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NEMO: Network Mobility in IPv6

Carlos J. Bernardos-Cano, Ignacio Soto-Campos, María Calderón-Pastor, Dirk von Hugo, and Emmanuel Riou

Nowadays, users request Internet access in more and more heterogeneous scenarios. In particular a need to access the Internet from mobile platforms, like trains, buses or planes, has appeared. A new working group has been formed within the IETF (Internet Engineering Task Force) NEMO WG (NEtwork MObility Working Group) whose main goal is to provide mechanisms allowing the management of the mobility of a network as a whole, enabling that network to change its point of attachment to an IP-based (Internet Protocol) fixed infrastructure without disrupting ongoing communications. This article describes the IPv6 (Internet Protocol version 6) network mobility basic support solution defined by the NEMO WG, analysing its limitations. In addition, some of the contributions to the network mobility research area developed within the framework of the European project DAIDALOS (Designing Advanced network Interfaces for the Delivery and Administration of Location independent, Optimised personal Services) are presented.

Keywords: Mobile IP, Mobile IPv6, Network Mobility, Route Optimisation.

1 Introduction

The success of cellular communications networks shows the interest of users in mobility. These networks are evolving to provide not only the traditional voice service but also data services. IP (Internet Protocol) appears to be the base technology of future networks, providing all kind of services and through different access technologies, both fixed and mobile. Nevertheless, IP was not designed to take into account mobility of users and terminals, and in fact, IP does not support it, neither in IPv4 (Internet Protocol version 4) nor in IPv6 (Internet Protocol version 6).

The IETF (Internet Engineering Task Force) has defined some IP-layer protocols that enable terminal mobility in IPv4 [1] and IPv6 [2] networks. Nevertheless, these protocols do not support the movement of a complete network that moves as a whole changing its point of attachment to the fixed infrastructure, that is, network mobility. The IETF created a working group: NEMO (from Network Mobility), with the aim of extending existing host mobility solutions to enable the movement of networks in IPv6.

The network mobility support has interesting applications like the provision of Internet access in public transportation systems, or the connection to the Internet of Personal Area Networks (PANs). In this article, different proposals of IPv6 network mobility support will be described,

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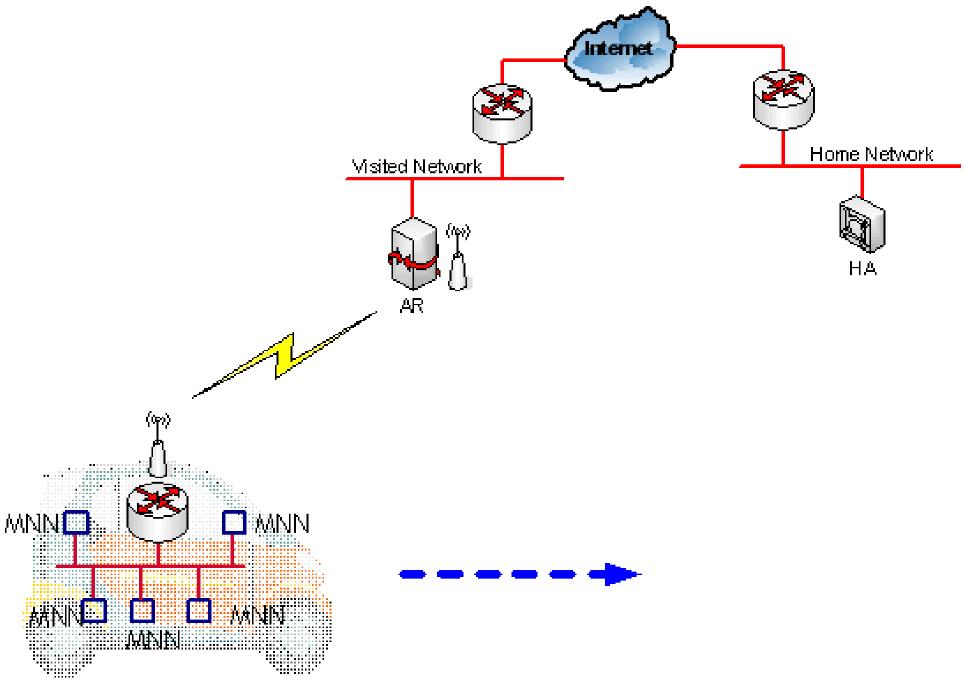

Figure 1. Mobile Network Scenario.

as well as the related work that is being done in the European project DAIDALOS.

