Regular Paper

Basic Network Mobility Support for Internet ITS

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In this paper, we propose a basic network mobility protocol which meets the requirements of Internet ITS and the IETF network mobility (NEMO) working group. Network mobility arises when an entire network is changing its point of attachment to the Internet topology, such as networks found in vehicles. Our solution is designed to provide extensions to Mobile IPv6, the IETF solution for host mobility The protocol assigns a unique unchanging prefix to each mobile network. A mobile router registers the prefix binding only to a home agent. The prefix binding is the association between the unique prefix and a mobile router's care-of address. All packets from and to the mobile network are tunneled through the bi-directional tunnel established between the mobile router and the home agent. The protocol supports various mobile network configurations such as nested mobility, multiple network interfaces on a mobile router, multiple mobile routers for a mobile network, and multiple home agents. Due to the strategy followed by the NEMO working group, this paper doesn't emphasize the routing optimization feature of our solution. We evaluate our solution against the Internet ITS requirements. Those are satisfied. Consequently, our proposal is well suited for Internet ITS systems.

1. Introduction

Intelligent Transportation Systems (ITS) comprise a number of technologies, such as advanced automobile navigation, safe driving, and tolling systems such as the Electronic Toll Collection System. ITS technologies are being widely developed at several organizations and are ready for deployment. Various applications and systems are proposed and tested. InternetITS is such an organization, so called because the Internet is expected to become one of the network infrastructures for ITS.

InternetCAR is a project investigating the means to provide network connectivity to automobiles. Automobiles contain many computers which need to be connected to the Internet. From a network point of view, mobility support is required to conceal movements of automobiles [7),13)]. Network mobility is a key technology for the Internet ITS systems. The nodes inside automobiles include micro devices such as sensors, wearable devices carried by passengers, and systems controlling units such as engines. It is a waste of network and device resources to operate a host mobility protocol such as Mobile IPv6 [9)] on all the devices mentioned above, therefore it is reasonable to aggregate mobility support by means of a single mobile router in each automobile. The other motivation to manage the mobility of the entire network at the mobile router only is to provide permanent connectivity transparently to tiny sensors which are unable to support extended protocol stacks.

The remainder of this paper is organized as follows. We first list related work in Section 2. We explain requirements from Internet ITS in Section 3. Then, we define our network mobility solution in Section 4. Advanced operations of our network mobility solution are described in Section 5. We finally shows advantages of our solution in Section 6 and conclude in Section 7.

2. Related Work

Network mobility is currently discussed in the "NEtwork MObility" (NEMO) working group [16)] at the IETF. The NEMO working group discusses a Mobile IPv6 based solution as a standard for network mobility. Many protocols have been proposed to the NEMO working group, including approaches such as Hierarchal Mobile IPv6 or routing protocols. Since routing optimization is currently out of scope at the IETF, we mostly focus on tunneling solutions based on Mobile IPv6.

The Prefix Scope Binding Update protocol (PSBU) [6)] is the first proposed solution based on Mobile IPv6. A Mobile Router (MR) has its own home address for MR's host mobility and its own home network prefix for network mobility. The MR sends an extended binding

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update with a prefix sub-option to the Home Agent (HA) and Correspondent Nodes (CN). Receiving nodes will create two bindings for the home address and the home network prefix. While a MR is away from its home network, all the packets destined to the mobile network are routed through the bi-directional tunnel which MR establishes with registered HA and CNs.

The second protocol named Mobile Router Tunneling Protocol (MRTP) [10] proposes a solution based on Mobile IPv6 as well. MRTP is backward compatible with Mobile IPv6. When the MR returns to the home network, it starts to advertise route information of the mobile network by means of a routing protocol and stops using the bi-directional tunnel. Then, packets are routed according to their routing table. It is not simple to maintain the interaction between MRTP and a routing protocol running on the MR. Existing routing protocols are not surely proved to work with a router like MR which comes and goes in its network. Administratively speaking, network management becomes harder due to MR's movement.

3. Requirements of Internet ITS

This section details the Internet ITS requirements. The requirements for a network inside vehicles have been discussed within the Research and Development Working Group of the InternetITS project. The InternetITS project is composed by more than 100 groups including the Japanese government, industries and academics. As a result, the communication architecture requirement draft is published in Japan [8]. The papers [7,13] discuss a network framework with requirements of ITS applications.

Session Continuation:
Existing applications manage session information based on IP addresses of end nodes, therefore the change of IP address triggers disconnection of a session of communications. It is required to hide the changes of IP address in the same manner as Mobile IPv6. Mobile IPv6 conceals the change from applications. Our solution provides a unique address to each node inside a mobile network. All nodes inside vehicles can be identified by their fixed IP address all the time. Therefore, this disconnection is avoided. PSBU and MRTP also meet this requirement.

