# R-BU : Recursive Binding Update for Route Optimization in Nested Mobile Networks

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**Abstract** - This paper proposes ***Recursive Binding Update (R-BU)*** that optimizes routing for nested mobile networks. Nested mobile network is a hierarchical form of mobile networks, e.g. a wireless personal area network (PAN) in a vehicular network. A mobile network moves as a single unit with one or more mobile routers that connect it to the global Internet. Nested mobile networks have pinball routing problem with hierarchical mobile routers. This problem becomes more serious in the case of macro mobility as the routing distance becomes longer. To solve the pinball routing problem of nested mobile networks, we propose routing optimization scheme called R-BU based on recursive binding update. R-BU maintains optimal route to the destination by updating its binding recursively. R-BU requires no changes in existing mobile IP except binding update operation. By using R-BU, correspondent nodes can maintain optimal route to their destinations after some convergent time. R-BU reduces pinball routing cost and the reduction is more useful as the degree of nesting becomes deeper and the distance between the home agents of a mobile router and its parent/child mobile routers becomes longer.

**KEY WORDS: Nested mobile networks, Route optimization, Binding update**

## I. Introduction

In trend of ubiquitous computing, many electric appliances are having capability of communications through wireless technologies by using their own IP addresses. MobileIP Working Group in Internet Engineering Task Force (IETF) has proposed Mobile IP [1,2] to support mobility in IP networks. Mobile IP aims at maintaining transport or higher layer Internet connectivity while a host is moving. Binding Cache (BC) in a Home Agent (HA) has the information of current host location (CoA, Care-of Address), and a Correspondent Node (CN) can also have binding cache for route optimization.

Not only devices but also vehicles can be connected to the Internet [3]. Mobile devices can get connected to the Internet even in vehicles. In addition, they can move in groups, e.g. a radio, a Personal Digital Assistants (PDA), and a mobile phone of one person can organize together to form a personal area network (PAN) that can move in a large vehicle. To route IP packets for such complex applications, nested mobile networks can be used. Network Mobility (NEMO) Working Group in IETF [4] has focused on this issue and been working to extend existing Mobile IP to support network mobility.

The NEMO manages the mobility of an entire network, viewed as a single unit, which changes its point of attachment to the Internet and thus its reachability in the topology [5,6,7]. A mobile network includes one or more mobile routers (MRs) that connect it to the global Internet. A mobile network can contain both fixed and mobile nodes behind the MR (e.g. a trains with sensors and mobile phones). If we use existing mobile IP protocol for mobile network, the packets from a CN to a MR are successfully delivered but the packets destined to the nodes behind the MR are dropped at HA since binding cache in HA has no information about the mobile network but only about the MR. To extend mobile IP to support network mobility, binding cache must have information about the mobile network prefix of MR’s ingress interface.

Mobile networks can have very complex form of hierarchy, e.g. mobile networks in a mobile network, visiting mobile nodes (VMNs) in a mobile network, and so on. This situation is referred to as a *nested mobile network*.

Fig. 1 is a simple illustration of nested mobile network. At the beginning MR1, MR2, and VMN are attached to their own home link. After MR1 moves to a foreign link, MR2 moves under MR1, so subnet of MR1 is the foreign link of MR2. This makes the simplest form of nested mobile network. As VMN goes into MR2’s subnet, the degree of nesting becomes deeper. This paper proposes a routing optimization scheme called Recursive Binding Update (R-BU) for nested mobile networks.

The rest of this paper is organized as follows. Section II introduces pinball routing problem in NEMO and section III describes proposed route optimization scheme called Recursive Binding Update. In Section IV, we evaluate the performance of the proposed scheme. Finally, Section V concludes this paper.