The article is organised as follows: in Section 2, the applications of network mobility, the difficulties that appear in the provision of this movement support in IPv6, and the basic solution developed by the NEMO WG are explained. The limitations of the basic solution are described in Section 3. Section 4 analyses in detail the network mobility related work done in the European project DAIDALOS. Finally, the Section 5 concludes the paper, highlighting some of the future trends in the solutions of network mobility in IPv6.

2 Network Mobility in IPv6

IP networks were not designed for mobile environments. In both IPv4 and IPv6, IP addresses play two different roles. On the one hand, they are locators that specify, based on a routing system, how to reach the terminal that is using that address. The routing system maintains information on how to reach different set of address that have a common network prefix. This address aggregation in the routing system provides scalability guarantees. On the other hand, IP addresses are also part of the end-point identifiers of a communication, and upper layers use the identifiers of the peers of a communication to identify it.

This dual role played by IP addresses imposes some restrictions on the mobility, because when a terminal moves from one location of a network (IP subnet) to another, we would like, on the one hand, to maintain the IP address associated to the terminal that moves (associated to one of its network interfaces) in order not to change the identifier that upper layers are using in their ongoing sessions (i.e., communications); but, on the other hand, we need to change the IP address to make it topologically correct in the new location of the terminal in the network, allowing in this way the routing system to reach the terminal.

The problem of terminal mobility in IP networks has been studied for a long time within the IETF, and there exist IP-layer solutions for both IPv4 [1] and IPv6 [2] that enable the movement of terminals without stopping their ongoing sessions. These solutions are even being completed with proposals that improve the efficiency of the base solution, particularly in micro-mobility environments [3][4]. The issue of terminal mobility in IP networks has been analysed recently in [5].

Terminal mobility support in IP networks is a first step in the adaptation of these networks to the needs of users in this field. However, there is also a need to support the movement of a complete network that changes its point of attachment to the fixed infrastructure, maintaining the sessions of every device of the network, known as network mobility in IP networks. In this case, the mobile network will have at least a router that connects to the fixed infrastructure, and the devices of the mobile network will obtain connectivity to the exterior through this mobile router (Figure 1). The IP terminal mobility solution does not support, as is now defined, the movement of networks. Because of that, the IETF NEMO WG [6] was created, and it is now studying solutions, at the IP layer, to enable network mobility in IPv6.

The terminology used by the NEMO group [7] names a router that provides connectivity to the mobile network as a Mobile Router (MR). Devices belonging to the mobile network, that obtain connectivity through the MR, are called Mobile Network Nodes (MNNs) and there are different types: Local Fixed Node (LFN), that is a node that has no mobility specific software; Local Mobile Node (LMN), that is a node that implements the Mobile IP protocol and whose home network is located in the mobile network; and Visiting Mobile Node (VMN) that is a node that implements the Mobile IP protocol, has its home network outside the mobile network, and is visiting the mobile network.

There are a great number of applications of network mobility; some examples are the provision of Internet access in:

·Public transportation systems. This would enable passengers in trains, planes, ships, etc to travel with their own terminals (e.g., laptops, cellular phones, PDAs or Personal Digital Assistants, etc.) and obtain Internet access through the MR located at the transport vehicle, that connects to the fixed infrastructure.

·Personal Networks. Electronic devices carried by people, like PDAs, photo cameras, etc. obtain connectivity through a cellular phone acting as the MR of the personal network.

·Sensor networks within a vehicle. Sensors could control multiple aspects of the vehicle operation, its interaction with the environment, and communicate with the exterior through a MR.