Nested Mobility Support:
When a user brings a mobile phone using Mobile IP to an in-vehicle network, both host mobility support and network mobility support are needed. Our solution supports nested mobility as described in Section 5.1. MRTP supports this feature, whereas PSBU does not really give indications about it.

Using Multiple Interfaces:
Vehicles must have the Internet reachability all the time regardless of its driving location, but there is no network interface which covers all the areas where vehicles run. For example, if a vehicle drives in a tunnel, the vehicle needs to get Internet connectivity in the tunnel. It is also required to use an appropriate interface depending on network environments, because each interface has different characteristics for bandwidth, delay, access range, reliability, privacy, and cost performance. In Section 5.2, our solution allows MR to have multiple network interfaces and use them simultaneously. Vehicles can access to the Internet from the most appropriate interface at all times. Both PSBU and MRTP do not consider the use of MR with multiple interfaces.

Multicast Support:
It is preferable to handle multicast traffic in vehicles, because a lot of applications assumes multicast such as managements of traffic information, listening streaming data. Our solution supports multicast by running Multicast Listener Discovery (MLD) [3] and a multicast routing protocol on a MR. Nodes inside a mobile network can join a multicast group through the MR and receive multicast packets through the bi-directional tunnel regardless of vehicles movements.

Scalability:
There are approximately 70,000,000 vehicles in Japan. Mobility solutions for vehicles should take scalability into account. However we have not evaluated the protocol quantitatively, our solution works with a number of vehicles. On the other hand, HA may become a considerable bottleneck of the system, because all packets are tunneled through HA. Therefore, route optimization support may be needed to reduce the overhead at HA. PSBU supports route optimization whereas MRTP doesn't. Our solution has a possible mechanism, as described in Section 4 .

The other important aspect of our solution is that we adapt it to the standardization activity at IETF to keep interoperability among MRs and HAs. Interoperability is a requisite for scalability. The NEMO working group first standardizes a simple basic NEMO support without route optimization. Route optimization brings a lot of advantages for scalability, but supporting route optimization still requests more research into the solution space. ITS requires a solution deployable by 2007. Current solutions of route optimization such as Mobile IPv6 and PSBU have not proven anything for 70,000,000 vehicles yet.

Redundance:
The NEMO solution must keep working to ensure Internet access to MR in all situations. Although it is not desirable if HA goes down, MR must keep its connectivity to the Internet with network mobility support. For instance, even when HA goes down, the other HA must inherit the HA service. Protocol durability is highly important on Internet ITS. As described in Section 5.4, our solution supports multiple HAs. MRTP and PSBU do not allow the MR to register its prefix binding to multiple HAs simultaneously.

Seamless Roaming:
The latency of network handoff sometimes causes the communication to be shut down due to session timeout, etc. The latency also affects the performance of applications like VoIP severely. Therefore, it is crucial to reduce the latency. Seamless roaming is not addressed in this paper, but our solution is based on Mobile IPv6 and there are many proposals of seamless roaming for Mobile IPv6. These proposals can be applied to our solution.

Quality of Service (Urgent Packets):
ITS applications must be capable to deliver urgent data such as a rescue calls with the highest priority and reliability. Currently, there are no schemes to handle urgent data on our solution. QoS schemes can be used for this purpose, but none of them is yet deployed in the Internet. This requirement should be discussed as an issue for the whole Internet.

The network mobility protocol proposed in this paper provides the basic functions which match these Internet ITS requirements. Some requirements are not addressed in this paper at this time, but these should be solved before ITS applications get deployed.

4. Basic Network Mobility Support

We have been working on the NEMO solution at the InternetCAR project. Optimized Route Cache Management Protocol (ORC)[22] is our ongoing work which offers a solution for NEMO basic support and route optimization. ORC allows a MR to securely register its binding to correspondent routers and nodes. ORC extends the return routability procedure of Mobile IPv6 to protect binding updates.

As we mentioned, the NEMO working group does not discuss route optimization support at the moment. Our research must stick to the IETF standardization activity as much as possible in order to keep interoperability among MRs and HAs, as described in Section 3. For this reason, we omit the routing optimization feature of the protocol described in this paper. The protocol which description follows is thus a subset of ORC, but can easily be extended for route optimization. We need to conduct more research and experimentations on route optimization whether it is useful for Internet ITS or not.

This section gives a brief explanation of Mobile IPv6 and the operation of our proposal.☆ Most of terms used in this paper are defined in the internet-draft (draft-ietf-nemo-terminology)[5] and in the internet-draft (draft-ietf-mobileip-ipv6)[9].