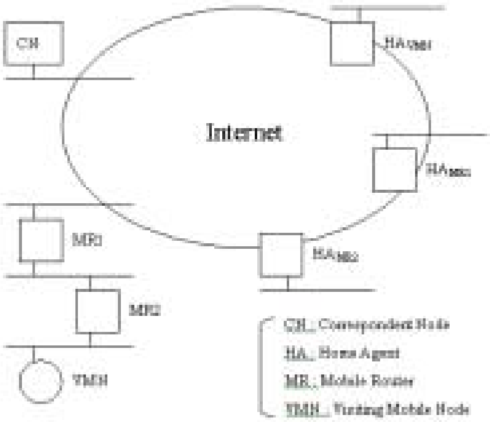


**Fig. 1. Nested Mobile Network**

## II. Pinball Routing Problem in NEMO

Nested mobile networks have pinball routing problem. Based on Mobile IPv6 [5], each MR and mobile network node (MNN) has it's own HA. So if correspondent nodes (CNs) want to send data to the leaf MNN which is located at the bottom of the nested mobile network, the data have to travel all Home Agents that mapped the MRs consisting nested mobile networks.

Fig. 2 shows an example of pinball routing problem with 2 degrees nesting. At first the data from a CN to a Visiting Mobile Node (VMN) is routed to the HA of the VMN ($HA_{VMN}$). The binding cache of the $HA_{VMN}$ has the binding information that the VMN is located under MR2. So the data is tunneled to the HA of MR2 ($HA_{MR2}$). In this time, $HA_{MR2}$ has the binding information that MR2 is located under MR1. The data is encapsulated again and re-routed to the HA of MR1 ($HA_{MR1}$). The $HA_{MR1}$ tunnels the data once again to successfully deliver the data to the MR1. In this case the original data is encapsulated three times. MR1 and MR2 decapsulate the packet and forward the packet to the destination node. If the packet is encapsulated by its HA, MRs and VMN send binding update (BU) message to the sender of the packet for route optimization. In this example, VMN sends BU to CN, MR2 sends BU to $HA_{VMN}$, and MR1 sends BU to $HA_{MR2}$ at the first stage of routing. In the next stage, the CN knows that VMN is under MR2 so the data is routed directly to $HA_{MR2}$. $HA_{MR2}$ has the information about MR1's location obtained by previous binding update from MR1. But $HA_{MR2}$ cannot use this information in the existing mechanism so simply tunnels the packet to $HA_{MR1}$. When MR2 receives the packet encapsulated by its HA, MR2 sends BU to CN, the sender of that packet. In the final stage, CN knows that VMN is under MR2 and MR2 is under MR1. But CN cannot deduce the relation between those two binding information.

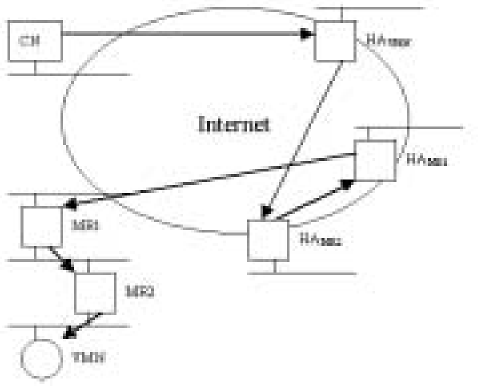


**Fig. 2. Pinball routing problem in NEMO**

The problem becomes more serious in the case of macro mobility as the routing distance becomes longer. For example, there is a PAN in the international flight with home network of the PAN in Korea and home network of the airplane in America. If someone wants to send data to a PDA in the PAN, the data has to first go to the HA of the PDA and the PAN in Korea and then to the America, the home agent of airplane network. After visiting the HA of the airplane, the data finally arrives at the MR in the airplane maybe over another country. If the data has real-time characteristics, the delay and jitter cause serious trouble.

## III. Proposed Route Optimization scheme

To solve the pinball routing problem of nested mobile networks, we propose route optimization scheme based on *recursive binding update*.

