Route Optimization Using Tree Information Option for Nested Mobile Networks

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***Abstract*—Mobile IP is the basic solution to provide host mobility, whereas network mobility refers to the concept of collective mobility of a set of nodes. In the simplest scenario, a mobile network moves as a single unit with one mobile router (MR) that connects it to the global Internet. Also, multiple mobile networks can be nested in a hierarchical form, e.g., a wireless personal area network (PAN) in a vehicular network. In a nested mobile network, multiple MRs form a tree hierarchy in which the root MR is called the top-level mobile router (TLMR). Nested mobile networks exhibit the pinball routing problem, which becomes worse in proportion to the number of nested levels in the hierarchy. To solve this problem, we propose a routing optimization scheme using a tree information option (ROTIO) that extends the NEMO basic support protocol. In the ROTIO scheme, each MR in the nested mobile network sends two binding updates (BUs): one to its home agent and the other to the TLMR. The former BU contains the TLMR's home address, while the latter contains routing information between the issuing MR and the TLMR. This alleviates the pinball routing problem significantly. Now, a packet from a correspondent node 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.**

***Index Terms*—Location privacy, mobility transparency, nested mobile network, network mobility, route optimization.**

I. Introduction

As UBIQUITOUS computing proliferates, more electronic devices become capable of wireless communications, often with their own Internet protocol (IP) addresses. The Mobile IP Working Group within the Internet Engineering Task Force (IETF) has proposed the Mobile IP protocol [1], [2] 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 an 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.

This is fine for a single node but a group of nodes in a single moving entity (i.e., a vehicle) may also need to be connected to the Internet. The Network mobility (NEMO[1]) 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 [4]. Such a network will include one or more mobile routers (MRs) that connect it to the global Internet. Basically, an MR has two interfaces; for egress and ingress. An MR can access the Internet through the egress interface and detect movements (by listening for router advertisement messages) and registers its location (by sending binding update messages) using the egress interface. 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.

There are two kind of MNNs: local fixed nodes (LFNs) and visiting mobile nodes (VMNs). An LFN belongs to the subnet of an MR and is unable to change its point of attachment, while a VMN is temporarily attached to the MR's subnet by obtaining its CoA. We focus on LFNs rather than VMNs, since a VMN is independent of the NEMO basic support protocol and only uses the Mobile IPv6 protocol. If we use the current Mobile IP protocol for the mobile network, a packet from a CN to the MR is successfully delivered but a packet destined for an MNN behind the MR is dropped at the HA of the MR, since the HA has no information about the MNN, only about the MR. To extend Mobile IP to support network mobility, the HA should have binding information about the mobile network prefix of the MR's ingress interface. The Network Mobility (NEMO) Working Group of the IETF [5] has focused on this issue and sought to extend the current Mobile IP to support network mobility. This extension is called the NEMO basic support protocol [3].

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. Fig. 1 illustrates a simple nested mobile network. Initially, MR_1, MR_2, and MR_3 are attached to their own home links. Suppose that the LFN is connected to MR_3's ingress interface. After MR_1 moves to a foreign link [MR_1 is attached to the access router (AR)], MR_2 is connected to MR_1. Then, MR_3 (with the LFN) is connected to MR_2. Fig. 1 is a snapshot at this moment. Note that the subnet of MR_1 is also the foreign link of MR_2. The same relation applies between MR_2 and MR_3. Here, MR_1 is the top-level mobile router (TLMR) of the nested mobile network and is deemed to be the gateway to the whole

[1]The abbreviation NEMO stands for either "a NEtwork that is MObile" or "NEtwork MObility."

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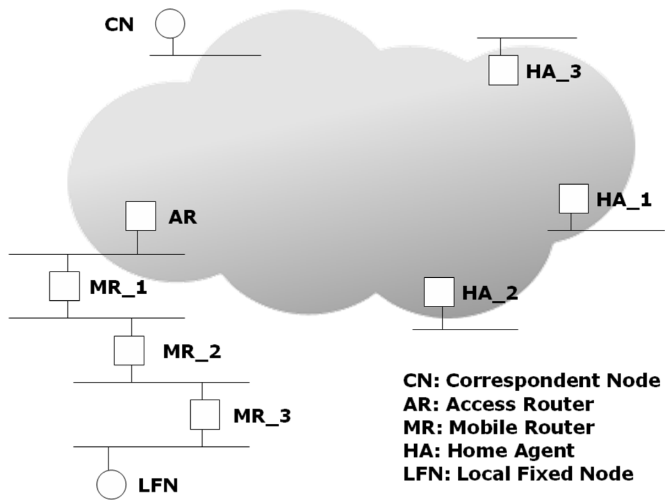