The first step followed by the NEMO working group was the development of a basic solution to the network mobility problem in IPv6 networks, modifying the IPv6 host mobility solution (MIPv6) just to get an operational solution valid also for mobile networks. Nevertheless, the solution had to be flexible enough to deal with different mobile network configurations, in particular, networks containing different subnets (i.e., mobile networks with more routers than the MR), and nested mobile networks (i.e., a mobile network that provides connectivity to the fixed infrastructure to other mobile networks). An example of the applicability of the latter is a user that enters a vehicle with his personal area network (mobile network 1) and that network connects through a MR, like a WiFi (Wireless Fidelity) enabled PDA, to the car's network (mobile network 2), that is connected to the fixed infrastructure.

The network mobility basic solution (see Figure 2) for IPv6 [8] is conceptually similar to that of terminals. It is based in the set-up of a bidirectional tunnel between the MR and its Home Agent (HA). The HA is located in the home network of the mobile network, that is, in a location where the addressing of the mobile network is topologically correct. All the traffic addressed to the mobile network is delivered to its HA, that send it towards the MR through the tunnel. The MR removes the tunnel header and forwards the traffic to its destination within the mobile network. The traffic originated in the mobile network is sent by the MR towards the HA through the tunnel, the HA removes the tunnel header and forwards the packets to their destination.

The MR has to detect that the mobile network has moved and the simplest way of doing that is by using the same procedure as is defined for hosts in MIPv6, that is, listening to Router Advertisements at the interface that connects the MR to the infrastructure. The received Router Advertisements are also used for the configuration of an IP address that is topologically correct at the attachment point to the infrastructure, this address (Care-of Address, CoA) is the MR's tunnel endpoint.

In order to inform the HA about a movement of the mobile network, the MR sends a registration message to the HA. This registration process is the same as that in MIPv6, thus a Binding Update message protected with IPsec ESP (Secure Internet Protocol Encapsulating Security Paylodad)

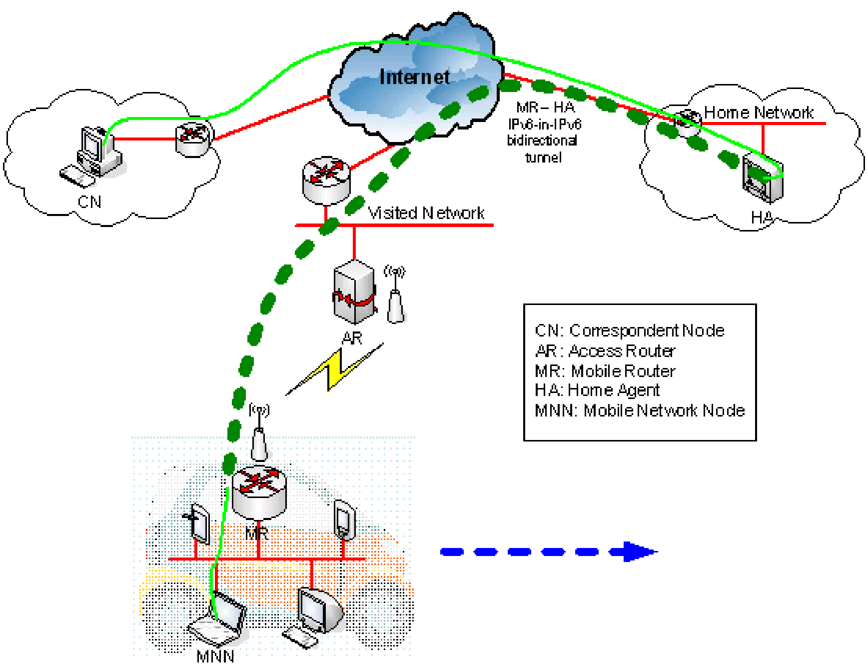

Figure 2. NEMO Basic Support Protocol Operation.

