A New Project to Optimize the Nested Structure of NEMO

Xing Yin [1,2]

[1] School of Computer Science and Engineering, Southeast University, Nanjing 210096, China;

[2] School of Electrical and Information Engineering, Jiangsu University, Zhenjiang 212013, China;

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Abstract. Network Mobility (NEMO) can ensure continuous connectivity for an entire network and manage the mobility when a mobile router of the mobile network changes its point of attachment to the Internet. However, nested structure of NEMO has its weakness in route optimization (RO) even it does expand the communication coverage. Although recent RO solutions for nested NEMO partly solve this problem, they also suffer various limitations. This work analyzed the structure of nested NEMO and proposed a new route optimization project for nested NEMO. Only by modifying mobile routers and sending the location of top-level mobile routers to correspondent nodes can this method can be used to provide optimal routes. Performance evaluation shows that the proposed method is superior for its lower total overhead when compared with other optimization schemes.

Introduction

Background

With the development of wireless network and mobile terminal technologies, mobile IP devices are required to have the ability to connect to the Internet through various means anytime anywhere. Mobile IPv6 (MIPv6) protocols can provide uninterrupted connectivity for a single mobile host [1]. In practice, however, continuous Internet connection is necessary for mobile networks. To this end, the Internet Engineering Task Force (IETF) proposed the Network Mobility (NEMO) Basic Support Protocol (BSP) based on the IPv6 protocol [2]. This protocol uses the mobile router to provide mobility management and continuous connections for all nodes in the mobile network.

The nested mobile network in NEMO BSP is created when a mobile network cannot directly connect to the access router (AR) in the Internet due to limited signal coverage but still can access the Internet indirectly by connecting to another mobile network. The greatest advantage of the nested structure lies in its ability to expand the coverage of communication. However, since communication with mobile network nodes (MNN) and remote correspondent nodes (CN) relies on a bi-directional tunnel between the mobile router and its home agent, the data message will become multi-tiered tunnel encapsulated as the number of nested level increases. This also increases the end-to-end delay and results in inefficient bandwidth utilization due to the overhead of multi-level encapsulation [3]. Therefore, nested routers must be optimized before NEMO techniques can be widely used [4].

Nesting Problem Statement

A typical structural model of nested mobile networks is shown in Fig.1. In this figure, full lines represent wireless links and dotted lines the wireless links. Because the mobile network NEMO3 and the access router (AR) of the Internet are far apart, the wireless signals cannot reach each other; therefore, we connect AR to the Internet via the mobile networks NEMO2 and NEMO1. The system thus forms a nested mobile network with a nested level L = 2. Because NEMO1 is at the highest level in the entire nested network, MR1 is referred to as the top level mobile router (TLMR) as well as the MR2 of the Parent MR (PMR).

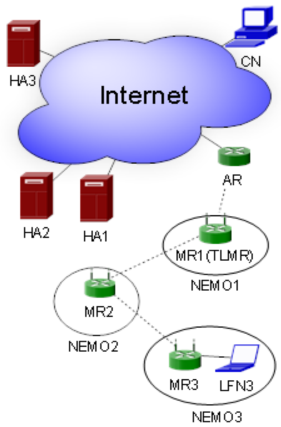

Fig.1: Structural model of a nested mobile network

For the multilayer nested mobile networks shown in Fig.1, the local fixed node 3 (LFN3) message from CN will first be routed to MR3's home network and then sent to MR3 by home agent HA3 via tunnel encapsulation. The current address of MR3 is generated based on the mobile network prefix 2 (MNP2) advertised by MR2; thus, the message will be routed to MR2's home network. By repeating the encapsulation and retransmission procedure mentioned above, the message will finally be retransmitted to MR1 by HA1 via the tunnels. At this point, the message with 3-layer encapsulating packet headers will be decapsulated by MR1, MR2, and MR3, respectively, then retransmitted to routers at lower levels, and finally reach LFN3. The path of this message can be described as CN->HA3=>HA2=>HA1=>AR=>MR1=>MR2=>MR3->LFN3, where "=>" represents tunnel encapsulation. This type of message routing is referred to as "pinball routing" [3]. As the number of nested layers increases, the negative impact of this non-optimized router will become even greater.