Fig. 1. A nested mobile network.

nested mobile network. From the perspective of the LFN, MR_3 is the closest MR. When a CN sends a packet to the LFN in the nested mobile network, the current NEMO protocol requires the packet to visit all the HAs of all the MRs (from the closest MR of the LFN to the TLMR). Note that HA_n is the HA of MR_n. As the degree of nesting increases, the packets destined for an LFN in a nested mobile network will suffer more and more inefficient routing. This is the so-called pinball routing problem, which will be detailed in the next section. To route IP packets efficiently in such complicated networking environments, the current NEMO basic support protocol should be extended [6]–[8].

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 exposed to a nonadministrative domain (e.g., a CN). However, the location privacy is not mandatory, since the mobile IPv6 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.

Several papers and Internet drafts [9]–[11] have proposed solutions to the pinball routing problem. ARO [9] is based on the route optimization mechanism of Mobile IPv6, which is then extended with an access router option. 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 correspondent node also participates in the route optimization mechanism, location privacy is not guaranteed.

RBU+ [12] is a modification of ARO, in which the optimal route is found when the binding update messages are received by the HAs. This recursive binding update allows the HAs to maintain the binding information for the CoA of the TLMR. To handle a packet that arrives at the TLMR, RBU+ adopts ad hoc network routing inside the mobile network. MRs can maintain a routing table (proactive) or construct a routing path on demand (reactive). However, the extensive handoff disruption caused by a long convergence time, and weak location privacy, are still problems in RBU+.

Another approach is that of reverse routing header (RRH) [10] and nested path information (NPI) [13], which use new extension headers to inform an MR's home agents of the nested structure of a mobile network and route the packets optimally, using multiple routing headers. In RRH, when a packet is sent from an MNN, each intermediate MR inserts its HoA into the reverse routing header of the packet. This means that, when a packet arrives at its destination, that node can determine the optimal route back to the MNN. RRH has the problem that this header modification needs to be performed for every outgoing packet. This problem is fixed in NPI, in which the binding update message is updated so that it informs the HAs (of the MRs) of the nested path information. However, when the TLMR moves to another site, the new nested path information will be propagated to the whole nested mobile network. After receiving this new information, every MR and VMN in the nested mobile network will send BUs at the same time; this is called a binding update storm [7].

HMIP-RO [11] borrows the concept of a mobility anchor point (MAP) from Hierarchical MIPv6 [14], and uses it to separate routing between the CN and the MAP (outside the NEMO) and routing inside the NEMO. HMIP-RO uses a modified version of HMIPv6 to propagate MAP advertisement messages. So an MR has two care-of addresses, as it would in HMIPv6 by listening to the MAP advertisement and router advertisement messages; one is the regional CoA from the MAP and another is the on-link CoA from its closest MR. By informing the HA of the MR of the regional CoA and the MAP of the on-link CoA, respectively, packets for the MR can be routed via the MAP. However, when the MR moves to the domain of another MAP, a similar problem may occur with NPI.

In this paper, we propose a routing optimization scheme for nested mobile networks, called Route Optimization using a Tree Information Option (ROTIO). ROTIO guarantees location privacy and mobility transparency. Our approach also achieves intra-NEMO route optimization and seamless handoff support by modifying router advertisement and binding update messages.

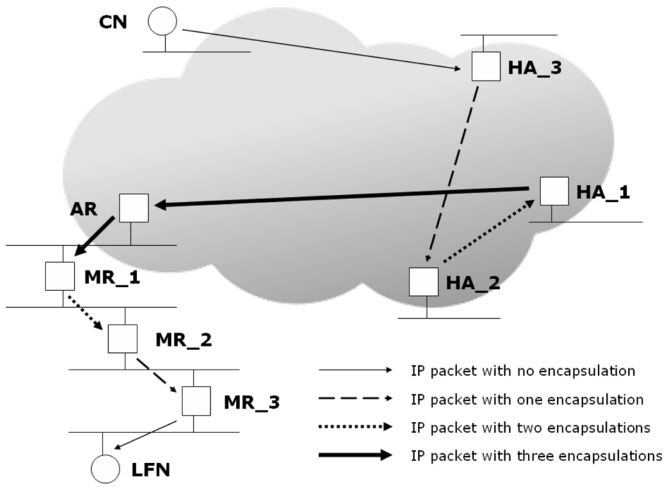

Fig. 2. Pinball routing problem in NEMO.