4.1 Mobile IPv6 and NEMO Extensions

Mobile IPv6 allows a Mobile Node (MN) to be addressed by a home address at all times even though the MN changes its point of attachment to the Internet. When the MN is attached to a new network, the MN sends a binding update to its HA, a router on the MN's home link. A binding update describes the relation between the home address and an IP address, called care-of address, associated with the MN while it is on the visiting link. After receiving the binding update, the HA caches the binding into the binding cache database. When a CN sends a packet to the home address of the MN, the packet is transmitted to HA by normal routing in the Internet. Since the HA has the binding for MN, it can forward the packet to the current MN's care-of address by an encapsulation protocol. After the MN receives the tunneled packet, it sends a binding update, causing the CN to cache the mobile node's binding into its binding cache database. Consequently, the CN routes packets directly to the MN's care-

☆ More detailed operations and definitions can be found at our internet-draft (draft-wakikawa-nemo-basic)[19].

0	1	2	3	4byte
Type (TBD)	Length = 2	Prefix Length	Reserved = 0	

alignment: 2n

Fig. 1 Prefix sub-option.

of address according to the registered binding cache (i.e., support route optimization).

Network mobility support is very similar to Mobile IPv6. The changes are basically for binding registration and binding cache search because a care-of address must be associated with a prefix instead of a sole home address. MR can carry its prefix in the Internet by registering the prefix to HA as a prefix binding. The prefix binding is extended Mobile IPv6 binding to accommodate prefix information instead of a home address and is registered by a binding update.

When MR registers its prefix to its HA by means of a binding update, it includes a prefix sub-option in the binding update. The Prefix sub-option is defined as shown in **Fig. 1**. The prefix length field contains the length of a mobile network prefix. MR includes the Mobile Router Address (MR-A) into the home address option. MR-A is MR's address and is generated from MR's mobile network prefix. Thus, HA can retrieve the mobile network prefix from MR-A and the prefix length. However MR can not use the home address option for any packets other than binding updates and its originated packets. Packets from MNN is tunneled to HA by IP-in-IP encapsulation [2]. If MR originates data packets to its registering HA as a mobile node, it can use the home address option as defined in Mobile IPv6.

Prefix binding enables HA to find an appropriate cache entry for packets destined to a mobile network. The binding cache is searched using the mobile network prefix. First HA searches a binding with 128-bit prefix length for intercepted packets. If HA finds the binding, it tunnels packets to MR with routing header as specified by Mobile IPv6. Otherwise, HA compares the destination address of the intercepted packets with the MR's mobile network prefix. If HA finds a prefix binding, it tunnels packets to the registering MR-CoA by means of IP-in-IP encapsulation.

4.2 Basic Protocol Operations

Mobile network prefix is the network prefix assigned to a mobile network as an unique unchanging prefix. A mobile network prefix is securely delegated by a Home Agent (HA). The operation of prefix delegation is not discussed in this paper.

Mobile Router (MR) is the router which carries a mobile network around the Internet. MR has two network interfaces for connectivity both to the internet (egress interface) and to the mobile network (ingress interface). The Mobile Router Address (MR-A) is the address of MR's ingress interface and is configured with the mobile network prefix. MR is always identified by MR-A. Mobile Router Care-of Address (MR-CoA) is dynamically assigned to the egress interface at the visited network. MR must not advertise its mobile network prefix to the Internet's routing fabric through its egress interface. Instead, MR sends router advertisements [15] containing its own mobile prefix on its ingress interface.

HA is configured at the home domain and advertises route information to a mobile network prefix using any routing protocol on behalf of MR. All packets meant for the mobile network are routed to HA. Thus, it becomes the gateway between the mobile network prefix and the Internet. Mobile IPv6 bindings are extended to associate between the mobile network prefix and the MR-CoA. This is what we call a prefix binding. Prefix bindings are stored in the binding cache as Mobile IPv6 bindings are. HA has a home link instead of a home network. The home link is defined as the link which is managed by HA. Mobile IPv6 has the concept of returning home in terms of bindings de-registration, but our MR does not deregister its bindings from HA. A substitute operation of returning home is provided as shown in Section 4.2.3. Mobile Network Node (MNN) is the node which is attached to a mobile network. MNN is unaware of the network mobility protocol.

There are two typical situations on MR, one is when MR is away from a home link, and the other is when MR returns to a home link. The protocol operations are divided into three parts: the common operation and the operation of the above two situations.

Figures 3 and **4** show the same network environment except for MR's location. In the middle, there are three Border Gateway Protocol (BGP) [11] routers which are BGP-R1, BGP-R2, and BGP-R3. Each BGP router has a different prefix and announces the prefix to the BGP network.

