ROUTE OPTIMIZATION IN NESTED MOBILE NETWORKS (NEMO) USING OLSR

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ABSTRACT

Internet edge mobility has been possible for a number of years: mobile IP[8], allows a host to change its point of attachment to the Internet and NEMO [6] allows the same functionality for a group of hosts along with a mobile router. The virtue of NEMO and mobile IP is transparency: a host remains identifiable through the same IP address, and traffic sent to that IP address will be tunneled to arrive at the intended node.

NEMO allows "nested networks": a mobile network which attaches to another mobile network to arbitrary depth. However for each level of nesting, traffic is encapsulated and tunneled to reach the destination. This leads to increased overhead (encapsulation) and to sub-optimal paths (tunneling without consideration for the actual network topology).

In this paper, we investigate route-optimization in nested NEMO networks. We employ an ad-hoc routing protocol between mobile routers to ensure shortest routes when both source and destination for traffic is within the nested NEMO network. The mechanism also simplifies the requirements for route optimization when the source node is located outside of the nested NEMO network.

KEY WORDS

OLSR, Ad-hoc Networking, Network Mobility, Routing, Internet Architecture

1 Introduction

The global Internet is build on a relatively simple architecture, illustrated in figure 1: a mostly static core of routers perform the task of ensuring connectivity through maintaining links with each other, calculating suitable paths for data traffic and finally, forward data traffic on behalf of the hosts, located on the edge of the Internet. Each host and router is identified by an IP address – which serves two purposes:

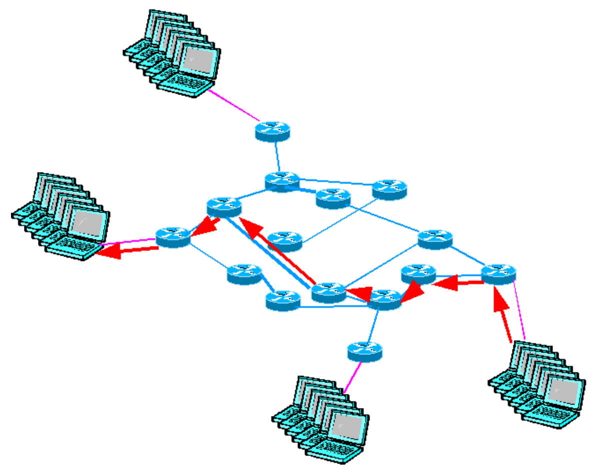

Figure 1. The basic Internet

- an IP-address serves as an unique identifier for a communication endpoint[1];
- an IP-address serves as a convenient way of reducing the overhead of maintaining topological information in the core routers. This is achieved through "delegating" a sequence of IP-addresses (a "prefix") to a given router which then rather than advertise each IP-address individually will advertise connectivity to an entire prefix. For example, all the hosts in a cluster on figure 1 share the same prefix[2].

If a node changes its point of attachment (e.g. moves from one cluster to another in figure 1), then in order to maintain the advantage of the routers being able to advertise only prefixes, the node must change its IP-address. However this would imply that a node would no longer be reachable with its previous identity. Conversely, preserving the identity of a node would compromise the signaling advantage of having each node be responsible for and advertising a prefix.

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[1]Strictly speaking, a communication endpoint is defined by an IP-address and a port number, the IP-address uniquely identifying the host in the Internet, and the port number uniquely identifying a process on that host. However as far as routing in the Internet is concerned, only the IP-address is of relevance.

[2]In IPv4, commonly also called "network address".

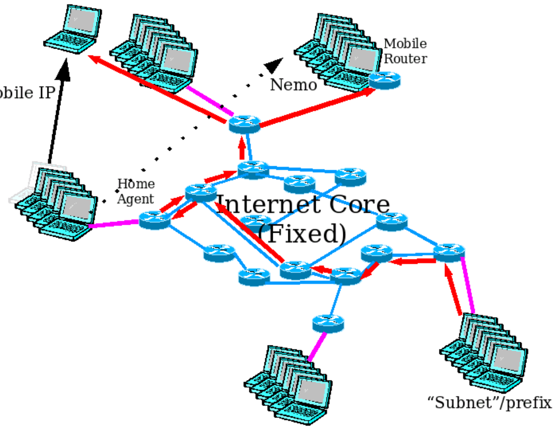

Figure 2. Mobile IP and NEMO exemplified. The solid arrow indicates that one single node moves (mobile IP) to a new network where it associates with a foreign agent, the dotted arrow indicates where a whole network moves (NEMO), using the same mechanisms as mobile IP. Notice tunneling causes a link to be transversed twice by the same data packets.