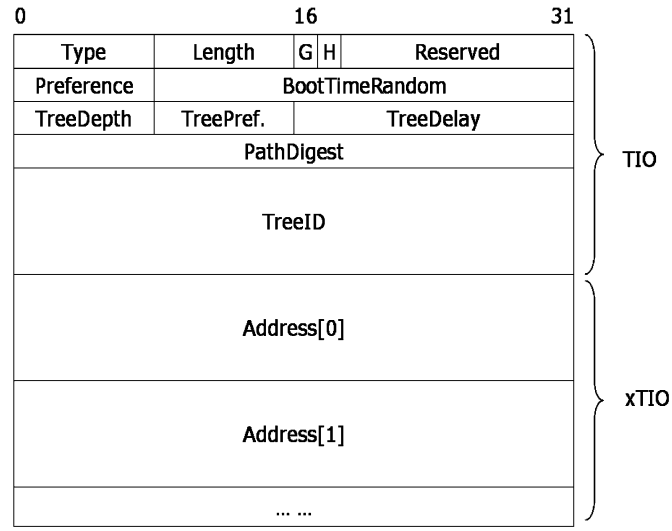

Fig. 3. Tree information option and xTIO suboption.

The rest of this paper is organized as follows. Section II introduces the pinball routing problem in NEMO and Section III describes ROTIO. In Section IV, we evaluate the performance of the ROTIO scheme by simulation. Finally, Section V concludes this paper.

II. The Pinball Routing Problem in NEMO

Nested mobile networks exhibit 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 level of the nested mobile network, the packet has to visit the HAs of all the MRs.

Fig. 2 illustrates the pinball routing problem with three degrees of nesting. First, the data going from a CN to an LFN is routed to MR_3's HA (HA_3). The binding cache of HA_3 contains the information that MR_3 is located below MR_2. So the data is tunneled to MR_2's HA (HA_2). At this point, HA_2 has binding information specifying that MR_2 is located below MR_1. So the data is encapsulated again and rerouted to MR_1's HA (HA_1). HA_1 tunnels the data once again and delivers it successfully to MR_1. In this case, the original data is encapsulated three times. The MRs decapsulate the packet and forward the packet to the LFN.

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.

III. ROTIO

To solve the pinball routing problem for nested mobile networks, we propose a route optimization scheme that is based on tree information option (TIO) [15].

A. *Extended TIO (xTIO)*

The tree information option (TIO) [15] avoids routing loops in a nested NEMO. Fig. 3 shows the TIO format in an RA message. To prevent a loop, MRs form a tree topology based on various metrics (the tree depth and preference fields in Fig. 3). We extend TIO by introducing a suboption called xTIO. xTIO contains the care-of addresses of the MRs in a nested mobile network. Additionally, xTIO is appended to each binding update message so as to inform an MR of all its ancestor MRs. In our scheme, router advertisement (RA) messages contain the xTIO. The TLMR forms an RA message with its HoA in the TreeID field and each MR appends its CoA using the xTIO suboption as the RA is propagated through the tree.

The ROTIO process is divided into two parts: basic ROTIO and extended ROTIO. Basic ROTIO defines the route optimization mechanism between the CN and the LFN on both the forward and the reverse routing path. Extended ROTIO supports intra-NEMO routing optimization and seamless handoff.

B. *Basic ROTIO*

When 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 the intermediate MR (IMR). Each IMR appends its CoA into the xTIO option and propagates the RA message downwards. By listening for this RA message, IMRs can maintain an IMR list,

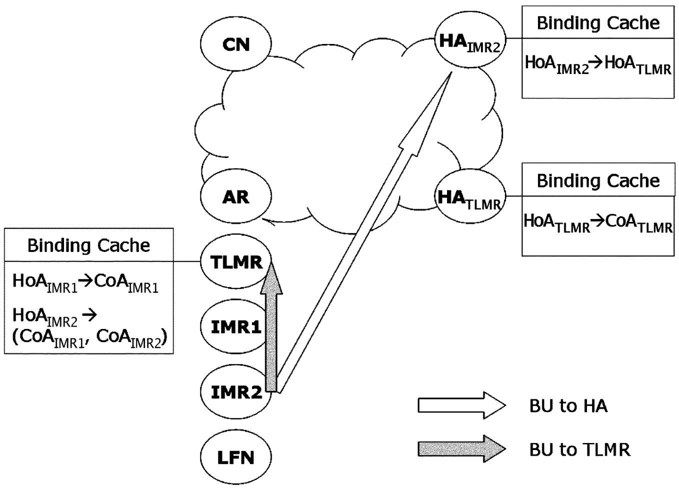

Fig. 4. Binding update of IMR2 in ROTIO.