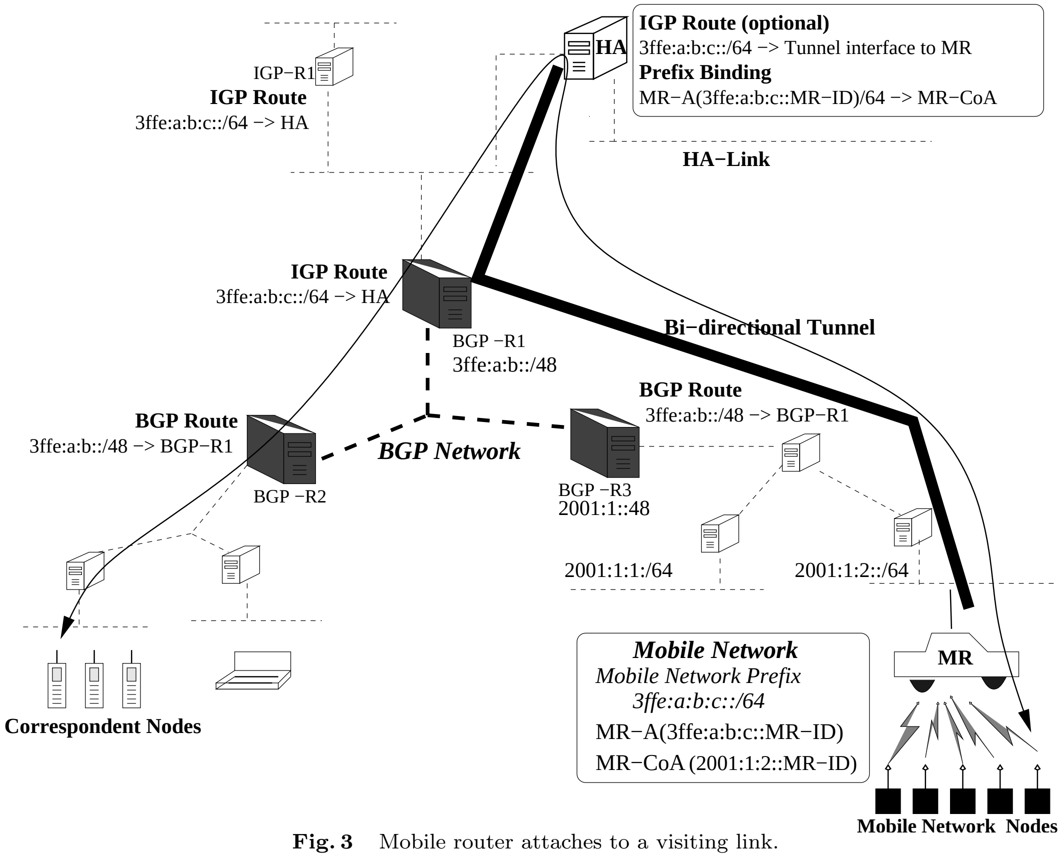

Fig. 3 Mobile router attaches to a visiting link.

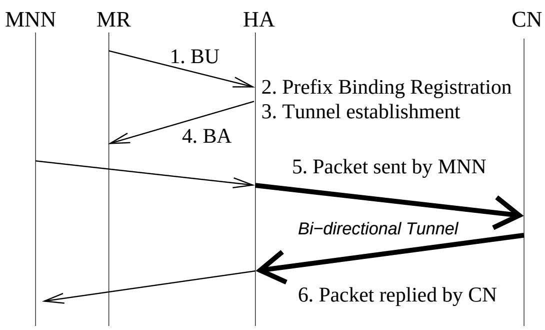

Fig. 2 Signal and data packets sequence.

4.2.1 Common Operations

At the beginning, a MR has a mobile network prefix delegated from its HA. The MR has a MR-A assigned to its ingress interface. When the MR moves, the MR obtains a topologically correct care-of address on its egress interface. The MR sends a binding update to its HA to create a prefix binding instead of a host binding.

Figure 2 shows general signal and data packet sequences among MNN, MR, HA, and CN. The binding update consists of the home address option containing the MR-A and the prefix sub-option with the length of the mobile network prefix. The MR-CoA is stored in the source address field of IPv6 header. When receiving the binding update, the HA caches the prefix binding. The HA retrieves the mobile network prefix from the MR-A with the mobile network prefix length in the prefix sub-option. This prefix binding can also be treated as a host binding of the MR. After the binding update is successfully processed by the HA, the MR establishes a bi-directional tunnel to the HA as done in Mobile IPv6.

