Local Route Optimization for Visiting Mobile Nodes in Mobile IPv6 Networks

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***Abstract*— Route Optimization in Mobile IPv6 environments addresses one of the major problems of IP based mobility, traffic overhead resulting from packet tunneling using non-optimal routes.**

The impact of non optimal routes is even more severe if not only dealing with single mobile hosts but with a combination of mobile hosts and entire mobile networks, as it has been done in the IST project OverDRiVE [1] .

In this paper, we describe an approach that addresses specifically this kind of multi-mobility scenarios. It provides route optimization between visiting mobile nodes and mobility unaware nodes within a mobile network, even in case the mobile network is currently totally disconnected from any infrastructure. This is a most likely event when looking at vehicular networks in cars or trains.

***Index Terms*— Mobile Router(MR), Visiting Mobile Node (VMN), IPv6 Network Mobility (NEMO), Route Optimization.**

I. Introduction

Transparent IPv6 network mobility is realized by the usage of at least two special nodes, a mobile router (MR) and a mobile router home agent (MRHA) [1]. These two nodes are able to provide mobility for entire networks consisting of several other nodes, not necessarily aware of mobility (see Figure 1). The MR attaches to different access networks and communicates its current care-of address to the MRHA. The MRHA at the home link of the MR assures the permanent reachability of the mobile network via its home prefix. It forwards all respective packets through a bi-directional tunnel to the MR's currently registered care-of address (see Figure 2).

From an architectural point of view, vehicles can be looked at as ideal example of mobile networks [2] [3]. The MR inside the vehicle is responsible for the connection of intra-vehicular sub-networks to different external access routers within a fixed IPv6 infrastructure, i.e. the Internet.

[1] This work has been performed in the framework of the IST project IST-2001-35125 OverDRiVE (Spectrum Efficient Uni- and Multicast Over Dynamic Radio Networks in Vehicular Environments), which is partly funded by the European Union. The OverDRiVE consortium consists of Ericsson (co-ordinator) DaimlerChrysler, France Telecom, Motorola and Radiotelevisione Italiana as well as RWTH Aachen, Universität Bonn and the University of Surrey. The authors acknowledge the contributions of their colleagues in the OverDRiVE consortium.

One can imagine the following scenario. Three persons drive in a car. Two of them use personal devices (Laptop or PDA) that are connected via Bluetooth or WLAN to the car's internal network. They are able to access senor data from nodes inside the car and they can use the car's uplink connection (e.g. UMTS) to be able to communicate with the Internet. At the same time, the navigation system receives updated traffic information from a traffic service station.

In contrast to simple mobile host environments, the combination of mobile networks and mobile hosts as discussed in this paper allows efficient route updates only once for the entire in-vehicular network (which includes all currently attached visiting mobile nodes) instead of an individual update for every host in the network. Furthermore, it allows that nodes participate which are not aware of mobility (i.e. standard IPv6 supporting nodes, as specified in [4]).

In this paper we discuss route optimization between visiting mobile nodes and fixed nodes inside the visited mobile network. This means, communication between visiting mobile nodes and non-mobility supporting nodes inside the mobile network does *not* have to be tunneled via any home agent, located anywhere in the Internet. The communication remains local in the mobile network. Our approach requires only minor changes, but provides enormous advantages compared to non-optimized tunneling solutions. The participating MR, the visiting mobile host (node) as well as eventual intermediate routers have to be slightly adapted.

The paper is organized as follows. In the next section we describe MR and route optimization. Then we elaborate the drawback of non-optimized routing and provide solutions, followed by the analysis of the features and the advantages of our selected solution. At the end, we provide a conclusion and an outlook on future work.