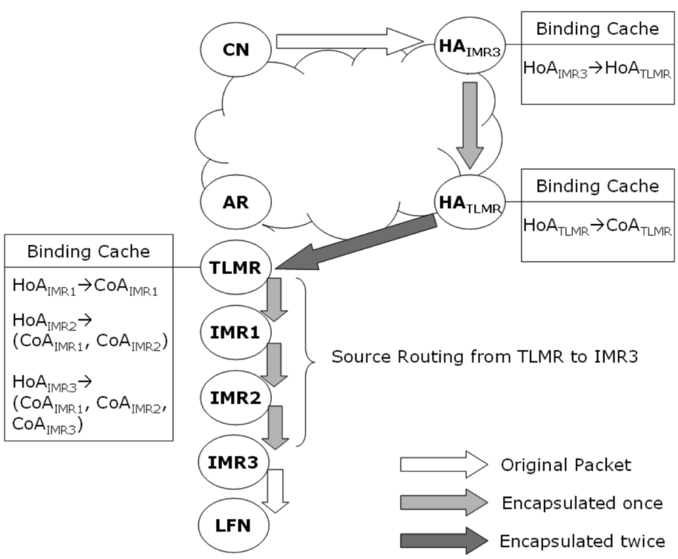

Fig. 5. Route optimization from the CN to the LFN.

that stores the list of CoAs of all ancestor MRs (for the TLMR, its HoA is stored). In ROTIO, each MR sends two kinds of BUs: a local BU and a normal BU. The local BU is sent to the TLMR and the normal BU is sent to the MR's HA. The IMR list is contained in the xTIO option of the local BU. Fig. 4 shows a ROTIO BU from IMR2's perspective. Even though it is not shown in Fig. 4, the TLMR sends a BU message to its HA to indicate that the TLMR has now reached by the CoA. IMR2 sends two BU messages (as shown in Fig. 4): one to its HA and the other to the TLMR. The BU message sent to the HA contains the HoA of the TLMR, which implies that the IMR2 is the descendant of the TLMR. The local BU message sent to the TLMR contains the xTIO option that lets the TLMR learn the topology of the nested mobile network.

Fig. 5 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.

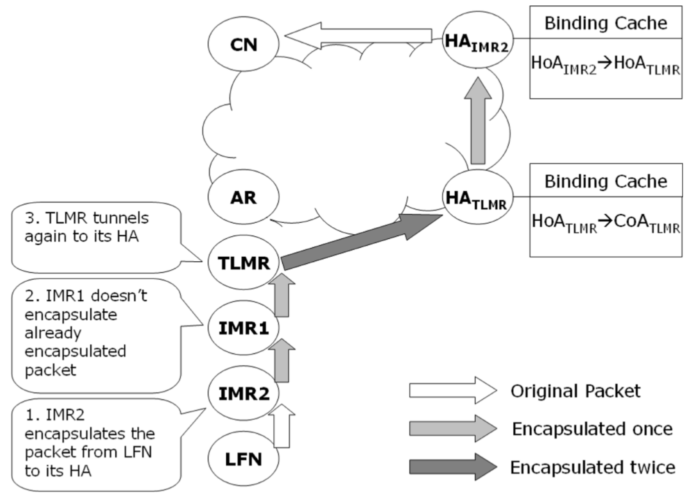

Fig. 6. Route optimization from the LFN to the CN.

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 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 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.

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. Fig. 6 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.

C. Extended ROTIO

In the basic ROTIO scheme, both forward and reverse route optimization can be achieved. But, there are also other issues such as intra-NEMO routing and seamless handoff. Using basic ROTIO, two LFNs belonging to different MRs do not know of each other's, even though the TLMR maintains the prefixes of all the IMRs inside the nested mobile network. This happens because the MR closest to an LFN encapsulates a packet destined for another LFN located at a different MR. Therefore, the TLMR cannot decide whether to tunnel that packet to its

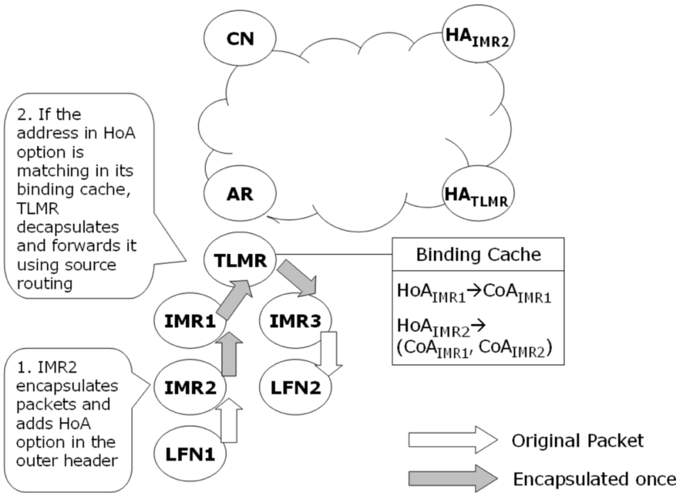

Fig. 7. Route optimization between LFNs in the same mobile network.