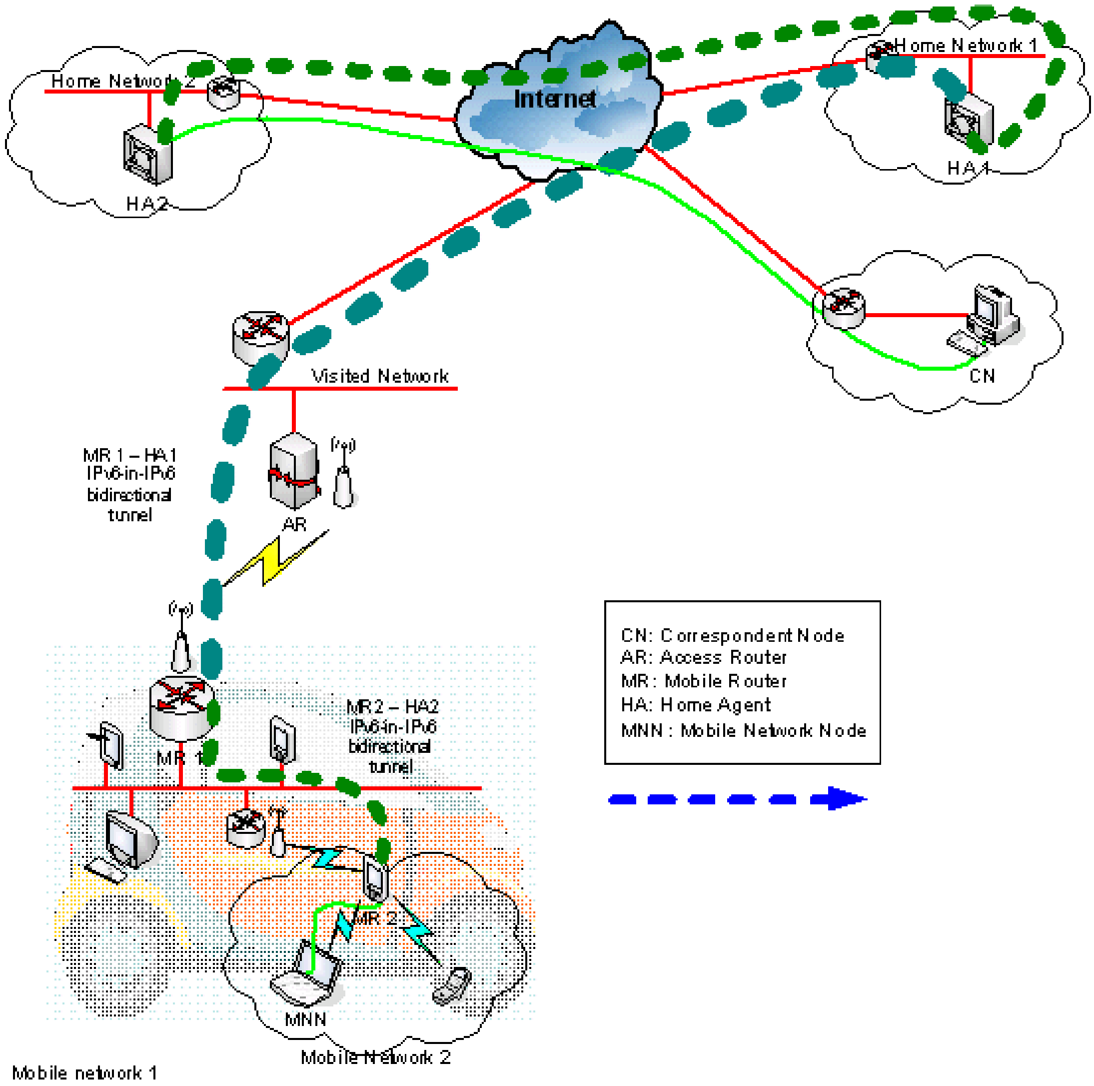

Figure 3. NEMO Basic Support Protocol Operation with Nesting.

is used. The only modification is that a previously reserved bit of the message header is used now as a flag indicating that the registration corresponds to a complete network, meaning that the HA should forward not only the traffic addressed to the MR's Home Address, but also that sent to addresses belonging to the network prefix of the mobile network (Mobile Network Prefix, MNP). There are several ways for the HA to know the MR's MNP: static configuration, adding the MNP in an option of the Binding Update, or running a dynamic routing protocol with the MR through the tunnel.