II. Background and Definitions

A. Mobile Router (MR)

MR is a combination of mobile host and standard router that is capable to connect an entire mobile network to different access networks, while the mobile network does not

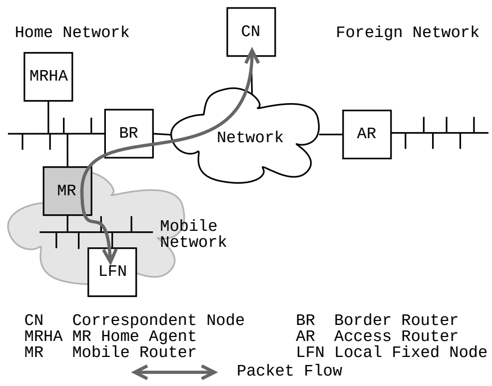

Fig. 1
MR AT HOME

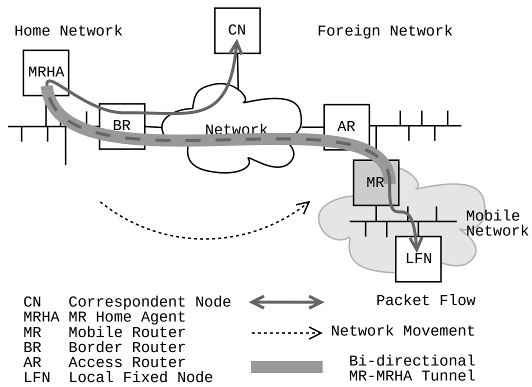

Fig. 2
MR CONNECTED TO A FOREIGN NETWORK

have to change its internal network addressing scheme. The network remains permanently attached to the mobile router.

In general, packets from and to the mobile network are always routed through the bi-directional MR - MRHA tunnel. This behavior is described in the NEMO basic support draft, [1].

B. *Visiting Mobile Node (VMN)*

A visiting mobile node is a standard mobile node, as described in [5]. It is either a host or a router that can move topologically with respect to the MR and whose home link doesn't belong to the mobile network. It becomes a visiting mobile node as soon as it gets attached to a foreign link within the mobile network and obtains an address on that link. Examples for visiting mobile nodes as used in the OverDRiVE project, are PDAs or Smartphones that join the vehicular network.

C. *Home Agent (HA) and Mobile Router Home Agent (MRHA)*

A home agent [5] is a node on a mobile node's home link with which the mobile node can register its current care-of address. While the mobile node is away from home, the home agent uses proxy neighbor discovery to intercept packets on the home link destined to the mobile node's home address. Then it encapsulates them, and tunnels them to the mobile node's currently registered care-of address.

What we call mobile router home agent (MRHA) is a NEMO [1] compliant home agent. Basically this is a standard Mobile IPv6 home agent, extended to support not only host mobility but also mobility for entire mobile networks.

D. *Route Optimization*

Route optimization is a process that is used to enable packet delivery along the (topologically) shortest path between two communicating nodes. Basically, in Mobile IP scenarios this means to eliminate tunneling over a home agent and to establish a direct connection between two communicating nodes.

Optimization for the communication between a single mobile host and a correspondent node is described in [5]. Proposed approaches for mobile networks are discussed in section IV.

III. PROBLEM DESCRIPTION

Assuming that a mobile node somewhere in the Internet (a user checking his vehicle's status from his work desk) has connections to several nodes within a mobile network (e.g. sensors, an onboard unit, or a car web-server) that do *not* support standard MIPv6 route optimization. This mobile node then joins the mobile network, i.e. the user enters the vehicle, and thus the mobile node becomes a visiting mobile node of this network. Without route optimization, the entire traffic between the mobile node and the local fixed nodes in the mobile network is routed via at least the home agent of the mobile node, or in case the mobile network is not at home, also via the mobile router's home agent. This is in many cases not acceptable, since in-vehicle entertainment, e.g. a video played on the car DVD player and displayed on a PDA display is a quite likely scenario. Without route optimization this is not possible at all (due to limited bandwidth of the wireless link or much to expensive)

To look into this problem in more detail, we consider a simplified example with only one ongoing communication between the mobile node and a (local fixed) node in the mobile network, as shown in figure 3. [2] The mobile network is connected to a foreign access system and the mobile node is directly attached to one of the mobile network sub-nets. The packet flow of such a communication is depicted in figure 4. This means, if the visiting mobile node sends a packet to the local fixed node, the visiting mobile node first encapsulates the packet and forwards it in direction to its home agent. In this path, the mobile

[2] We left out packet flow indicators in this figure due to visibility reasons.