### *A. Recursive Binding Update (R-BU)*

Proposed recursive binding update scheme maintains optimal route to the destination by updating its binding information recursively not only when it searches Binding Cache but also when it receives Binding Update message. In the case of nested mobile networks, both MRs and VMNs send Binding Update messages to a CN. So Binding Cache in CN has more than one entry involved a session. A CN uses this redundant entry to optimize route to the VMN in nested mobile networks. Suppose, for example, Binding Cache has two entries, $VMN_{HoA} \rightarrow VMN_{CoA}(MR_{HoA})$ and $MR_{HoA} \rightarrow MR_{CoA}$. If a CN wants to send data to the VMN, the CN will search Binding Cache for the entry $VMN_{HoA} \rightarrow VMN_{CoA}$, i.e. $MR_{HoA}$. But the MR is also not in his home network. So before sending data to $MR_{HoA}$, the CN searches Binding Cache to find entry for $MR_{HoA}$. If an entry matches, CN searches its Binding Cache recursively until no entry matches. In this manner, CN obtains the optimal route to the VMN. But this recursive searching method becomes inefficient, as the degree of nesting becomes deeper. So we propose recursive binding update scheme, R-BU that makes the CN maintain the optimal route to the destination. R-BU is performed as follows.

Algorithm 1. Recursive Binding Update

```
received BU(HoA:CoA)
foreach BE(HoA:CoA) binding entry in BC
    if BE.CoA equals BU.HoA then
        BE.CoA ← BU.CoA
insert BU(HoA:CoA) to Binding Cache
```

In the recursive binding update algorithm, Binding Update (BU) message and binding entries (BE) in Binding Cache contain Home Address (HoA) and Care-of Address (CoA) pair of MRs or VMNs. When a HA receives new Binding Update message from a mobile node, the HA searches all binding entries in binding cache. So if the CoA of BE is equal to the HoA of BU, HA updates the CoA of BE to CoA of BU. And finally HA inserts received Binding Update message in its Binding Cache.

### *B. Routing with R-BU*

Fig. 3 shows the process of recursive binding update. First packet from a CN travels all HAs. After the MR and VMN send Binding Update message to CN and $HA_{VMN}$ for route optimization, the CN obtains optimal route to VMN with the convergent algorithm of R-BU. Though the convergent time increase linearly by the degree of nesting, it is trivial for large-scale vehicles like ship or airplane moving world wide. When the distance between CNs to HAs or HAs to MRs is long, e.g. across the country, pinball routing cost is expensive than the cost of recursive binding update. Moreover from the view of macro mobility, convergent time is trivial.

At the beginning, binding cache of CN is empty. When a CN wants to send data to VMN, the CN send data to Home Agent of VMN. $HA_{VMN}$ knows that the VMN is under MR, so $HA_{VMN}$ encapsulates the packet to $HA_{MR}$. At this time, $HA_{MR}$ tunnels the packet to $MR_{CoA}$. When VMN receives the packet that is encapsulated by $HA_{VMN}$, VMN sends binding update message to the sender of the packet. After CN receives BU from the VMN, packets to the VMN are routed directly to $MR_{HoA}$. $HA_{MR}$ tunnels again the packet to $MR_{CoA}$. When the MR receives the packet that is encapsulated by $HA_{MR}$, MR sends BU to CN. With R-BU algorithm, the binding cache of CN merges existing binding information about VMN and new binding information about MR. As a result, CN obtains the information that VMN is under MR and the MR is located at $MR_{CoA}$. Now CN has optimal route to VMN.

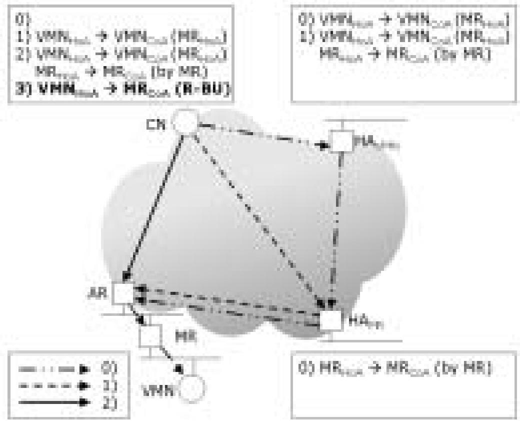


**Fig. 3. Recursive Binding Update**

## IV. Performance Evaluation

R-BU has several advantages. First, R-BU requires no changes in existing Mobile IP except MR's Binding Update operation. It does not require any change to CNs of end-user. Second, R-BU merges redundant binding entries into one. Smaller number of binding entry reduces binding cache searching time. Third, R-BU provides optimal route from a source to destination.

We simulated R-BU using Network Simulator 2 (NS2) [8] and MobiWan [9] extension for MIPv6.