Proposed solutions to this problem exists in form of Mobile IP [8] and NEMO [6]: for both, the basic approach is that when a node moves, as indicated in figure 2, it acquires a new address (care-of address) at the destination network. This address belongs to the prefix of the router, through which the node will connect to the Internet. Once thus connected, the mobile node contacts its *home agent*, requesting that all traffic to the nodes former address (called *home address*) now be tunneled to its new location. As illustrated by the arrows in figure 2, this may involve suboptimal routes, links which are transversed twice etc.

Figure 3 illustrates the situation, where a NEMO network attaches to another NEMO network, in order to gain connectivity to the Internet. This situation is called a "nested NEMO network". The mechanisms, provided by NEMO, ensures connectivity, however f nodes from the two nested NEMO networks wish to communicate with each other, tunneling, as indicated by the arrows along the links in the network, occurs. In a more deeply nested NEMO network, such as the one illustrated in figure 4, the path taken by the tunneled traffic in order to reach a node in an adjacent NEMO network can be substantially longer. It is clear, that in the networks in figure 3 and figure 4, shorter paths exist – but are not used.

In addition to the long and suboptimal paths, an additional overhead incurs from tunneling: essentially, whenever an IP packet transverses a home agent encapsulation happens. Returning to figure 4, an IP packet from a node in network B, destined to a node in network A, will first be sent to the home agent for network A. Here, a binding exists, stating that mobile network A is attached to mobile network B – and hence, the IP packet is encapsulated with another IP-header and sent to the home agent for mobile

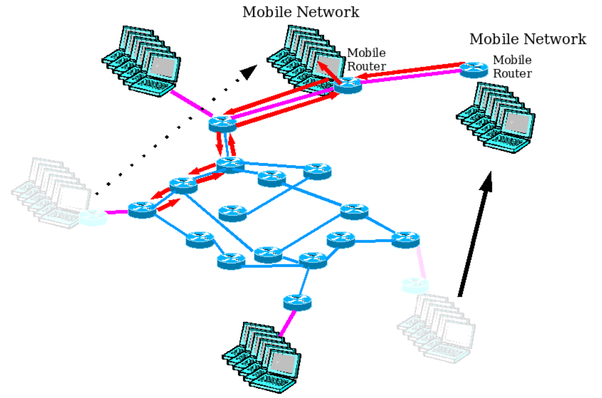

Figure 3. A simple nested NEMO network: one NEMO network connects to another NEMO network in order to gain connectivity to the Internet. Notice how data traffic, in case of communication between nodes in the two NEMO networks, transverses the Internet before being delivered.

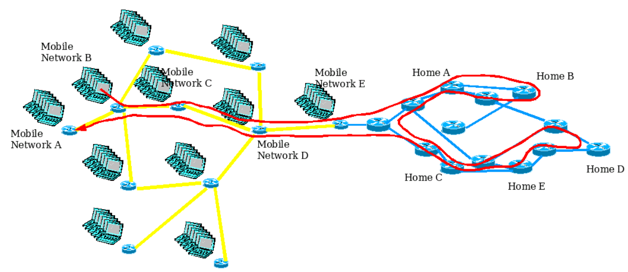

Figure 4. Deeply nested NEMO network

network B. At the home agent for network B (and then C, D and E) the same happens – and when the packet finally arrives back at the nested NEMO network, it thus carries the overhead of 5 encapsulations. In NEMO, this is required: none of the mobile routers in the nested NEMO network maintain topological information about the nested NEMO network, and thus are not able to correctly forward the packet without this encapsulation header.

Thus, in situations where nodes in nested NEMO networks communicate, this communication is subject to the overhead from suboptimal paths due to tunneling combined with the overhead from nested encapsulations.

1.1 Route Optimization in nested NEMO networks

While NEMO solves the problem of providing connectivity for nested mobile networks, suboptimal paths and large encapsulation overheads result even from relatively simple situations such as illustrated above. This originates in the following issues:

- the node which originates data traffic does not know where the destination node is located and therefore assumes that the node is at its "home network", relying on subsequent tunneling to reach the nodes current location;

- no router knows the full path to the destination, which in particular means that;
- no router knows the topology of the nested NEMO network(s), thus relying on the encapsulation information in order to provide forwarding/routing.