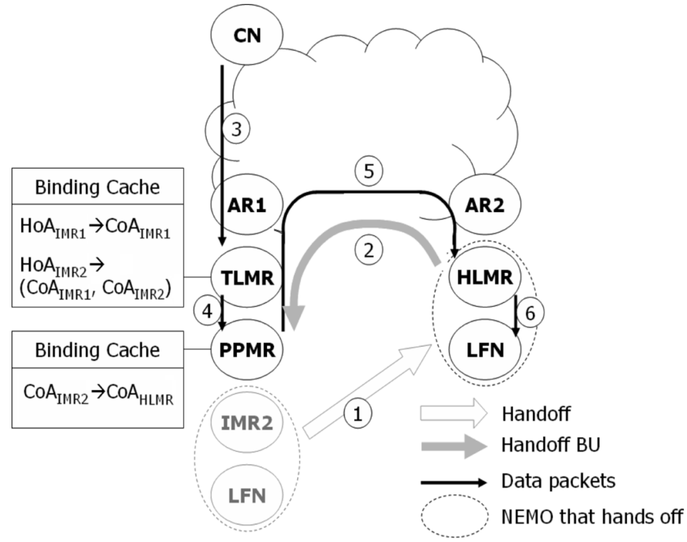

Fig. 8. Handoff considerations.

HA or to decapsulate the packet and perform source routing according to the data in its binding cache. To help the TLMR to perform intra-NEMO routing efficiently, the closest MR adds optional data to the outer header to inform the TLMR of the original destination. For this, we use the HoA option, rather than defining a new one, since the HoA option is not used for encapsulated packets. Fig. 7 illustrates intra-NEMO routing optimization. IMR2 encapsulates a packet from LFN1 and adds the HoA option to the outer header. When the TLMR receives that packet, it searches its binding cache to find out whether the destination address in the HoA option belongs to the mobile network itself or not. If there is a match in the binding cache, the TLMR decapsulates and forwards the packet using source routing. By using the intra-NEMO route optimization feature of extended ROTIO, the delay in communication significantly reduced.

In basic ROTIO, each MR sends the BU messages only when the BU timer expires (so as to prevent a BU storm), and not when the connectivity changes (as announced by a new RA message). However, this strategy will cause extensive disruption of active flows, since the BU interval is much longer that the RA interval. Basic ROTIO is augmented to provide seamless handoff: A previous parent MR (PPMR) and a handoff leader MR (HLMR) are defined when the tree topology changes (e.g., when a PAN disconnects from a vehicle network). When a subset of a nested NEMO (a subtree of a tree) is detached, the root MR of the departing subtree is the HLMR; and the MR to which the HLMR was attached is called the PPMR. Since each MR maintains an IMR list, as in the basic ROTIO scheme, during handoff the MRs of the subtree can detect changes in connectivity (by comparing the old IMR list with the new one), and therefore they know whether they are the HLMR or not. If an MR is the HLMR, it sends a handoff BU as soon as it detects its new connectivity to ask the PPMR to reroute packets in transit to the MR's subnet towards the new CoA of the HLMR. Fig. 8 illustrates the handoff operation in the extended ROTIO scheme when a CN sends packets to an LFN of IMR2. When IMR2 (attached below IMR1) moves to AR2 (Step 1 in Fig. 8), IMR2 becomes the HLMR and IMR1 becomes the PPMR. Once the HLMR detects the movement of itself (IMR2), it sends a BU (which will be called a handoff BU from now on) to the PPMR (Step 2). Because the HLMR knows the topology of the network from the TLMR to the PPMR, it can perform source routing, so that its handoff BU is routed within the mobile network as it existed before handoff. In this case, the handoff BU will traverse AR2, the HA of the TLMR, AR1, the TLMR, and the PPMR, in sequence. If the CN sends a packet before the HLMR's BU timer (normal BU, not handoff BU) expires, the packet is routed using the existing binding information in IMR2's HA (Step 3). Thus, the packet will arrive at the PPMR (Step 4). Since the PPMR knows where the HLMR is, it encapsulates the packet and sends it to the current location of the HLMR (Step 5). When the packet arrives at the HLMR, the HLMR removes the encapsulation header from the PPMR and resumes source routing to the LFN (Step 6). By sending the handoff BU with the HLMR's new CoA to the PPMR as soon as possible, the loss of packets during handoff is minimized. Furthermore, since only the HLMR performs the BU procedure, no BU storm will occur, even when the descendant MRs learn that their NEMO has changed its point of attachment. Table I compares existing route optimization schemes with ROTIO. The packet overhead is a quantification of the extent to which the header size is increased for each data packet. The processing overhead refers to the complexity of binding cache lookup and header modifications.