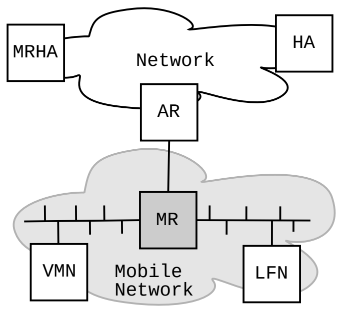

Fig. 3
SIMPLIFIED EXAMPLE SCENARIO

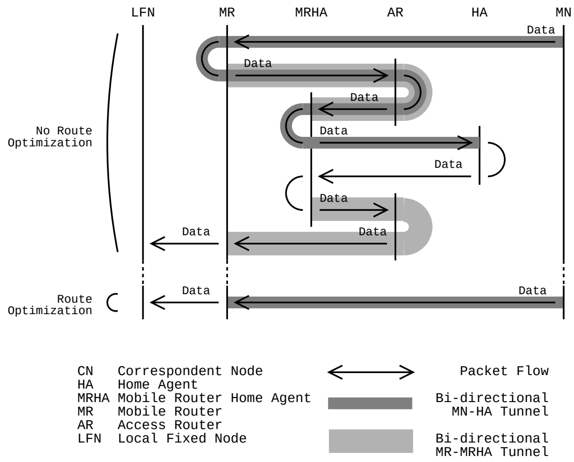

Fig. 4
PACKET FLOW

router receives this packet and decides that the packet destination is not inside its mobile network (the destination of the encapsulated packet is the mobile node's home agent) and thus encapsulates the packet once more and sends it to its MRHA. At the MRHA the packet is decapsulated once and forwarded to the mobile node's home agent. This one does the second decapsulation, and thus receives the original packet, with destination local fixed node. Therefore, it sends the packet in direction to the home link of the mobile network. On this link, the packet is intercepted by the MRHA and tunneled to the MR, which finally delivers the packet to its destination, the local fixed node.

Since in general the up-link connection of a mobile network, connected to any foreign access network, is a non high-speed connection, e.g. a UMTS connection as used in the OverDRiVE project, this kind of tunneling is not a long-term satisfying solution. Even more, apart from this being a tremendous waste of scarce resources, in case of a breakdown of the up-link connection, communication between the mobile node and any other node within the mobile network is impossible.

IV. RELATED WORK

The IETF draft [6] tries to establish a taxonomy on the route optimization problem area. Regarding to that documents the problem scope of this paper relates to the case of MIPv6 route optimization over NEMO which in turn is a special case of nested mobile networks. With respect to [6] the approaches relevant to the scope of this paper are Hierarchical MIPv6 (HMIPv6) based approaches, route optimization based on prefix delegation [7] and route optimization based on neighbour discovery proxy functionality [8].

Hierarchical MIPv6 (HMIPv6) has been developed by Ericsson and INRIA. It is specified in an Internet-Draft [9] and was further developed regarding route optimization for mobile nodes in mobile networks [10]. A new Mobile IPv6 node, called mobility anchor point (MAP), is introduced, which can be located at any level in a hierarchical network of routers. In our scenario the MR would be a mobility anchor point. In HMIPv6, two different types of care-of addresses are distinguished: Beside the topologically correct care-of address, called "'local care-of address"' (LCoA) in this context, a mobile node also obtains an address from a mobility anchor point referred to as the "'regional care-of address"' (RCoA). The RCoA is an address on the mobility anchor point's subnet. If there is more than one hierarchy level, a mobile node may even have several RCoAs. In theory, the correspondent nodes are not affected. The mobile anchor point essentially acts as a local home agent, limiting the signaling outside a local domain.

In [7] route optimization is reached via prefix delegation (PD) which in turn requires that the access routers support that protocol. Through prefix delegation the route could be held optimal by delegating sub-prefixes of the original prefix acquired from the access router down to a moving subnetwork. Naturally that approach is not well suited in fast changing network topologies since it would require the whole networks to reconfigure.