Route optimization is, then, the task of reducing the encapsulation overhead and provide shorter (more optimal) paths for data traffic. This can be done through addressing the issues listed above in different ways.

1.2 Related Work

Previous work regarding route optimization in NEMO has mainly aimed at providing shorter tunnels through introducing additional state in the home agents or in some dedicated routers throughout the network.

In order to avoid the scenario described, where data packets for delivery within the nested NEMO network are routed through the Internet and the nested networks Home Agents when a more localized approach would have been possible, additional state can be maintained in the nested NEMO networks.

Some approaches have been proposed to tackle the problem of route optimization inside nested NEMO networks. For instance, Nested NEMO Tree Discovery [9] offers a mechanism that aims at avoiding routing loops by organizing and maintaining a tree structure within the network of nested NEMOs, the root being the Access Router or the Mobile Router directly connected to the Access Router (the Top Level Mobile Router).

Source routing is also proposed to be used in this environment. Approaches like RRH [14] use the recording of the sequences of traversed Mobile Routers on the way out of the nested NEMO network (to the Internet, say, to bind) in order to forward traffic efficiently in the nested NEMO network.

On the other hand, approaches like ORC (Optimized Route Cache Protocol) [17] could be adapted to serve the purpose of insuring some level of optimized routing inside nested NEMO networks. Some router, say the top level Mobile Router, could be configured to play a role similar to a correspondent router, organizing the forwarding of packets inside the nested NEMO network. This special router could be dynamically discovered inside the nested NEMO network.

1.3 Route Optimization Using a Routing Protocol

Essentially, the issue of route optimization within a nested NEMO network is one of routing: maintaining state in each Mobile Router such that an intelligent forwarding decision can be made. I.e., if the destination can be detected to be "local" to the nest of NEMO networks, a route to the destination can be constructed directly through the NEMO Mobile Routers without passing through the Home Agents. In figure 4, this would correspond to the Mobile Router for network A being able to directly forward traffic to the Mobile Router for network B, rather than take the long path indicated on the figure. Alternatively, if the destination is not local, data are routed to the Home Agent, where basic NEMO tunneling and encapsulation take effect. The general form of this mechanism is to have each Mobile Router in the nested NEMO network possess extended information about the nested NEMO networks. This does then, de-facto, become a situation where each mobile knows the entire topology of the nested NEMO network, and will be able to act in the capacity of router for such traffic.

1.4 Problem Statement

The problem, which we will address in this paper, is optimization of routes within a nested NEMO network. The mechanism we propose is based on applying a well-known MANET routing protocol to the task of distributing topology information about the nested NEMO network to the Mobile Routers within the network. The impact will be that any IP-packet, destined for a node in any the nested NEMO networks can be correctly routed by any Mobile Router. The immediate consequence of this is, that it will allow NEMO-to-NEMO communication to bypass the Internet and tunneling through home-agents. A convenient side-effect is, with routing information governing the nested NEMO networks in place within the nested NEMO networks, the task of performing route optimization on the Internet can be greatly simplified: the encapsulation header is, for example, no longer required to ensure correct data delivery in the nested NEMO network.

1.5 Paper Outline

The remainder of this paper will be organized as follows: section 2 will discuss ad-hoc routing in the context of route optimization for nested NEMO networks. Particular attention will be given to the the OLSR [2] routing protocol, since the protocol specification for OLSR directly contains features which make it suitable for nested NEMO networks. Following, section 3 describes how OLSR can be applied to provide NEMO-to-NEMO route optimizations. As mentioned, the solution proposed in this paper provides some features which may simplify the task of making route-optimization also for Internet-to-NEMO communication. We therefore outline this in section 4, before section 5 concludes the paper.

2 OLSR Networks and Ad-hoc Routing for Route Optimization

An ad-hoc network is a collection of nodes, connected by wireless links, forming an arbitrary, dynamic graph. The wireless medium typically implies a bandwidth-constrained network. This due to the lower bandwidth provided by the network adapters and to the fact that communication over any link will interfere with communication on any other link within radio range.

Mobility implies that links between nodes may change and that the number of nodes in a network is not constant. The physical size of a MANET is expected to be larger than the radio range of the wireless interfaces, thus for any two nodes in the network to be able to communicate, routing is necessary.

Two requirements are presented for ad-hoc routing protocols: the ability to maintain routes, despite a dynamic topology, while economizing bandwidth consumption through minimizing the signaling requirements.