### *A. Convergent Time*

Simulation topology is shown in Fig. 4. HA1 is home agent for MR and HA2 is that for the MN. The MR leaves its home network and gets CoA from BS. The MN also leaves its home network and gets CoA from MR. This makes the simplest form of nested mobile networks. After MR and MN send BUs to their HAs, the CN sends packets to MN.

**Phase I : Pinball routing**

If CN has no binding information about MN, packets from CN traverse through following sequence of routers.

CN → HA2 → HA1 → BS → MR → MN

In this process, MR sends BU to HA2 and MN sends BU to CN for routing optimization.

**Phase II : Normal route optimization**

Now CN has the information that MN is under MR, CN sends packets to MR's HA directly. So packets traverse through somewhat efficient route.

CN → HA1 → BS → MR → MN

In this process, MR receives the packet that is encapsulated by its HA and sends BU to CN.

**Phase III : Recursive binding update**

The CN knows the binding information about MR as well as MN. Using this information, CN sends packets to MR's CoA directly and this route is the optimal route to MN.

CN → BS → MR → MN

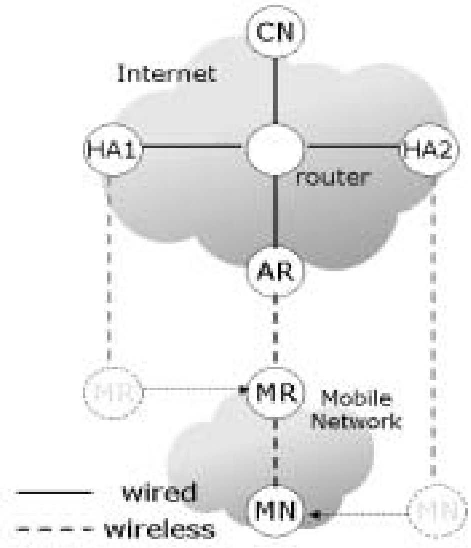


**Fig. 4. Network topology**

Fig. 5 shows end-to-end packet delay from CN to MN. Probes are started at 1 second and ended at 5 second. The simulation is started with topology of Fig. 4 and any movement does not occur during simulation. In Fig. 5, the period from 1 second to 2 second is Phase I. In this phase, the delay from CN to MN is high for packets visiting all HAs. Next one second is Phase II. Phase II starts when CN receives BU message from MN. In this phase, it shows decreased delay for packets do not visit HA1. After CN receives BU message from MR, the route from the CN to MN is optimal and this state is Phase III.

The convergent time to obtain optimal route is from the start time of Phase I to start time of Phase III. In this simulation, the convergent time is about two seconds, which is related to the degree of nesting of mobile network. If binding update is performed at every *t* second and the network is *N*-degree nesting mobile network, the convergent time *T* can be expressed as follows:

$$T = N*t \text{ seconds.}$$

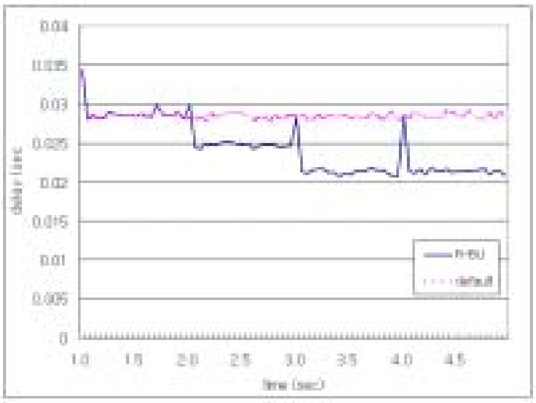


**Fig. 5. End-to-End packet delay**

Periodic pulses spacing about 1 second interval appear because the binding information of CN's binding cache is expired and there exist some gaps until the CN receives new BU message from MR and MN.

*B. Throughput*

If CN performs R-BU in its binding cache, CN can send packets through optimal route and packets have less delay than normal bi-directional tunneling. For this simulation, we set Constant Bit Rate (CBR) traffic at CN and LossMonitor agent at MN. Experimental packet size was 200 bytes and the interval was constant value 0.05 sec. Fig. 6 shows the result. The solid line represents R-BU and the dotted line represents normal operation without the route optimization.