The approach described in [8] relies on the principle that the mobile router relays the prefix of its care-of address to its mobile nodes by playing the role of a neighbour discovery (ND)-proxy. Through binding updates associated with the network prefix of an access network, the mobile nodes can perform route optimization.

For the reason of completeness we would like to add also a short description of Prefix Scope Binding Updates (PSBU). The utilization of Prefix Scope Binding Updates has been proposed by MOTOROLA Labs Paris and INRIA. It is specified in an Internet-Draft [11]. Basically, a Prefix Scope Binding Update is an enhanced Mobile IPv6 Binding Update associating a care-of address with a prefix instead of a single address. It is assumed that all nodes in a moving network share a common prefix, and MR's ingress interface is configured with this prefix. As in MIPv6, MR's egress interface is configured with the home prefix (when the MR is at home) or with the care-of address received by a foreign access network. The draft does not consider visiting mobile nodes so that with respect to the scope of the paper a major requirement is not full filed.

One can say none of these drafts covers the case we set up in section III but only, if at all, route optimization between a mobile node and a correspondent or a local fixed

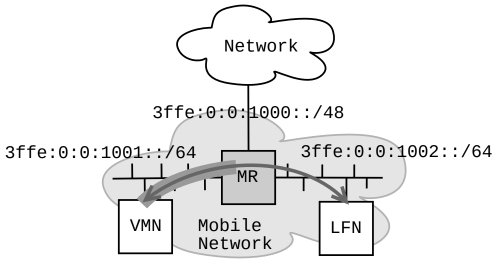

Fig. 5
EXAMPLE SCENARIO

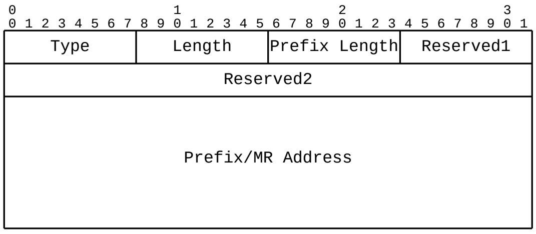

Fig. 6
MOBILE NETWORK PREFIX OPTION FORMAT

Type	-	not yet assigned
Length	-	4
Prefix Length	-	8-bit unsigned integer. The number of leading bits in the Prefix/MR Address field that define the prefix. The value ranges from 0 to 128.
Reserved1	-	8-bit unused field. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.
Reserved2	-	32-bit unused field. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.
Prefix/ MR Address	-	An IP address of the Mobile Router in the prefix space of the mobile network. The Prefix Length field contains the number of valid leading bits in the prefix. The bits in the prefix after the prefix length contain what is missing to complete the MR address.

TABLE I
MESSAGE FORMAT DESCRIPTION

node and a correspondent node (the correspondent node located in the infrastructure). The closest approach might be the one described in [10]. But it requires a HMIP infrastructure (HA, MAP, etc.) to be working with whereas our approach keeps to optimization local within the moving network.

V. ROUTE OPTIMIZATION FOR VISITING MOBILE NODES

To exemplify our approach, we consider the example scenario as depicted in figure 5. The mobile network consists of two separate subnets, interconnected by the mobile router. The entire mobile network prefix is 48 bit long, the subnet prefixes are only 64 bit. A visiting mobile node connects to subnet 1 and wants to communicate with a local fixed node in subnet 2. Without route optimization, the entire traffic resulting from this communication is tunneled twice through the external link (the packet flow results in what has already been shown in figure 4).

When the mobile node joins the mobile network, the node detects its movement by the reception of a router advertisement that contains a previously unknown prefix. In addition to the IPv6 standard [12], the router advertisement in our solution has a supplementary option that contains also the prefix of the entire mobile network (from which, the prefix on the respective link is only a subset) as well as the MR's IPv6 address on this link (see subsection V-A for a detailed explanation of this option). This option is required since the visiting mobile node needs to know the entire prefix to be able to do route optimization for the entire mobile network, otherwise route optimization would only be possible for the respective subnet.

After the reception of the router advertisement, the visiting mobile node updates the bindings with its home agent first (as it usually does, according to [5]). But instead of trying to do route optimization directly with the local fixed nodes, the visiting mobile node sends a binding update message to the MR. The MR responds with a binding acknowledgment.

