IPv6 based OverDRiVE Moving Networks for Vehicles

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The European IST project OverDRiVE[†] tackles the issue of the growing demand of telecommunication and digital broadcasting industry for cost-efficient provision of mobile multimedia services. This article focuses on one subject of the project, namely the mobility support for moving networks such as found in future cars and trains. The basic solution relies on Mobile IPv6 enhancements that lead to the development of a Mobile Router concept. Additionally, advanced topics like route optimization, multicast support and combination with micro-mobility approaches are discussed. The key findings were demonstrated and validated by performing trials.

Introduction

The OverDRiVE project (http://www.ist-overdrive.org) aims at UMTS enhancements and co-ordination of existing radio networks to a hybrid network to ensure resource efficient provision of mobile multimedia services. This is achieved by an IPv6 based overlay architecture to enable interworking of cellular and broadcast networks and dynamic spectrum allocation (DSA) techniques on the physical layer to allow system co-existence in a common frequency range. The project objective is to enable and demonstrate the delivery of spectrum efficient multi- and unicast services to vehicles. The project takes an integrated approach that takes into account the network side, the radio access side, and the vehicular terminal. OverDRiVE issues are:

- Improving spectrum efficiency by system coexistence in one frequency band and DSA.
- Enabling mobile multicast by UMTS enhancements and multiradio multicast group management.
- Developing a Mobile Router (MR) supporting roaming into the Intra-Vehicular Area Network (IVAN).

The common approach achieves a significant improvement for delivering uni- and multicast services in terms of service quality, efficiency and cost.

This article focuses on the development of a Mobile Router (MR) by investigating the idea of mobile hosts and mobile networks in vehicular environments. The research takes into account scenarios starting from mobile networks in passenger cars and moving up to larger mobile networks in public transport vehicles (e.g. buses and trains) that comprise a dynamic number of nodes. In these scenarios, vehicles are seen as moving IPv6 networks which can use several access technologies to provide Internet connectivity. OverDRiVE denotes these networks as IVANs (Intra Vehicular Area Networks). The following discussion concentrates on mobility management and IVAN management. Mobility management includes special issues like nesting of mobile networks, mobility within large vehicles, and optimized use of the network in terms of routing. Moreover, IVAN management tasks are regarded with respect to the effect of mobility management on transport protocols, bandwidth scheduling and protection against congestion. These topics are taken from the field of authentication, authorization and accounting (AAA) and reflect the issues that have to be considered in heterogeneous wireless environments. This article also describes the validation of OverDRiVE concepts which was accomplished by field trials and two prototypical implementations.

The remaining part of the article is organized as follows: Section 1 describes the scenarios that were taken into consideration for the research work and a problem statement. Section 2 explains the findings with respect to the Mobile IPv6 based mobility management approach. Advanced topics like route optimization, combination with micro-mobility approaches and traffic management within a moving network are described in Section 3. The validation and prototypical implementation is explained in Section 4.

1 Scenarios

The scenarios investigated in the project are driven by vehicular requirements and necessities. The project assumes vehicles (e.g. cars, trains and ships) that are equipped with an IPv6 based infrastructure with mobility unaware components (e.g. single-purpose sensors with IPv6 connectivity, displays, etc.). Besides, the users (e.g. car driver) bring their own devices into the vehicular

[†] 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 Rheinisch-Westfälische Technische Hochschule RWTH Aachen, Universität Bonn and the University of Surrey. The authors acknowledge the contributions of their colleagues in the OverDRiVE consortium.

environment. While the vehicle is on the move it connects to a variety of wireless access technologies to satisfy the user's/application's need for system performance (WLAN, GPRS, UMTS and DVB-T, which are envisioned to coexist in one frequency band supported by dynamic spectrum allocation).

While the moving network as a whole needs to accommodate mobility related actions (handover, roaming, etc.), the applications running on devices inside the moving network will not be involved in the mobility management — it is the Mobile Router (MR) that takes all the necessary actions to let the moving network stay online in a seamless manner. Figure 1 shows a vehicular environment particularized to a car and consisting of several interconnected networks and technologies.