Related Work and Motivation

Many published studies attempt to optimize routers of nested mobile networks using diverse methods. A typical example of such effort is provided in [5]. Each MR configures a CoA according to the MNP advertised by the foreign prefix advertised by the AR of the foreign link. Consequently, the CoA of the MR and the TLMR is added to the binding update sent to HA and CN. Later, the message sent from CN or HA contains the two CoAs in the routing header. In this manner, this scheme results in a larger packet header.

Recently, another important and typical optimization scheme is proposed in [6]. Each MR in this scheme registers the CoA of TLMR to CN and HA. In the message from CN to nodes in nested NEMO, the CoA of TLMR is inserted into the packet header; the message is then routed directly to TLMR where the header is deleted, and the message is forwarded by MR. Because MR requires reconfiguration and registration of CoA when moving in the same AR area, higher expense is incurred.

Based on the above analysis, the existing nested route optimization schemes mainly suffer from the following deficiencies: First, the existing route optimization schemes are expensive in terms of their optimization overhead. Second, due to the requirement for applying new network entities and protocols or modifying randomly distributed CN, HA or AR in the internet, the current optimization schemes are not easily to implemented. To overcome the weakness mentioned above, we propose a thorough route optimization solution featuring the lowest cost by modifying only the MR inside the nested mobile network.

The Proposed Optimization Scheme

In this article, we treat the set including all the nodes and sub-networks connecting to the Internet using the same AR as an AR domain. We provide the details of the route optimization scheme in the following sections.

Modification of Route Advertisement

To ensure that each MR advertises the same foreign prefix in its subnet, we need to extend the standard NDP. This scheme defines a new Optimized Prefix Option (OPO) by revising the prefix message option in RA messages. Its format is shown in Fig. 2. While keeping the remaining fields the same as the corresponding parts in standard RA message [7], this scheme adds 3 fields as follows:

i) M-flag: By locating a reserved bit neighboring bit A as the M-flag, we can use this flag to find the source of the RA messages and then determine whether the position of the MR receiving this RA message is at the top level of the nested network. The default value of this flag is 1.

ii) TCoA-field: This field is a 128-bit IPv6 address that records the TLMR's CoA (TCoA). The MR receiving RA messages can combine this field with an 8-bit prefix length field to generate a foreign AR advertisement prefix according to which the MR judges whether inter-domain movements have occurred.

iii) PMRA-field: This field is a 128-bit IPv6 address that records the parent mobile router's ingress interface's address (PMRA). When generating an extending RA message, each MR inserts its own ingress interface's address into the PMRA field.

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<table>
<tr><td>Type</td><td>Length</td><td>Prefix Length</td><td>L</td><td>A</td><td>M</td><td>Reserved</td></tr>
<tr><td colspan="7">TCoA (TLMR's CoA)</td></tr>
<tr><td colspan="7">PMRA (Parent Mobile Router's Address)</td></tr>
</table>

Fig.2: Optimized prefix option (OPO) format

In this scheme, we need to run this detection within the entire AR domain. This scheme extends the standard Neighbor Solicitation (NS) and Neighbor Advertisement (NA) message by adding an N-flag to the reserved fields of NS and NA messages. If the message receiver determines that this N-flag is 1, then the extended NA or NS message needs to be delivered to another link.

Mobility Detection and CoA Configuration

In this scheme, MR uses the RA message to detect mobility and to configure CoA. After receiving the RA message, MR first needs to diagnose whether it is a TLMR or an ordinary non-top-level MR by checking whether the value of the M-flag in prefix option is 0 or 1 and then judges and handles the inter- and intra-domain mobility for these two kinds of MRs accordingly.

TLMR first obtains the foreign prefix from the received standard RA message [2] and combines the foreign prefix with the last 64-bit of the RA message source address to obtain AR's ingress interface's address; it then compares the prefix with the prefix of its CoA. If they are different, it can be inferred that there is an inter-domain mobility in the TLMR. In order to perform DAD for the new address, TLMR will reconfigure the message's CoA using the foreign prefix and subsequently send a standard NS message to AR. If the TLMR fails to receive an AR reply within a reasonable period of time, the reconfigured CoA is available and will send a standard NA message to AR instructing AR to generate an entry for the new address in a neighbor cache and to perform the binding update progress.