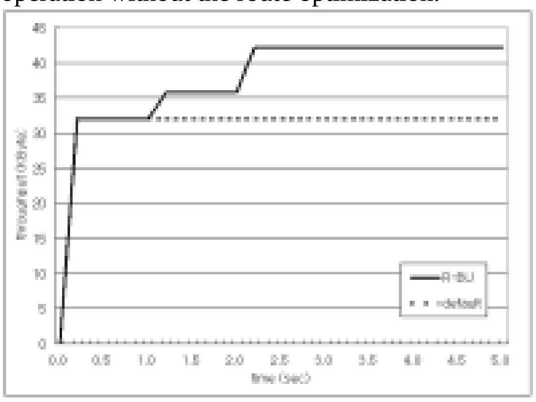


**Fig. 6. Throughput**

At the beginning, the result is same for both normal binding update and R-BU. But as the time goes it shows that the performance is improved 25% by using R-BU. In Fig. 6, the phases mentioned above are distinguishable from each other. The interval between 0 and 1 second is Phase I. In this phase, packets suffer pinball routing. After 1 second, the state enters Phase II. In this phase, packets are delivered through somewhat improved route but not optimal one. Finally, the state enters Phase III (about 2.5 second), in which the packets are delivered through optimal route from CN to MN.

### *C. Degree of nesting*

Nested mobile network can have very complex form of hierarchy. Fig. 7 is a simulation scenario for n-nested mobile network. There exist n HAs and each HA is related to one MR or MN.

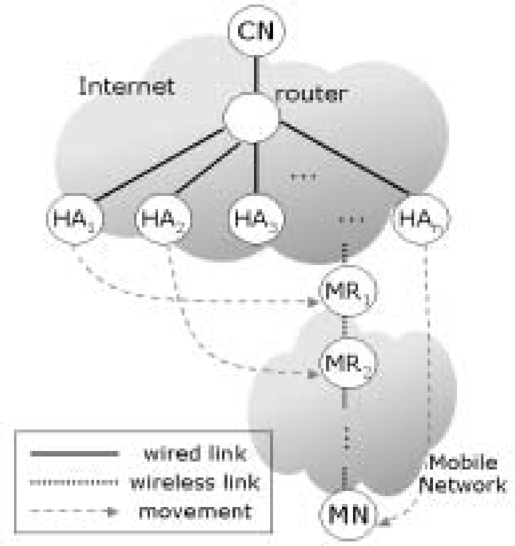


**Fig. 7. Nested mobile network topology**

Fig.8 is the result of this simulation. The degree of nesting, i.e. the number of MRs consisting mobile network, is varied from 2 to 6. As the degree of nesting deepens, the delay from CN to MN increases. But in all cases, R-BU scheme shows higher performances than none-route optimization or normal route optimization.

## V. Conclusion

With the proposed Route Optimization scheme in nested mobile networks, modifying Binding Cache update process, R-BU, reduces pinball routing cost. The R-BU scheme is useful when the degree of nesting is high and the routing distance becomes longer as Home Agents are scattered over the world.

R-BU is proposed for the large vehicular networks mobility with wireless PANs of passengers. So, R-BU assumes nested network mobility with long distance movement. It also assumes seldom handoff for satellite access networks since large vehicles across nations will access satellite networks for their large access range. We are further improving the scheme for frequent handoff of other access technologies.

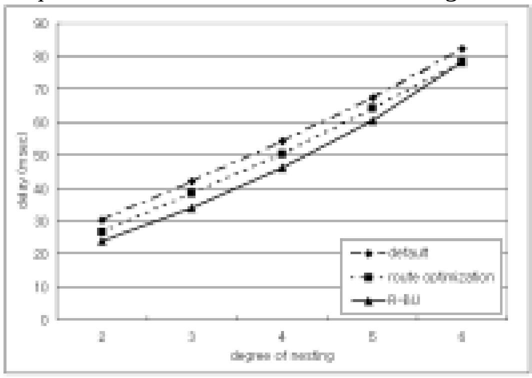


**Fig. 8. The end-to-end packet delay by the degree of nesting**

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