Two classes of ad-hoc routing protocols exist: reactive protocols, including DSR [7] and AODV [4], discovers and maintains routes only when required through a request-reply flooding cycle. Proactive protocols, including OLSR [2] and TBRPF [3], maintain routes to all destinations at all times through periodic advertisements.

Of the different ad-hoc routing protocols, we chose to apply OLSR to the problem of route optimization in nested NEMO networks. OLSR can be described as a light-weight version of OSPF [1], which is currently the predominant IGP in use on the Internet, adopted to the characteristics of ad-hoc networks. Additionally, the OLSR specification includes a way by which it is possible for a router to advertise routes to non-routing Mobile Network Nodes as well as routers.

2.1 The Optimized Link State Routing Protocol

OLSR [2] employs periodic flooding of topological information, contained in *TC-messages*, to all OLSR routers in the network. This flooding is performed through a connected dominating set, using the concept of *multipoint relays* (MPRs) [5]. Each OLSR router selects among its neighbor OLSR routers a subset, called "*multipoint-relays*". This set is selected such that any OLSR router in the 2-hop neighborhood is reachable through at least one MPR. An OLSR router periodically declares its MPRs to its neighboring routers, whereby each OLSR router will learn about its "*MPR selectors*" - the set of neighbor routers which have selected a given router as MPR.

TC messages are interpreted by receiving OLSR routers, whereby they are able to learn the topology graph of the ad-hoc network – and calculate routes accordingly in the ad-hoc network.

Additionally OLSR supports HNA-messages, whereby an OLSR router can advertise routes to directly attached non-routing nodes – i.e. Mobile Network Nodes. These HNA messages are generated only by OLSR routers which have attached Mobile Network Nodes.

Section 3 details how the mechanisms from OLSR can be applied for route optimization within nested NEMO networks.

3 OLSR Networks in Nested NEMO

Several techniques have been proposed in order to provide optimized paths inside nested NEMO networks. However, the best known algorithms to provide paths in a network are routing protocols. In the case of arbitrary sized nested NEMO networks, the Mobile Routers naturally form an ad-hoc network that can efficiently use OLSR, which was engineered to optimally provide routing in such environments. With OLSR, Mobile Routers can simply discover and maintain optimal routes to the Access Router, but also between Mobile Network Nodes themselves. This implies that communication between nodes within nested NEMO network can be routed through optimal paths, thereby avoiding layers of over-encapsulation and sub-optimal routing over the Internet, through the Home Agents, and back into the same nested NEMO network. With reference to figure 4, this implies that the nodes in mobile network A and mobile network B can communicate directly via the link between their Mobile Routers, rather than through the long path (indicated in the figure) through the Internet.

Mobile Routers supporting OLSR exchange information in order to discover and maintain the network they form at the edge of the Internet (behind the Access Router) through TC and HNA messages, using the light-weight signaling features of OLSR: by periodically exchanging (i) the network prefix(es) of the Mobile Network Nodes they aggregate (using HNA messages) and (ii) summarize topology information (using TC messages), the Mobile Routers in a nested NEMO can provide fully optimized routing in the ad-hoc network they naturally form.

Thus, a Mobile Router running OLSR will include links to selected (via the MPR selection mechanism described in section 2) adjacent Mobile Routers running OLSR in its TC-messages. Mobile Network Nodes, which are not Mobile Routers, will be advertised through HNA messages.

Mobile Network Nodes inside the same nested NEMO network can thereby communicate directly through the routing provided by OLSR and the paths formed by the links between the Mobile Routers. Note that the Access Router doesn't necessarily need to be OLSR capable in order to benefit from the routing inside the OLSR NEMO network. Coming from the Internet, once a packet reaches an OLSR capable node, say a top level Mobile Router (if the Access Router is indeed not OLSR capable), fully optimized routing is available to allow the packet to be routed to the destination. Reaching out for the Internet, a packet is naturally routed from its NEMO network to the Access Router over an optimal (in terms of number of hops) path of Mobile Routers. The packet then reaches a top level Mobile Router, which will perform simple NEMO Mobile IP processing in order to forward it to the Internet through the Access Router. The top level Mobile Routers (*i.e.* the Mobile Routers that attach directly to an Access Router) advertise a default route in order to route packets going out of the nested NEMO to the Internet. In case the Access Router is OLSR capable, OLSR will naturally and dynamically transfer the role of the top level Mobile Routers described above, to the Access router itself.