The routing management inside a mobile network is not discussed in this paper, but any protocol such as OSPF6 [14], RIPng [12], or Mobile Ad-hoc Network [17] can be used.

4.2.2 Mobile Router on Visiting Link

Figure 3 shows the network configuration when the MR is away from the home link. The HA is located at the home link and advertises the mobile network prefix (i.e., 3ffe:a:b:c::/64) inside its domain. All the other routers have the network route for the mobile network prefix. The network route consists of the mobile

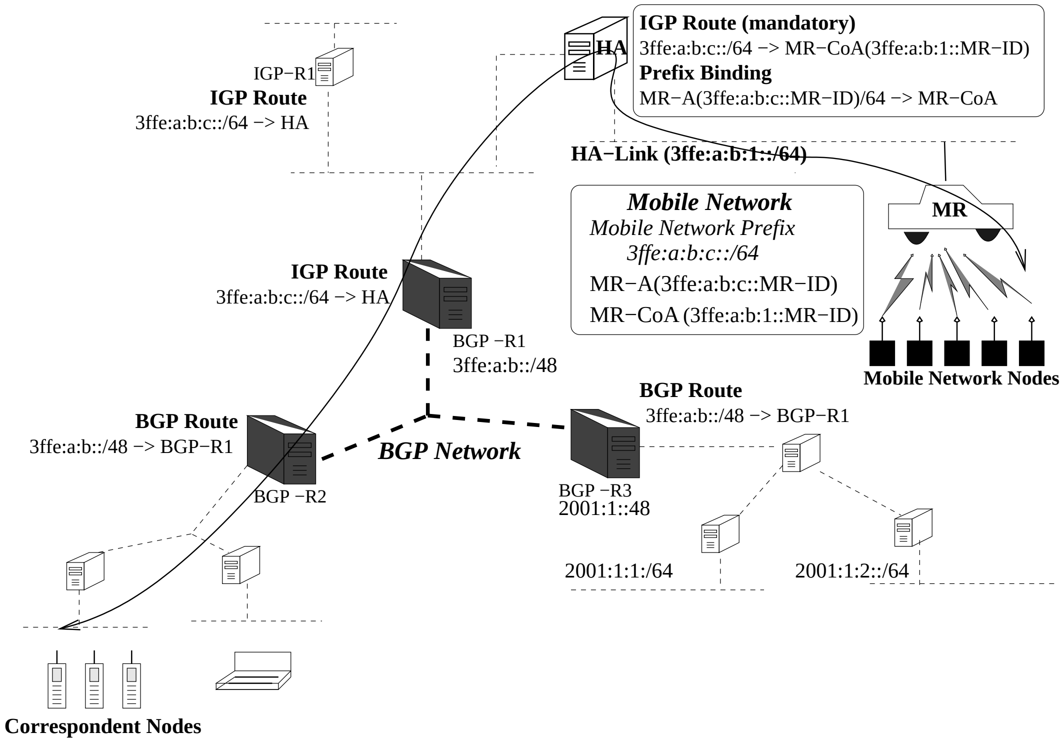

Fig. 4 Mobile router returns to a home link.

network prefix as the destination and the HA as the next hop. On the other hand, the HA may have the network route for the mobile network prefix which next hop is the tunnel interface of the bi-directional tunnel to the MR.

The bi-directional tunnel is maintained by the prefix binding registered by the MR. The HA can treat the prefix binding as a route entry to the mobile network prefix without having the above network route. The HA routes all packets destined to the mobile network prefix to the MR according to either the route entry or the prefix binding. Whenever the MR changes its point of attachment, it updates the prefix binding registered with the HA. The latency of updating the prefix binding is expected to be same as the latency of Mobile IPv6 [20]. The HA intercepts and tunnels all packets destined to the mobile network prefix by IP-in-IP encapsulation. The tunneling operation is the same as Mobile IPv6 except the binding search described in Section 4.1.

When a MNN in the mobile network sends packets to the Internet, the MR intercepts the packets and encapsulates them to the HA. The outer source address of the encapsulated packets is the MR-CoA to bypass ingress filtering. The MR does not insert the home address option, since alteration of MNNs' packets on an intermediate node like MR should be avoided from security considerations. Encapsulation of packets add additional IPv6 header, however does not change the orignal packets.

4.2.3 Mobile Router on Home Link

Figure 4 shows the configuration when the MR returns to the home link. The routing operation such as advertisements of the mobile network prefix, etc. are as explained in Section 4.2.2. Even when the MR returns to the home link, MR does not advertise the route to the mobile network prefix by any routing protocol. The HA keeps advertising the network route to the mobile network prefix on behalf of the MR.

