneficial and more efficient.

Signaling Overflow: Route optimization techniques require additional signaling messages, which might exceed the amount of signaling allowed in the NEMO Basic Support protocol. Therefore, the focus should be on the amount of signaling required in the effort needed to make an optimized route.

Complexity and Processing Load: Implementation of Route Optimization schemes requires more complexity on behalf of nodes than already required for NEMO basic support protocol. This fact has to be taken into consideration due to limited processing resources and limited power in mobile nodes.

Delay during Handoff: Route Optimization schemes may take longer to finish their handoff procedures than NEMO Basic Support due to the additional signaling involved. This increase in handoff delay affects performance of application.

Detection and Integration of Nodes with New Functionalities: NEMO route optimization might require some nodes to be changed or upgraded. A mechanism would be needed to detect support for these new functions, before route optimization can be initiated.

Mobility Transparency and Location Privacy: Some route optimization schemes might require MRs to reveal the point of attachment to the mobile network nodes. This might mean trading off the Mobility Transparency and Location Privacy offered by the NEMO Basic Support, for an optimized route.

Security: Route optimization can involve nodes, which might belong to different administrative domains e.g. MR and a Correspondent Entity (CR or CN). Such a binding offers weaker security than bindings within the same administrative domain e.g. HA and MR. It might be helpful to look at some of the security issues considered in the designing of Mobile IPv6 Route Optimization [1].

Need of a unique solution: There is different route optimization solutions suggested for different scenarios. Still there is not even a single solution which fits well for all the possible scenarios. Need of the hour is a single solution which fits well in all possible situations.

Table 1: A comparison of the RO schemes in different perspectives

RO criteria	NBS	ARO	AODV_RO	RRH	HMIP_RO	ROTIO	ROTIO+	Fast_RO
End-to-End Route Optimization	Poor	Good	Good	Good	Moderate	Moderate+	Good	Good
Location Privacy	Strong	Weak	Moderate	Weak	Strong	Strong	Strong	Strong
Mobility Transparency	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Intra-NEMO Route Optimization	Poor	Poor	Good	Poor	Moderate	Good	Good	Good
Handoff Disruption	Moderate	Poor	Moderate	Poor	Moderate	Good	Moderate+	Good
Packet Overhead	Heavy	Light	Light	Heavy	Light	Moderate+	Light	Light
Processing Overhead	Light	Moderate	Light	Moderate	Heavy	Moderate+	Light	Light
Convergence Time(C)	O(N)	O(N)	O(1)	O(N)	O(N)	O(1)	O(1)	O(1)
Handoff, TLMR changed	No	No	No	No	No	Restrictive	Restrictive	Yes

9 Conclusions

NEtwork MObility (NEMO) has various features such as wireless links, sub-NEMO mobility patterns, connectivity to the Internet, and nestedness. In particular, NEMO has different impacts according to the method of configuring an address in the nested NEMO, because the major applications of NEMO require connectivity with the Internet. However, NEMO basic support involves the configuration of a TICA (Topologically Incorrect Address) as an CoA in a visited network.

In this paper, we present classification and comparison among the RO schemes for NEMO. The number of RO schemes reported in this article indicates the exhausting and diverse efforts for RO, and therefore, requires a quantitative evaluation of the RO schemes to determine their suitability and adaptability to the existing Internet infrastructure.

The comparison among the schemes within each class reveals the differences among the schemes in more depth. Moreover, signaling and memory requirement depend on the number and types of MNNs in the mobile network, and therefore, might guide the selection of the schemes. Route optimization in NEMO is a developing field with a number of solutions provided till date. All these solutions are short of being declared unique and complete as all have some shortcomings. Signaling overflow, complexity, delay, detection of nodes and security issues are yet to be resolved. Hence no solution thus far claims to be fit for all the scenarios. Thus the focus should be on finding a unique route optimization solution which can address all the above mentioned issues. The following table compares some of the RO schemes in different perspectives.

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