If the CoA's prefix and foreign prefix are the same, this means that TLMR has not moved into another domain. By referring to the routing table, TLMR will compare the next hop of the default route with AR's ingress interface's address; if they are different, there is then an intra-domain mobility happened in TLAR. At this time, the TLMR needs to generate standard unsolicited NA messages for its CoA and send it to AR. The purpose of this is to inform AR of TLMR's CoA and to premise of not revising the AR and to make AR generate an entry for this CoA in its neighbor cache. Each link-layer address in the tables is the link-local address of TLMR's egress interface.

For a non-top-level ordinary MR such as the MR3 in Fig.1, the system will generate a foreign prefix according to the TCoA of the received extending RA message and prefix length field and compare the foreign prefix against the current CoA's prefix of MR3; if they are different, an inter-domain mobility event has occurred in MR3. At present, MR3 will regenerate CoA in terms of the foreign prefix and then perform DAD in the whole AR domain. MR3 generates an extending NS message containing an N-flag, whose target address is TCoA, uses its new CoA as the source address, and inserts the network address MNP3 of the subnet into the target address of the NS message. This NS message will be retransmitted to the upper level MR2 from MR3 on the basis of the default route. If MR2 receives this message and finds that the N-flag bit is 1, then this NS message needs a cross-link transfer. MR2 will substitute the source address of the NS message for its own CoA and retransmit the NS message to upper-level MRs. Meanwhile, MR2 adds an entry for the MNP3 in the target address into its routing table, and the next hop of this new entry is the CoA of MR3.

After receiving an extended NS message, TLMR uses the method described above to update the routing table. To ensure that AR obtains the CoA of MR3 and performs DAD on the premise of not revising AR, TLMR needs to generate a standard NS message without options and inserts the CoA of MR3 into the target address field of this message, and then send it to AR. After receiving this message, AR will test the CoA in the target address. If there is no duplication of this CoA, AR will not return a NA message to TLMR. If no NA message from AR returns after a reasonable period of time, TLMR and MR3 will treat this address as having no duplicate and MR will treat this CoA as a usable address. After receiving an extended NS message from each MR, TLMR adds one entry for each MNP to its routing table, adds a new entry for MR3's new CoA to the neighbor cache and makes the corresponding next hops the message's source address.

If there is no inter-domain mobility in MR3 but the access location has changed, this means that the PMRA field in the received RA message is different from the default route in the routing table. It also indicates that MR3 only has intra-domain mobility but no inter-domain mobility. At this time, MR3 needs to send the relative routing information regarding its subnet to the upper MRs to update their routing tables. MR3 therefore generates an extending NA message including an N-flag whose target address is TCoA, uses its CoA as the source address, and inserts its subnet prefix MNP3 into the target address of the extended NA message. This message will be retransmitted to upper-level MR2 according to MR3's default route. If MR2 receives this message and finds that the N-flag bit is 1, it learns that this extended NA message needs to be retransmitted to other links. MR2 will add a new entry for the subnet prefix MNP3 in the target address of this message into its routing table, and the corresponding address of the next hop of this entry will be set as the source address of the NA message. MR2 will then replace the source address of the NA message with its CoA and retransmit it to the upper-level MRs according to the default route.

Upon receiving this NA message, TLMR only needs to update the routing table using the same method and abandon the received extended NA message. After completing the updating process above, MR3 can perform the binding update procedure presented in the next section.

Binding Update Procedure

After performing the DAD, MR needs to inserts its MNP and TCoA into binding update (BU) messages and send them to HA and CN. These processes are called "home registration" and "correspondent registration", respectively. The purpose of correspondent registration is to make the message sent from CN move to the TLMR via the optimal path and thus to achieve route optimization. As this process is similar to the optimization process in the MIPv6 protocol, we need to execute the return routability (RR) procedure before applying correspondent registration [1].

Optimal Routing Analysis

As showed in Fig.1, if a CN has received a binding update generated by MR3, then communications between CN and LFN3 should be similar to those in MIPv6 protocol. For messages from CN to LFN3, CN first looks up the binding cache according to LFN3's IP address and finds the corresponding TCoA. It then treats this address as the destination address, and inserts LFN3's IP address into the type 2 routing header (T2RH) and sends them out. The messages sent by CN will be routed to the TLMR. After receiving the messages, TLMR deletes the routing headers, then restores their destination addresses to LFN3's IP address and forwards them to MR2 according to its routing table. MR2 and MR3 then transfer the messages to LFN3 following their own routing tables. The path of the messages can be described as CN—>AR—>MR1—>MR2—>MR3—>LFN3. Thus the path optimized by this scheme is optimal.