3 Limitations of the IPv6 Network Mobility Basic Solution

The network mobility basic solution (see Figure 2) forces, when a mobile network is not at home, all the traffic destined to an MNN to traverse the HA and be forwarded to the mobile network through the tunnel established between the MR and the HA. An inverse path is followed by packets sent by an MNN. This phenomenon, known as triangular routing, supposes some inefficiency both in terms of latency and effective throughput and can be unacceptable for certain applications.

These performance problems are even worse when the mobile network is nested (see Figure 3), because the traffic goes through all the involved HAs (one per traversed mobile network), problem known as 'pinball' routing. In addition, packets in the path between the last HA and the first MR have one additional header per traversed network as every MR within the path removes a header. The same happens in the opposite direction. In this case the HAs are the ones that remove tunnel headers (see fig. 3). The case of having a VMN (a node that implements Mobile IP) visiting a mobile network can be considered as a particular case of nested network. Traffic sent/received by a VMN goes through the VMN's HA and also through the HA of the mobile network that it is visiting, therefore this traffic is encapsulated in a double tunnel, this situation being analogous to a two-level nested mobile network.

In nested mobile networks there is another source of inefficiency. Terminals of different mobile networks belonging to the same nesting communicate through their HAs, when they would communicate far more efficiently directly. Moreover, if there were a communication problem with any of the HAs, the communication would stop, even though the direct communication between the mobile networks was possible. An example to help understand the importance of such a scenario is two passengers that enter the same train with their respective personal area networks and want to interact with each other or exchange documents.

Different proposals, known as Route Optimisation (RO) solutions, try to extend the basic solution with the aim of mitigating the performance problems described before. These solutions are very diverse and each of them tries to solve one or some of the problems introduced previously. A taxonomy of the solutions proposed so far can be found in [9].

4 Network Mobility in DAIDALOS

The contributions to the network mobility problem within the framework of the European project DAIDALOS (IST-1-506997) [10] deal with three different aspects that are described next.

4.1 Modelling of NEMO Basic Support Protocol

Modelling activities are perceived as essential to guarantee the success of developing and integration tasks in such a complex project as DAIDALOS. UML 2.0 (Unified Modelling Language) has been chosen in the project to model NEMO Basic Support protocol. The reason is that the language allows the modelling of protocols and real time applications thanks to a new means of communication between classes called signal. Basically, signals allow the sending of asynchronous messages between active classes, which is indispensable when you need to model a protocol.

Each protocol entity (e.g. the Mobile Router) is modelled using an active class. Each class entity realizes a protocol interface which describes the protocol messages the entity can receive from other classes. These messages are modelled using signals. An entity may also realize an IPC (Inter-Process Communication) interface describing the public IPCs the class is able to handle.

Four UML diagrams are used to offer different views of the system. Package diagrams show the relations between packages which enable the structuring of the model (protocol, entities, and IPC packages). Class diagrams are used to describe the relations between the entities (association, inheritance …). Sequence diagrams allow us to describe scenarios showing the interactions between the objects (instantiation of entities), while state chart diagrams are used to describe the internal behaviour of each entity.

Figure 4 depicts some of the key aspects of the model, i.e. an active class, two interfaces and two signals with inheritance relations.