IV. Performance Evaluation

We will now compare the ROTIO scheme, the NEMO basic support protocol, and the RBU+ scheme by means of simulations. ROTIO requires no changes to existing Mobile IP except to the operation of MRs. It does not need any modifications of CNs or NEMO basic support-compliant HAs. We simulated ROTIO using Network Simulator 2 (NS2) [16] with the MobiWan [17] extension for MIPv6. Fig. 9 shows the MR node architecture for ROTIO. As shown in Fig. 9, an MR in ROTIO should have a binding cache that can encapsulate packets for sending not only to its HA but also to any other nodes. We evaluate the NEMO basic support protocol (NBS), the recursive

TABLE I
SUMMARIZED CHARACTERISTICS OF ROUTE OPTIMIZATION SCHEMES

RO criteria	NBS	ARO	RBU+	RRH	NPI	HMIP-RO	ROTIO
End-to-end route optimization	poor	good	moderate	good	good	moderate	good
Location privacy	strong	weak	weak	weak	weak	strong	strong
Mobility transparency	yes	yes	yes	no	no	no	yes
Intra-NEMO route optimization	poor	poor	moderate	poor	poor	moderate	good
Handoff disruption	moderate	poor	poor	poor	poor	moderate	good
Packet overhead	heavy	light	light	heavy	light	light	light
Processing overhead	light	moderate	moderate	moderate	moderate	heavy	moderate

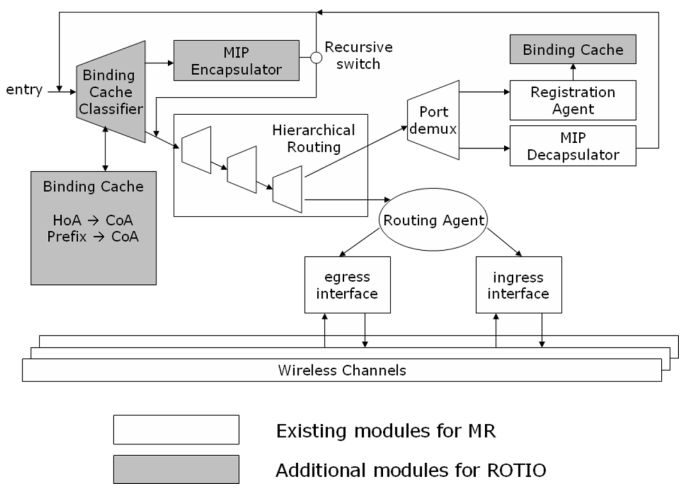

Fig. 9. MR node architecture for ROTIO in NS2.

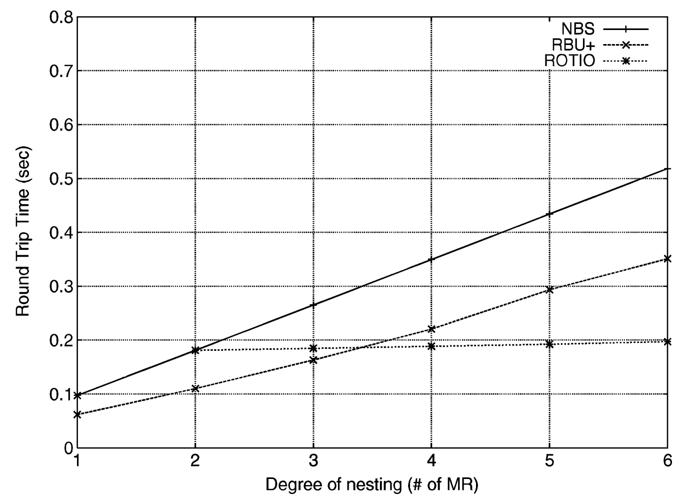

Fig. 11. The effect of the degree of nesting on RTT.