Performance Analysis

Generally, the route optimization scheme needs additional data traffic to optimize the routers, and this will increase the consumption the bandwidth of the nested mobile networks. Thus, the extra overhead induced by RO solutions is an essential criterion of their performance [8].

There are two kinds of extra overhead of the routing optimization scheme. Header overhead is an extra overhead induced by providing the optimal routing information from AR to MR in data packets' extra header. Registration overhead is an extra overhead induced by the process of sending the binding update from MR to CN and HA. In the following section, a comparison between the overhead of NTICA, NE and MYSCH is made and analyzed.

The header overhead depends on the total number of packets, the size of single extra packets and the hop count that the packets pass through. Therefore, with the condition that the number of the data packets sent to the mobile network is the same and the topology of the net configuration (namely, the hop count) is the same, the size of the extra header beyond the basic header Deh determines the header overhead. The basic header of an IPv6 packet is Dbh. Table 1 illustrates the size of extra header for different schemes. It can be seen that NEMO has the largest header overhead because the number of encapsulated packets increases with the number of nested levels. Because NE has two IPv6 addresses in the routing header, the extra packet header is relatively larger. NTICA and MYSCH have only one IPv6 address in their respective routing header, so their header overheads are the smallest.

Table 1: Size of extra header for different schemes (byte)

Scheme	NEMO	NTICA	NE	MYSCH
D_{eh}	$40 \times L$	24	40	24

Table 1 shows that the proposed MYSCH scheme features lowest header overhead. So the extra bandwidth consumption of caused by packet header of our scheme is lower than the other optimization schemes.

The registration overhead is the product of the size of the binding update message, the number of binding update messages and the hop count that the messages pass through. To simplify the analysis, we represent the number of the nested level of the nested network by L, with each level having a mobile network, and assume that each mobile network in the nested network has moved K and N times on average in the inter- and intra-domains. DbuHA and DbuCN are the size of the home registration message and correspondent registration message respectively, and d(a,b) is the distance between nodes a and b in the form of hop count. The comparison of registration overheads with increasing nested levels is shown in Fig.3. This figure presents how the registration overheads of the above-mentioned schemes change with the number of nested levels L, when the numbers of mobility inter- and intra-domain respectively are set 3.

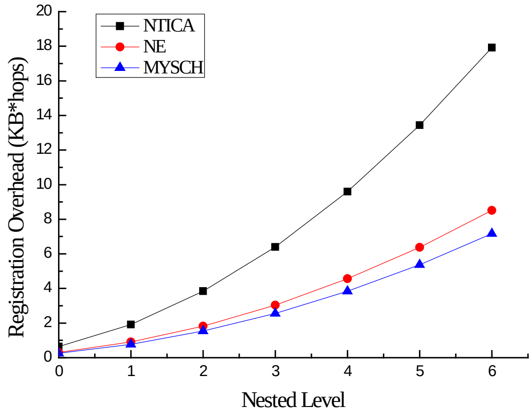

Fig.3: Comparison of registration overheads with increasing nested levels

Fig.3 illustrates that the increases in the registration overhead for the three optimization schemes show gentle trends because they have diminished the nested tunnels. In the NTICA scheme, the MR needs to reconfigure the CoA and register after a intra-domain mobility, so it's registration overhead is generally larger than that of the other two schemes. Because the binding update of NE contains two IPv6 addresses, the registration overhead of NE is always a little larger than that of MYSCH. In summary, MYSCH has the smallest registration overhead.

Conclusions

In this paper, a route optimization scheme for nested mobile networks is proposed. By extending the RA messages in the nested network, the foreign subnet prefix is used to configure the CoA of MR, and the NS and NA messages are then extended to update the routing table of each MR. Finally, through registration the TLMR's CoA to the correspondent nodes, the messages sent by the CN to some nodes inside the nested network are directly routed to TLMR of the nested mobile network in the foreign network. After that, the message is modified by TLMR and transmitted to final target node by the TLMR and the following MRs according to their routing tables. Finally, the optimization of the routes in the nested mobile network is achieved. Performance analysis of the three schemes illustrates that the proposed MYSCH scheme is associated with the lowest header overhead and registration overhead. So the total overhead of our scheme is the lowest when compared with the other optimization schemes.

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