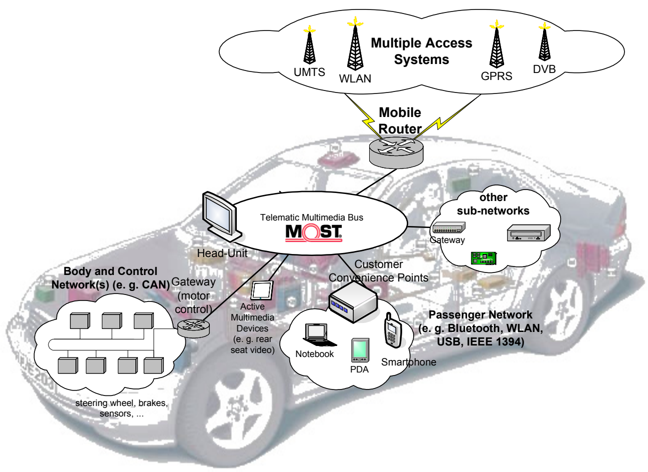

***Figure 1** Vehicular Environment*

Problem Statement

A moving network is a network segment that can move and change its point of attachment to the Internet. By definition, it is a leaf network and can only be accessed through specific gateways, called Mobile Routers (MRs). Mobile IPv6 (and Mobile IPv4) supports the mobility of the MR. However, the nodes in the subnetwork of the MR are no longer accessible when the MR (and thus the moving network) moves away from the home network as described below.

The main problem addressed by Mobile IPv6 is that in the current Internet design every IPv6 address corresponds to a fixed "location" in the routing fabric, the route information towards this location being maintained by all the intermediary routers. A mobile host (MH) or MR is permanently assigned a Home Address that is valid in the home domain, i.e. the official administrative domain to which this MH or MR belongs. Mobile IPv6 introduces a Home Agent (HA) that intercepts all packets addressed to the home address (using proxy Neighbour Discovery) and subsequently encapsulates them towards the MH's current Care-of-Address (CoA) – a unicast routable address associated with the MH on a foreign link. The CoA has a foreign subnet prefix. The association of the Home Address of a MH with a CoA for that MH is called a binding.

In a symmetric manner, the MH in a foreign domain will first encapsulate all its outgoing packets towards the HA which will decapsulate and resend them towards the original destination. These two encapsulation mechanisms are currently referred to as bidirectional tunnelling and together with binding cache management constitute the essence of the Mobile IPv6 protocol. Thus, Mobile IP provides ubiquitous accessibility at a permanent home address while being transparent to applications by maintaining existing connections even when the assigned address changes as a result of physical mobility.

Mobility of entire networks consisting of fixed nodes is not supported by the current Mobile IPv6 protocol. Experimental trials reported in [1] expose an inappropriate routing table management of Mobile IPv6. Basically, packets that are sent to a Local Fixed Node (LFN) while the MR is away from home enter a loop since the HA has no entry for the LFN in its binding cache and forwards the packet to the border router (BR). The BR in turn has the MR as default router for the moving network. These packets are intercepted by the HA and so forth. Details can be found in [1].

2 Mobility Management

The approach of OverDRiVE for network mobility is vanilla Mobile IPv6 wherever possible in order to keep the impact on existing implementations small. Therefore, only changes to the MR and its HA are suggested. The approach employs a bidirectional tunnel between the MR and its HA. The basic idea is to include a 'R' –flag for the MR in the HA's binding cache, indicating the relocation of a complete moving network (and not only a host) moved. The HA forwards packets through the MR-HA tunnel for all nodes within the network of the MR. The HA acts on behalf of the link-local addresses of MR's interfaces (when the MR is in a foreign network). As in the mobile host's case, the MR uses binding updates (BU) and binding acknowledgements (BAck) with the HA to maintain the MR-HA bidirectional tunnel. For a more detailed description please refer to [2].

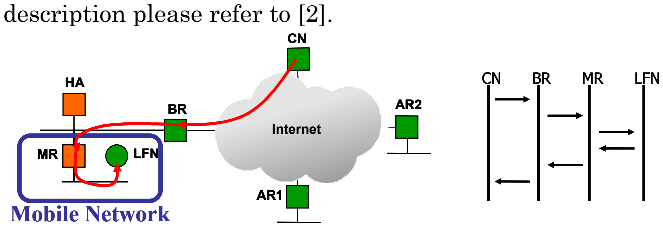

***Figure 2** Routing to Local Fixed Node of Mobile Network at Home*

Figure 2 illustrates a generic initial setting for moving networks. The following entities are depicted: a large Internet cloud, a Correspondent Node CN, two Access Routers AR1 and AR2 as well as the home network composed of a Border Router BR, a Home Agent HA and the moving network comprising the Mobile Router and a Local Fixed Node LFN. For this scenario we assume that an application continuously runs between the CN and the LFN. Here, changing addresses induced by the mobility of the MR do not affect the communication. In our particular trials, a CN continuously moves towards the Home Address of LFN and the LFN displays that stream on a video screen, as the packet exchanges in the right diagram of Figure 2 suggests.