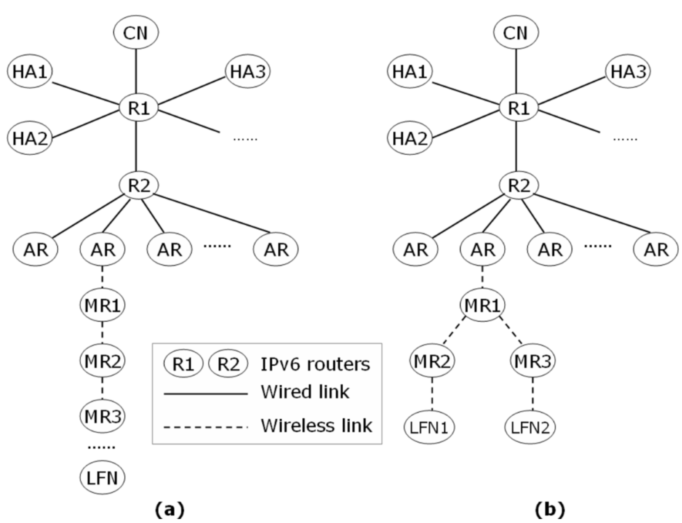

Fig. 10. Network topology for the ROTIO simulation.

binding update plus (RBU+), and the ROTIO scheme in terms of round-trip time (RTT) and handoff disruption time.

A. Route Optimization Between the CN and the MNN

The basic ROTIO scheme is focused on route optimization between the CN and the MNN in the nested mobile network. We define the cost of transmitting a packet as the RTT between the end hosts. Fig. 10(a) illustrates the topology of a nested mobile network. We varied the number of nested MRs from 1 to 6 and the link delay between the HA and the router (R1 in Fig. 10) from 10 to 100 ms. The bandwidth of the wired link is set to 100 Mb/s and that of the wireless link is set to 11 Mb/s. We measured the RTT between the CN and the MNN assuming that both the local BU and the normal BU have already been sent. Fig. 11 shows how the RTT changes as the degree of nesting increases. NBS and ROTIO exhibit exactly the same RTT for one and two degrees of nesting, since the ROTIO scheme needs at most two levels of nested tunneling. However, if there are three or more nesting levels, ROTIO yields almost the same RTT. In the case of RBU+, the RTT in the case of single MR is less than that for NBS and ROTIO, since RBU+ adopts the mobile IPv6 style of route optimization, with the CN being involved in route optimization. However, when the degree of nesting is deeper, ROTIO outperforms RBU+ while providing location privacy. Fig. 12 shows how the RTT changes as the distance between HAs increases. When the HAs are located close together, the routing inefficiency is not significant. But, as the distances among HAs increase, the RTT between the CN and the MNN also increases. The RTT of the ROTIO scheme increases slowly compared to the other schemes.

B. Route Optimization Between MNNs in the Same NEMO

The extended ROTIO scheme can localize a route between MNNs inside the same nested mobile network, since the basic ROTIO scheme maintains binding information in the binding cache of the TLMR. Fig. 10(b) shows the topology for intra-NEMO route optimization between LFN1 and LFN2. The degree of nesting is set to 2 and the distances between HAs are varied from 10 to 100 ms. We measured the RTT between LFN1 and LFN2. Fig. 13 shows how the RTT changes as the distances between HAs increases. For NBS and RBU+, the RTT increases

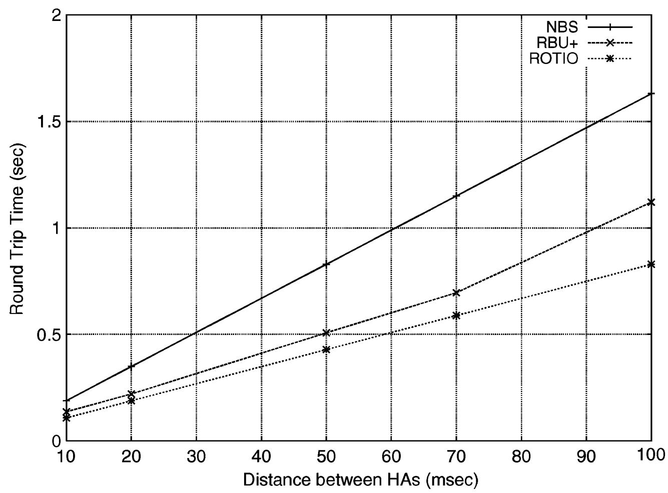

Fig. 12. How the RTT changes as the distance between HAs increases.