4 Tunnel Optimization outside the Nested NEMO

Several mechanisms have been proposed in order to avoid unnecessary encapsulation and dog-legged routing when communicating to a Mobile Node in a nested NEMO network from a node on the Internet. Indeed, it is highly desirable to avoid letting the level of nested mobility on the edges of the network dictate the number of Home Agents (and therefore the amount of encapsulation) the packets have to go through. There should be a way to limit the level of tunneling to only one encapsulation IP in IP, and at the same time, minimize the traffic relayed by Home Agents.

Existing solutions to route optimization problems in NEMO (see [12]) therefore aim at, basically, minimizing the required amount of tunneling in various nested mobility cases. An acceptable level of tunnel optimization is attained if whatever the depth of nested NEMO networking, the amount of tunneling stays the same (as if there is no nested mobility, but just simple mobility). That is to say: there is at most one level of encapsulation, and at most one Home Agent involved per distinct nested NEMO network. Ideally, full optimization would be ultimate: bypassing any Home Agents.

By combining a solution derived from HMIP like in [16], [13], or [15] with the solution presented in this paper for providing ad-hoc routing within a nested NEMO network, the above acceptable level of optimization easily achievable: essentially, the encapsulation performed by the Home Agents in the Internet serve to ensure that the Access Router (or top level Mobile Router) is able to "route" a packet to the destination, based on the information contained in the encapsulation headers. However with the Mobile Routers in the nested NEMO network forming an OLSR-network, the information from the encapsulation is no longer required to ensure correct routing within the nested NEMO network. This has some interesting implications:

- The Home Agents can carry out their usual role as forwarders (including encapsulation of outgoing messages), however can safely discard any existing encapsulation (relative to mobile networking) on incoming messages. The encapsulation on outgoing messages, essentially, is only required in order to ensure that packets are forwarded to the next "hop" along the path of Home Agents towards the nested NEMO network Access Router. Effectively, this implies that a packet never carries more than one encapsulation header – compared to one per Home Agent in basic NEMO.
- If a Home Agent along the path towards the nested NEMO network Access Router can identify the Access Router, to which the nested NEMO network is attached, any encapsulation (relative to mobile networking) in an incoming packet to the nested NEMO network can be discarded. The packet is encapsulated and transmitted directly to the Access Router, thereby bypassing the Home Agents and carrying only one encapsulation header as described above.
- Indeed, a signaling mechanism can be developed, whereby a Mobile Router can inform its Home Agent about its Access Router (defined as "the point at which the nested NEMO network attachers to the Internet). This signaling mechanism is identical to the signaling in basic NEMO, with the important difference that rather than signaling a binding with another Mobile Router (in the nested case), a binding is signaled with the Access Router between the Internet and the nested NEMO network. Referring to figure 4, this implies that the Mobile Router for mobile network A would not signal a binding with Mobile Router B – but rather with Mobile Router E, thereby accomplishing the desired route optimization.

Having an OLSR network in a nested NEMO network thereby provides an efficient way of reducing the route optimization problem to a simple application of the binding signaling mechanism found in basic NEMO.

5 Conclusion

The NEMO protocol suite extends Mobile IP in enabling a set of nodes, along with their mobile router, to change their point of attachment to the Internet. NEMO enables the traffic to these nodes to be tunneled to delivery through their new point of attachment. The use of tunneling makes this mechanism transparent to applications, wherever the new point of attachment, even in case of several layers of nested mobility (i.e. mobile nodes, or mobile routers, indirectly accessing the Internet through other mobile routers).

However, while encompassing such arbitrary levels of nested mobility, this approach (i) does not provide any effective means to manage the usage of optimal paths inside the network made of multiple levels of nested NEMO, and (ii) is also not without a certain cost: with arbitrarily deep nested mobile networks, the overhead due to tunneling, dog-legged routing and encapsulation of data traffic on the Internet can become large.

In this paper a solution to the first problem has been proposed: the usage of OLSR as a routing protocol over the ad hoc network naturally formed by the Mobile Routers of the nested NEMO structure enables to provide routing in a simple and optimal fashion for traffic inside nested NEMO networks. Through this solution, the second problem, avoiding costly encapsulation and suboptimal routes for traffic which originates outside the nested NEMO network, has been greatly reduced. We have discussed how route optimization for nested NEMO networks on the Internet can, essentially, be simplified to a slightly modified application of the signalling mechanism already present in basic NEMO.

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