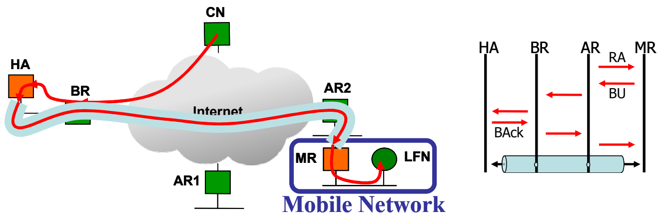

Figure 3 *Tunnel Setup for Simple Moving Networks*

The packet stream and the encapsulation/decapsulation actions are illustrated in Figure 4, where bent arrows at the left of vertical bars represent decapsulations, and at the right encapsulations. In that figure, the detailed Neighbour Discovery messaging between BR and HA is excluded; a complete description can be found in [3]. In the other direction, when a LFN needs to send a packet to CN and the mobile network is not at home, it will first send the packet to its default route, the MR. The MR encapsulates it back to HA which decapsulates and forwards it to the original destination. Figure 3 (left) describes the movement of the mobile network away from home towards any of the foreign networks governed by AR1 or AR2. The movement from the home network to AR2 triggers a binding message exchange between the HA and the MR in order to set up the MR-HA bidirectional tunnel. This is illustrated in the right diagram of Figure 3. The MR receives a Router Advertisement (RA), configures a new CoA and default route. Subsequently, the MR sends a BU to the HA. Subsequently, the HA sets up its endpoint of the MR-HA tunnel and replies with a BAck. At this moment the MR-HA tunnel endpoint at the MR is set up, as well. Once that tunnel is established, the streaming between the CN and the LFN continues via the new CoA. The CN sends the next application packet towards the BR and the latter asks for the link-layer address corresponding to the IPv6 address of the MR. The HA replies on behalf of the MR. Afterwards, the HA encapsulates and forwards this packet through the MR-HA tunnel towards the current CoA. The MR decapsulates the received packet and forwards it to the LFN. Symmetry can be noticed by drawing an imaginary horizontal axis through the centre of Figure 4: packets from CN to LFN take exactly the same path backwards, without a state being maintained neither on CN nor on LFN, as a consequence of bidirectional tunnelling.

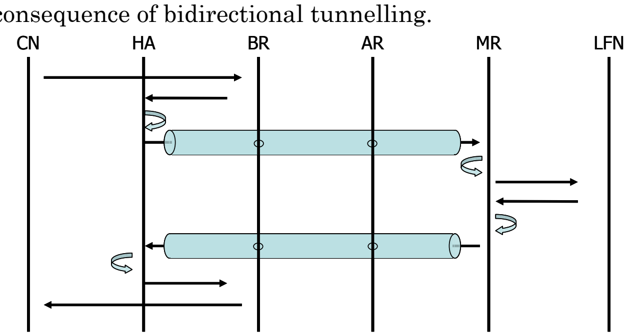

Figure 4 *CN-LFN Exchanges, Simple Moving Networks*

The simplicity of this approach is advantageous to supporting moving networks. The topology presented in Figure 2 can be easily augmented with a large number of moving networks, ARs and CNs. All packet exchanges involved are similar (if not the same) to the packet exchange in Figure 4.

3 Advanced Topics

While the mobility management solution described above provides a basic functionality, advanced features like route optimization, combination with micro-mobility solutions, multicast support and traffic management were investigated and described in the following subsections.

Route Optimization

Benefits of Route Optimization outside IVAN

Route Optimization (RO) is a process used for enabling packet delivery along the (topologically) shortest path between two communicating nodes. Basically, in Mobile IP scenarios this means to eliminate tunnelling over a HA and to establish a direct connection between two communicating nodes.

Route Optimization techniques offer solutions to a well-known challenging problem of the Mobile IP protocol family. Succinctly, the problem is induced by the artificial necessity to forward all packets between CN and MH through the MH's HA, even if HA is not in the (topologically) shortest IP path between MH and CN.

In the case of moving networks, the route optimization problem is much harder; due to the effects of nesting and the presence of several HA's.

We define the IP end-to-end distance between two communicating nodes as the number of IP hops through which the application-level packets flow. This is, of course, a generalization based on several simplifying assumptions:

- The path taken by the packet flow in one direction is the same as the path taken in the reverse direction.
- All intermediary point-to-point links have approximately the same costs and bandwidth, and are symmetric.
- Paths are stable during the entire application-level communication.

We used this simplifying definition of the IP path length when analyzing the benefits that can be obtained from using Route Optimization.

Intuitively, we have identified that the Route Optimization techniques are beneficial to the LFN-CN communication only if the IP end-to-end distance between CN and LFN is much shorter than the distance between LFN and HA and the distance between the CN and the HA. For more details on a detailed analysis and measurements confer to [4], section on "Validation of Mobile Router".

Protocol for Route Optimization inside IVAN

Route Optimization for Visiting Mobile Nodes inside the moving network is another facet of RO that has been addressed in OverDRiVE. 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 MR. 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 tunnelled twice through the external link.