The MR still sends a binding update with the MR-CoA generated from the prefix on the home link. Thus, when the HA receives the binding update from the address which prefix belongs to the HA, it knows MR is returning home. The HA updates the network route of the mobile network prefix on its routing table as shown in Fig. 4. Since the MR becomes the next hop router, HA turns the route directly to the MR instead of the tunnel interface. HA

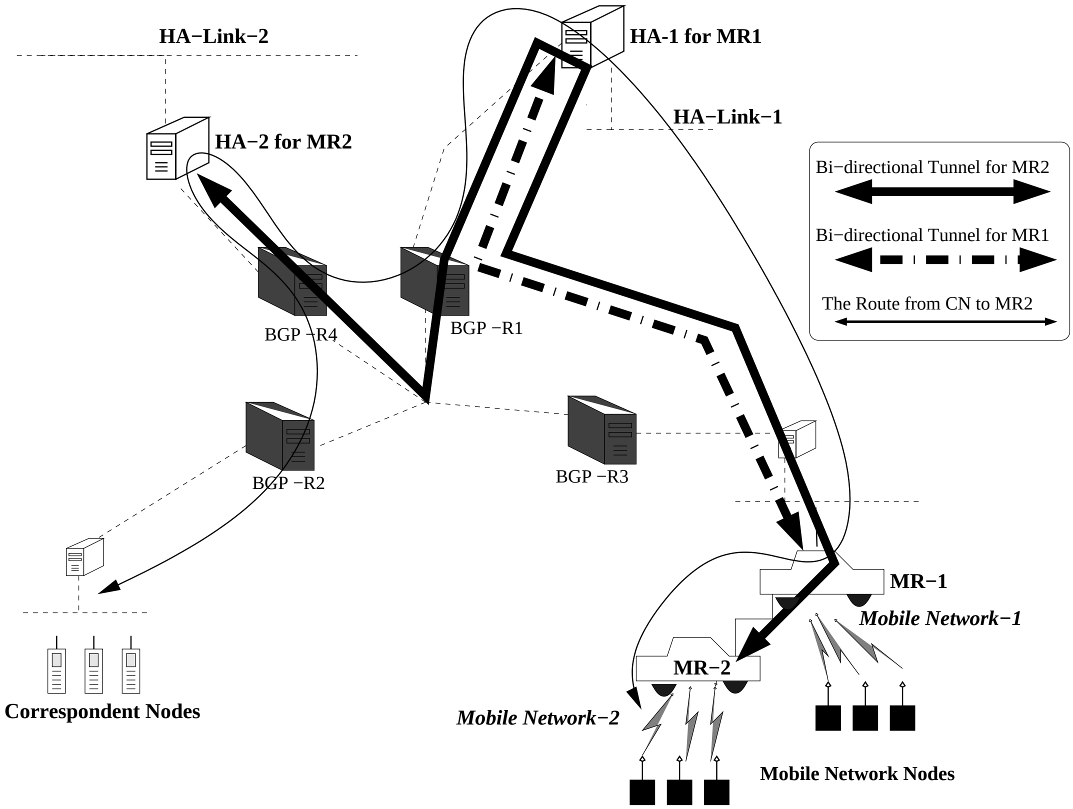

Fig. 5 Nested mobility.

returns a binding acknowledgment with a new defined status code. This status code implies "returning home link" to the MR. The MR stop using the bi-directional tunnel, because the HA becomes the next hop router. Whenever the MR forwards MNN's packets to the Internet, it always route the packets to the HA according to the routing entry without IP-in-IP encapsulation.

On the other direction, packets intended to the mobile network and intercepted by HA are neither transmitted through the bi-directional tunnel. While MR is being on the home link, the prefix binding is not referred by the HA for routing packets to the mobile network. The binding update is used to know whether MR returns to the home link or not.

5. Advanced Protocol Operations

Section 4.2 does not describe all the potential scenarios on the real world such as nested mobility, multiple network interfaces on a MR, multiple MRs, and multiple HAs. This section shows the advanced operations to support these situations.

5.1 Nested Mobility Support

Once Internet ITS is being deployed and many vehicles operating a mobile network are moving around, a MR may attach to a mobile network of another MR. This case is know as nested mobility. One example of nested mobility is a personal area network attached to an in-vehicle mobile network.

Figure 5 shows the network configuration when MR-2 attaches to the mobile network of MR-1. MR-1 is maintaining its bi-directional tunnel with HA-1 and routes all packets through the bi-directional tunnel. MR-2 sends a binding update with MR-CoA2 generated from the mobile network prefix of MR-1 to establish a bi-directional tunnel with HA-2. MR-1 intercepts and tunnels the binding update to HA-1, and then HA-1 routes the binding update to HA-2. Consequently, MR2 and HA-2 establish a bi-directional tunnel through the tunnel between MR-1 and HA-1.