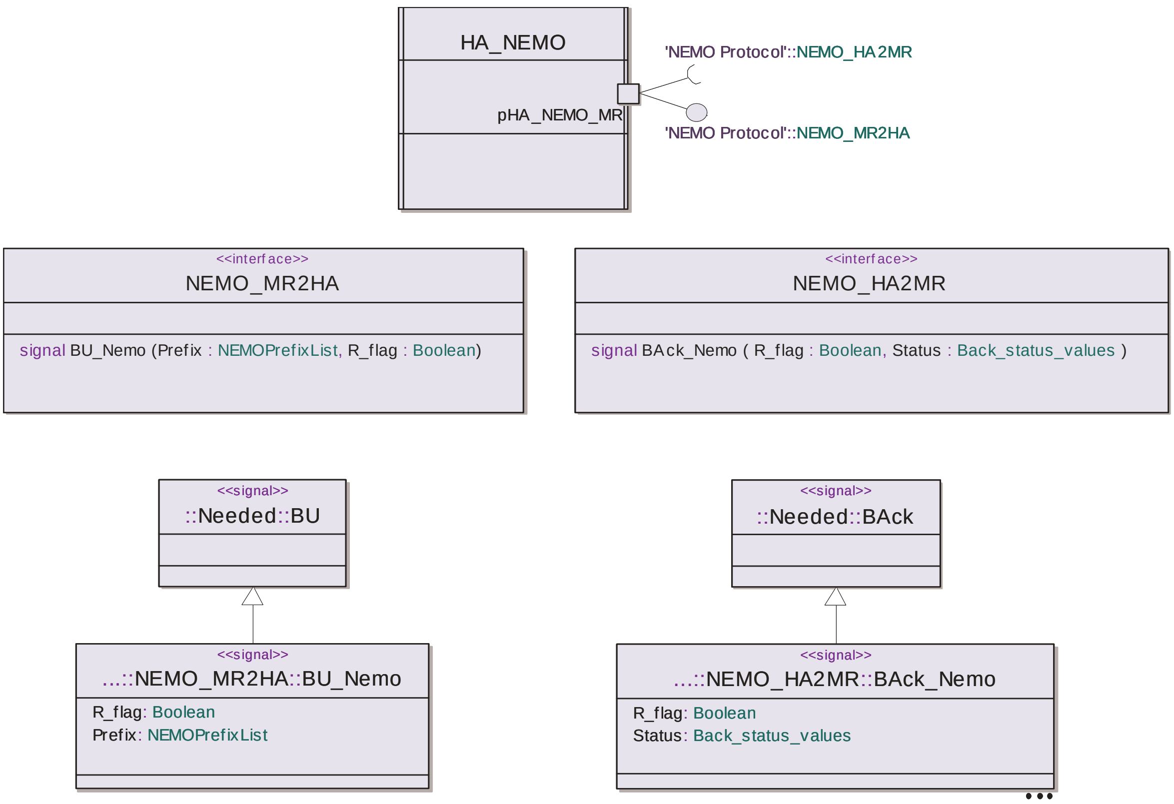

Figure 4. UML 2.0 Class Diagram of NEMO Basic Support Protocol.

4.2 Route Optimisation for Unicast Flows

The DAIDALOS route optimisation solution for unicast flows is called MIRON (MIPv6 Route Optimization for NEMO) [11]. MIRON is a route optimisation protocol that deals with two of the problems introduced in Section 3, on the one hand the triangular routing problem, and on the other hand, the multiple tunnels and the "pinball" routing present in nested networks.

The triangular routing problem is not specific to mobile networks. MIPv6 mobile hosts encounter the same issue. In order to solve such inefficiency MIPv6 defines a route optimisation procedure, essentially based on the following: When a communication between a mobile node and any other end system (called Correspondent Node, CN) is established, all the traffic, in both directions, initially goes through the HA. But the mobile terminal can initiate a route optimisation process by sending location information (i.e., Binding Updates) directly to the CN. As has been previously described, the BUs sent to the HA are protected with IPsec, but this operation does not seem viable in the case of BUs sent to CNs, as it cannot be assumed that every mobile terminal has a trusting relationship with every potential CN in the IP network. Therefore, an alternative mechanism, called Return Routability (RR) is used. This mechanism is based on the verification that a node is reachable at the same time through its Home Address and also through its Care-of Address.

In the approach followed by MIRON to avoid the triangular routing in the network mobility case, the MR acts as a proxy, performing the route optimisation procedure with the CN on behalf of the nodes of the mobile network. In this way, the MR sends to the CN location information that binds the MNN's address to the MR's CoA.