As soon as the registration is completed, packet transfers between the visiting mobile node and the local fixed nodes in the mobile network work as follows. When the visiting mobile node wants to send packets to local fixed nodes, it finds the MR's address in its binding cache, associated with the mobile network's prefix. That's why it decides to encapsulate the packets and to send them to the MR. The MR decapsulates the packets and forwards them to the destination nodes, which are the local fixed nodes.

Routing in the other direction, packets from local fixed nodes to a registered visiting mobile node is similar. The local fixed sends a packet to visiting mobile node's home address, which has to be routed via the MR. MR detects the visiting mobile node's home address in the IPv6 header destination address field and using its binding cache MR determines the actual care-of address of the visiting mobile node. MR encapsulates the packet and forwards it to the visiting mobile node, which finally decapsulates the packet.

In both directions, tunneling between the MR and the visiting mobile node is necessary to maintain topological correct routing and addressing. Moreover, there might be intermediate routers between the MR and the visiting mobile node, that would not be aware of the visiting mobile node's care-of address.

A. Protocol Extensions

To be able to announce the presence of a MR that supports route optimization for visiting mobile nodes, we define a new option (see Figure 6 and Table I) that has to be included in the router advertisements inside the mobile network. This option contains the entire mobile network prefix as well as one of the MR's internal IPv6 addresses. In case MR has several internal interfaces on different subnets, as shown in the example scenario, MR should send the address that is used on the respective interface.

B. Requirements on Participating Nodes

The MR *should* be configurable to send the new router advertisement option specified in subsection V-A to announce the mobile network's prefix and its own address. Furthermore, when sending this option, it *should* accept binding request from visiting mobile nodes and participate in route optimization as explained before.

A visiting mobile node *should* detect the new router advertisement option. On reception of a router advertisement containing this option, it must update its existing bindings and then it *should* send a binding update to the mobile router address that is indicated in the option. After the reception of a binding acknowledgment (i.e. the successful completion of the binding process), the visiting mobile node should act as described in this section and send packets to nodes inside the mobile network via the MR.

Intermediate routers inside the mobile network (especially routers that are meant to function as access routers for visiting mobile nodes) *should* be able to propagate the contents of the new router advertisement option to their sub-networks. This can be done either in a manual mode, or in an automatic mode. In manual mode, the contents of the option have to be configured by an administrator. In automatic mode the router detects the option in router advertisements of another router (e.g. the MR) and re-distributes it to its sub-networks.

VI. Security Considerations

A security issue for MR is to accept binding updates from the visiting mobile node. This problem can be eliminated by using network access control for OverDRiVE mobile networks as it was described in [13]. Then we can assume that the MR is able to authenticate the visiting mobile node and vice versa. In case the authentication data of both, the visiting mobile node and the MR, has been previously store inside the mobile network, secured route optimization is also possible, if the mobile network is temporarily disconnected from the Internet.

VII. Comparison to other Solutions

The advantages compared to other route optimization solutions for mobile networks are the following. Our approach works also in case the mobile network is at home. It works in disconnected mode, i.e. when the MR's up-link connection is interrupted or even totally broken. And, route optimization will only take place if visiting mobile node joins the mobile network, i.e. the optimization remains local inside the mobile network.

Compared to standard Mobile IPv6 we are able to provide route optimization for nodes that do not support route optimization themselves, i.e. for nodes that support only standard IPv6 (sensors or onboard units that are not upgradeable to support Mobile IPv6 route optimization).

VIII. Conclusions

We have analysed the specific problem of route optimization within mobile networks and have presented a new solution. The comparison to other proposals shows that our solution provides significant improvements to the previous approaches. This is the first approach that works even when the mobile network has no up-link connectivity in the initial phase of the route optimization.

In future work, we will enlarge our approach to not only support route optimization for mobile hosts but also for nested mobile networks. Amongst other things, we expect this to provide a solution for the crossover tunnels issue, described in [14].

Furthermore we are planning to include our approach in the Motorola LIVSIX IPv6 stack [15], which was used to build the OverDRiVE demonstrator.

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