When a CN sends packets to the mobile network of MR-2, packets first reach HA-2, and are tunneled to MR-2. The other bi-directional tunnel for MR-1 lies between MR-2 and HA-

2. Therefore, the tunneled packets are routed to HA-1 and therefrom re-tunneled to MR-1. The additional packet's size becomes 40 bytes (the size of the IPv6 header) larger than the original packet. When the additional packet's size reaches the Maximum Transmission Unit (MTU) between the CN and a MNN, no additional mobile network can be added to the nested mobile network.

5.2 Multiple Network Interfaces Support

A MR may manage multiple egress interfaces and get simultaneous access to the Internet to obtain wide internet coverage and higher bandwidth. Utilization of multiple network interfaces provides durable Internet connectivity [1),21),23)]. If a MR assigns a different mobile network prefix to each egress interface, no additional extensions are needed. MR just operates the basic protocol operations for each prefix independently. However, the MR can not manage egress interfaces with a single mobile network prefix, because Mobile IPv6 prohibits registration of multiple bindings for a home address. Utilization of a single mobile network prefix has the advantage of continuous communication, since an address stored at the session layer is never changed while the network interface changes.

This question has been already addressed for Mobile IPv6. We proposed multiple care-of address registrations for Mobile IPv6 in our internet-draft (MCOA) [18)]. MCOA proposes a new identification number for each interface of a mobile node . The mobile node registers bindings for all its belonging interfaces with the corresponding identification number. Thus, HA can distinguish which binding is associated with which interface. Since our NEMO support proposal well complies with Mobile IPv6, MCOA can also easily be applied. MR assigns an identification number to each interface, and registers with the HA all the MR-CoAs with identification numbers.

5.3 Multiple Mobile Routers Support

Multiple MRs may be configured for a mobile network to reduce overhead of each MR and to provide redundancy of MR.

In **Fig. 6**, there are two MRs (MR-1 and MR-2). Both MRs have the same mobile network prefix and are associated with a single HA. Both MRs advertise the mobile network prefix by means of router advertisements with a different preference value. Thus, MNNs can acquires two gateways to the Internet and use them depending on the preference value or network environments. The MR selection is not discussed in this paper.

Each MR registers its own prefix binding to the HA (Fig. 6). Therefore, the HA has two prefix bindings for the mobile network prefix. When packets to the mobile network are intercepted by the HA, the HA tunnels them to one MR according to the registered bindings. When the destination of packets is a MR itself (i.e., the destination address is a MR-A), the HA searches the binding cache comparing the 128-bit between the destination address and MR-A described in Section 4.1. The HA selects the prefix binding as a host binding for the destination, since each prefix binding is registered with the set of MR-A, the prefix length and MR-CoA.

5.4 Multiple Home Agents Support

Multiple HAs can be configured in the same domain to provide HA redundancy. If multiple HAs have the prefix binding of MR simultaneously, each HA advertises the route to the mobile network prefix in its routing domain with a different routing metric. When a HA goes down, another HA quickly takes over HA's functionality. If a primary HA goes down, all packets destined to the mobile network prefix are routed to another HA, because the route to the mobile network advertised by the primary HA is deleted from all routers in the routing domain.

6. Prominent Advantages

Our NEMO basic support proposal has several advantages compared to other solutions.

The Size of Binding Update sub-option: Our proposal does not require to store prefix address information in the sub-option. Only a prefix length is stored in the sub-option. To minimize signaling packets is important specially on wireless environments due to limited bandwidth.

Aggregated Binding Management: HA does not need to manage two bindings per mobile network, because MR registers its prefix binding both as a host and a network binding. If MR acts as a mobile node, it just sends a BU with the full prefix length. PSBU and MRTP need to manage home address of MR and a mobile network prefix.