The most important benefit of MIRON is that it allows a quick deployment of the route optimisation support in an IP network, such as the Internet. There are two main reasons for this. First, the route optimisation is transparent to the nodes of the mobile network, which is especially relevant for LFNs (i.e., nodes with no specific mobility software) and, second, it allows using the MIPv6 route optimisation support already available at the CNs.

The solution proposed for the nested mobile network case consists of enabling not only the root-MR (the top-level MR within the hierarchy of a nesting) but all the MRs to have a topologically valid Care-of Address. The addresses that fulfil that condition are the ones that belong to the network that the root-MR is connected to (i.e., the network that the MR is visiting). Having a topologically valid CoA enables the MR to perform the route optimisation procedure, introduced before, on behalf of the nodes of its mobile network, thus avoiding any tunnel. Therefore, MIRON enables a mechanism that allows the MR to request a CoA belonging to the IPv6 address space of the network that the root-MR is visiting. In order to learn how to route packets to these CoAs within the nesting, the MRs learn from DHCP messages, used to request/delegate the CoA, which is the next hop needed to reach each CoA.

4.3 Multicast Support

To support multicast traffic for mobile networks, the MR can use the bi-directional tunnel (BT) between the HA and the MR's CoA located in the visited network. Alternatively a remote subscription (RS) to a multicast group within the visited network as described in MIPv6 [2] is feasible. With respect to multicast traffic to and from mobile networks, the BT approach may prove inefficient in terms of non-optimal (triangular) routing, breach of the multicast nature of the flow, and limited scalability. The main disadvantage of applying RS for multicast services emerging or terminating within mobile networks is the required frequent re-construction of the multicast tree, especially if the traffic source is moving fast, resulting in high latency and network traffic overhead.

The approach considered in project DAIDALOS consists of combining both methods depending on current environment and communication parameters. Upon subscription of a node within the mobile network to a multicast group or transmission of multicast traffic, the MR forwards the request or the traffic to the HA utilising the MLD (Multicast Listener Discovery) [12] protocol. Subsequently the corresponding data traffic or group control messages are forwarded by the HA back to the MR. This proxy functionality of the HA is described in [13]. In case of reduced mobility of the subnetwork detected by means of low handover (CoA change) rate, the MR initiates routing of multicast traffic via the remote access point. Simulations indicate the advantage of this approach and a Linux-2.6 based implementation is under way. Introduction of an intermediate multicast agent is foreseen for following phases of the project.

5 Conclusions

This paper has presented some scenarios that motivate the need for mechanisms that enable the mobility of a network as a whole. The network mobility basic solution for IPv6 networks, developed by the IETF NEMO WG, has been described as well. The main advantage of the solution resides in its simplicity; it only imposes changes in a relatively small number of network devices. It requires a small upgrade of MIPv6 HAs and introduces a new type of device, the MR (at least one per mobile network) that enables the movement of the network as a whole. These characteristics simplify the protocol deployment.

The most important limitations and inefficiencies of the network mobility basic solution have been presented, as well as the motivation for research in route optimisation protocols to overcome these limitations.

Finally, the work related to network mobility that is currently being done in the DAIDALOS project has been presented. Within this framework, MIRON has been developed. MIRON is a route optimisation protocol in which the MR performs the route optimisation on behalf of the nodes of the mobile network, which enables nodes with no mobility support to benefit from the route optimisation functions of the mobile network. At the same time, MIRON does not impose any modification in the operation of the CNs, characteristic that greatly simplifies its deployment in IP networks, such as the Internet. Also, a solution for multicast traffic in mobile networks is proposed, an approach using two methods, with its use is adapted to the characteristics of the rate of movement of the mobile networks.

There are other solutions for route optimisation that require modifications in the terminals of the mobile network and in the CNs that are starting to be studied now [9]. These solutions may easily deal with some scenarios but may pay the prize of modifying a great number of nodes. A combination of both types of solutions is expected, at least initially.

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