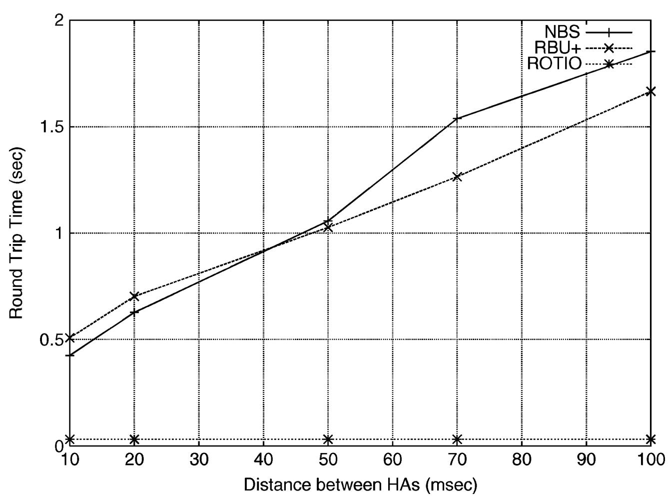

Fig. 13. How the RTT changes as the distances between HAs increases for intra-NEMO route optimization.

as the distances between HAs increase while, ROTIO shows a very low RTT, which is independent of the distances between HAs. In the ROTIO scheme, a packet sent from LFN1 to LFN2 does not need to go outside the mobile network. The packet generated by LFN1 is routed via the TLMR and *vice versa*.

C. Handoff Disruption

The extended ROTIO scheme also supports the seamless handoff. In the extended ROTIO scheme, each MR sends a BU whenever its binding update timer expires, and not when it detects a movement. The binding update timer has a value between 1–10 seconds, which means that numerous packets can be dropped during the handoff when an MR changes its point of attachment. Fig. 14 shows the length of the disruption during handoff. The simulation time is 100 s and handoffs occur five times in each run. The result show the average disruption time of the five handoffs. In this simulation, the ROTIO scheme shows a shorter disruption time during handoff. The speed with which movement can be detected is relevant to the RA interval. As the RA interval increases, the length of the disruption during handoff also increases, since an MR can detect movement from the RA message. In the case of ROTIO, the disruption time also increases as the RA interval increases. However, as the PPMR redirects packets toward the new location of the HLMR, the disruption time is much shorter than it is with the other schemes.

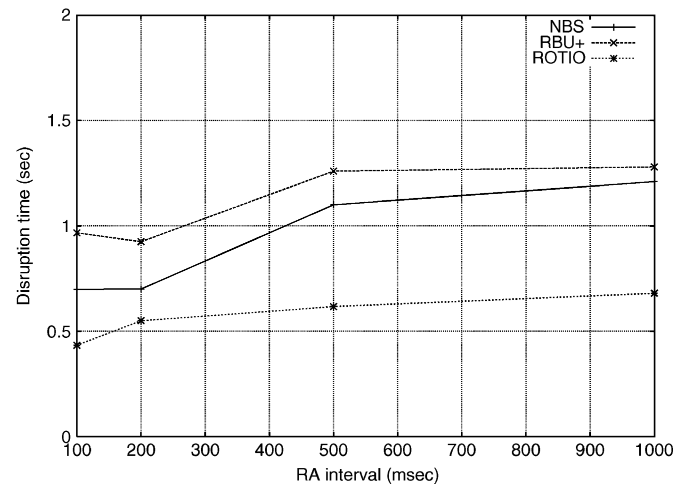

Fig. 14. The disruption time while handoff as the RA interval increases.

V. Conclusion

For a nested NEMO, routing inefficiency is exacerbated as the level of nesting increases, which is called the pinball routing problem. Thus, the NEMO basic support protocol needs to be extended with an appropriate route optimization scheme. To solve the pinball routing problem, we propose the ROTIO scheme, which uses the extended RA and BU messages with the xTIO option. The basic ROTIO scheme provides both forward and reverse route optimization while preserving the transparent mobility and location privacy of a NEMO. Furthermore, the extended ROTIO scheme localizes intra-NEMO communications and minimizes the handoff disruption. Our simulation results show that the ROTIO scheme becomes relatively more efficient as the degree of nesting increases or the average distance between HAs increases. Extended ROTIO also outperforms the other schemes in terms of intra-NEMO routing and NEMO handoff.

The ROTIO scheme assumes that all MRs consisting a nested NEMO are ROTIO-capable. Since each MR understands the xTIO extension messages and decides an efficient routing, the ROTIO scheme can achieve the route optimization in the nested NEMO environment. However, when the ROTIO-capable and normal MRs are coexistent, the ROTIO scheme may not work properly or shows declined performance. Hence, in the future work, we will examine the effect of heterogenous composition of MRs and improve our scheme to be compatible with the existing NEMO basic support protocol.

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