Support Various Configurations: Our proposal also supports various configura-

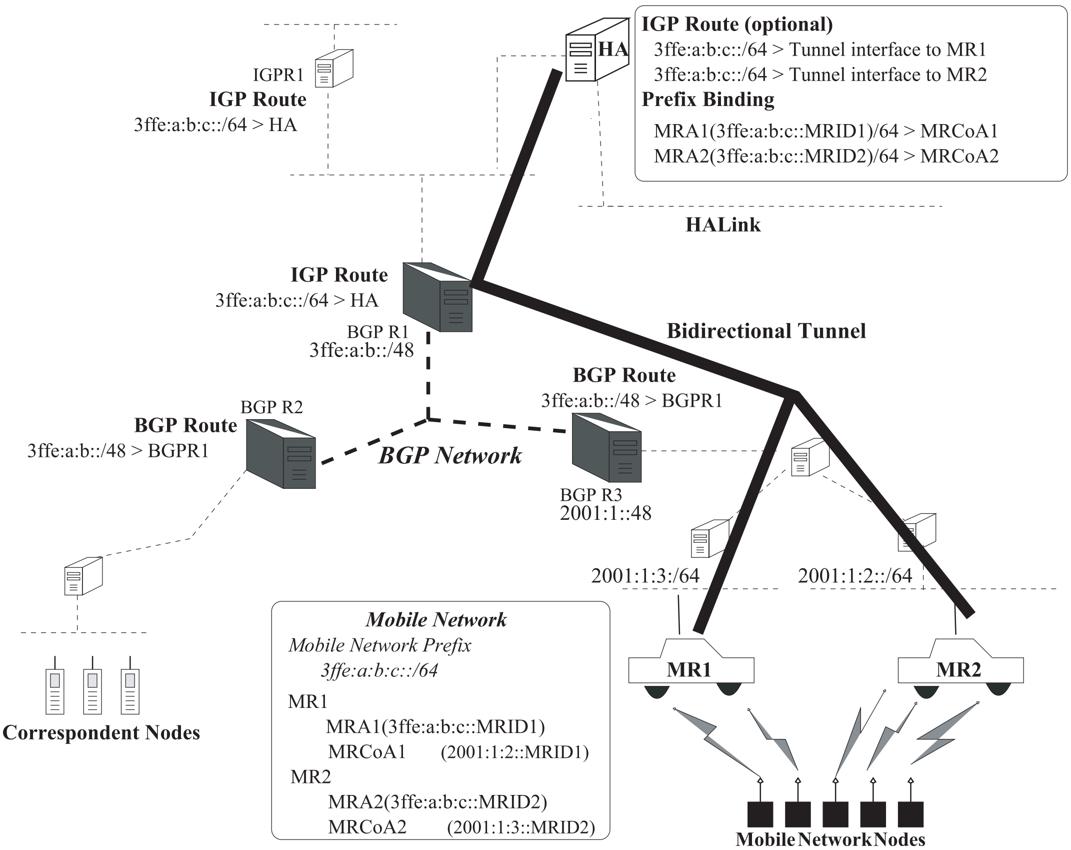

Fig. 6 Multiple mobile routers support.

tions such as multiple network interfaces, multiple MRs, and multiple HAs. These features are required specially for large systems such as Internet ITS. Nested mobility is supported by our solution as well as MRTP. In addition, Route optimization is not focused by the NEMO working group at this time, but Internet ITS needs other aspects of optimizations and redundancy in terms of multiple MRs and multiple HAs.

Consideration of Route Optimization: Our NEMO basic support solution is based on ORC. ORC considers route optimization. Although our NEMO basic solution does not support route optimization, it can quickly retrieves the route optimization feature from ORC.

With these features, our solution is applicable to Internet ITS compared to the other solutions. We work on the IETF standardization to deploy our solution on Internet ITS. We currently propose our NEMO basic support as an individual draft (draft-wakikawa-nemo-basic) [19] to the IETF NEMO working group. The NEMO basic support solution(draft-ietf-nemo-basic-support) [4] released by the NEMO working group merges ideas from our individual draft .

7. Conclusion

In this paper, we proposed a basic protocol to support network mobility. The protocol provides network transparency by assigning a unique and unchanging mobile network prefix to a mobile network. MR notifies the prefix by means of a binding update containing the association between MR-CoA and MR-A. HA caches the prefix binding. All packets destined to the mobile network are intercepted by HA and tunneled to MR. Packets from the mobile network are intercepted by MR, tunneled to HA and routed to the destination by HA. We describe the normal operations. We also describe the advanced operations for various network configurations. These advanced operations indicate that our protocol can be configured in several ways depending on environments of network mobility and administrative requirements.

Our protocol satisfies the requirements of Intelligent Transportation Systems as expressed in the InternetITS organization. There are many kinds of vehicle environments and various applications run on mobile networks. For this diversity system, we introduce the advanced operations to operate mobile networks in various ways. Thus, our proposal is well suited for Internet ITS systems.

Acknowledgments We specially thank Susumu Koshiba, Masafumi Watari, and Hiroki Matsutani at Keio University. We also thank members of the InternetCAR project at Keio University and members of the WIDE project for the discussions and feedback.

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(Received March 31, 2003)
(Accepted September 5, 2003)

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