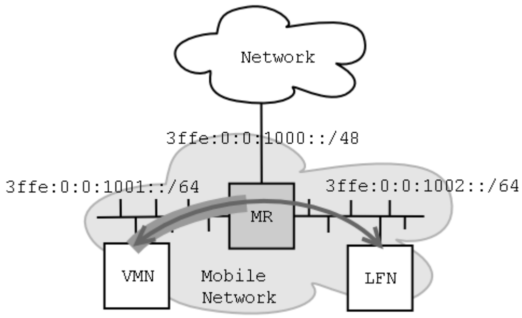

Figure 5 *Internal Route Optimization via VMN-MR Tunnel*

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 [5], the router advertisement in our solution has a supplementary option that also contains 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. This option is required because 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 [6]). 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 (BAck).

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. This is 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.

The routing of packets in the reverse direction – from a local fixed node to a registered visiting mobile node – follows the same pattern. The local fixed node sends a packet to the visiting mobile node's home address which has to be routed via the MR. The 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 (CoA) of the visiting mobile node. The MR encapsulates the packet and forwards it to the visiting mobile node, which finally decapsulates the packet.

In both directions, tunnelling between the MR and the visiting mobile node is necessary to maintain topologically 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.

Combination with Micro-Mobility Solutions

In large vehicles, such as trains, ships, etc., there is a need for local mobility management of users residing in the vehicle. The OverDRiVE project examined ways of combining network mobility with micro-mobility (as an alternative to RO described above). For example, the BRAIN Candidate Mobility Management Protocol (BCMP) [7], which was earlier developed in the IST BRAIN and MIND projects, can be used to handle the local mobility of user devices. The BCMP infrastructure hides the movement of the users inside the vehicle and, by providing fast handover mechanisms, handles the mobility of the passengers seamlessly.

In Figure 6, the theoretical overview of the MRHA-BCMP combined solution can be seen. Inside the moving network infrastructure BRAIN access routers (BAR) are connected to the MR. To have BCMP mobility management inside the moving network the MR is co-located with a BCMP anchor point (ANP) and a user registry (UR). Either visiting mobile nodes (VMN) or local fixed node (LFN) can be connected to the moving network's infrastructure.

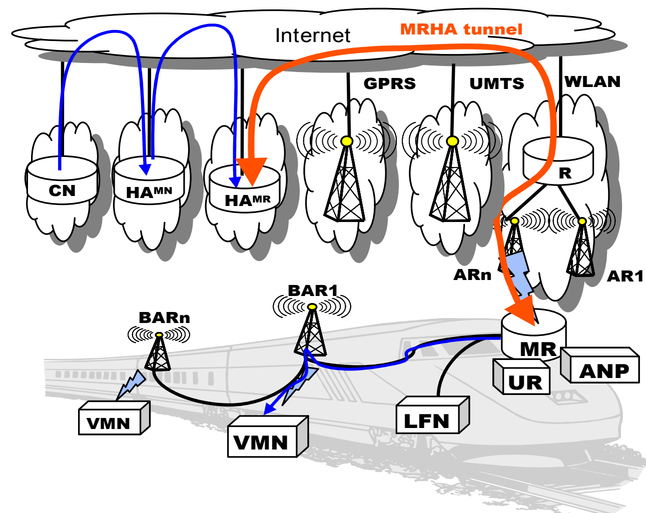

Figure 6 *Theoretical overview of the MRHA – BCMP combined solution*

VMNs get their IP address from the BCMP User Registry (UR) when they connect to the moving network. All IP addresses assigned to visiting mobile nodes point to the ANP and belong to the address space of the MR's home agent. After the VMN received its new IP address it sends a binding update (BU) to its home agent updating its location information using the new IP address as a care-of-address. LFNs get their IP addresses through IPv6 auto-configuration or they are configured manually. All IP addresses assigned to local fixed nodes also belong to the address space of the MR's home agent, but in this case the address points to the local fixed node itself.

If a correspondent node (CN) wants to communicate with a mobile node residing in the moving network, it sends the packets to the mobile node's home address. The home agent of the mobile node (HA^{MN}) intercepts the packets and forwards them to the MR's home agent (HA^{MR}), because the care-of-address of the mobile node points to this entity. The MR's home agent injects the packets into the MR-HA tunnel and on the other end of the tunnel the MR receives the packets.

Depending on the destination address and the MR's routing table, the MR sends the packets either directly to the local fixed nodes (LFN) or to the BCMP anchor point (ANP). In case the destination is a VMN, the ANP receives the packet and it tunnels the packet to that BAR, where the visiting mobile node is located. Finally the BAR sends the packet to the visiting mobile node.

Multicast

As described previously, the OverDRiVE base network mobility solution relies on a bidirectional tunnel between the MR and its Home Agent (HA). It provides the continuity of unicast sessions for nodes in a moving network by extending the MR's Home Agent to support redirection for the whole moving network prefix (MNP) in addition to the MR's home address.

Since multicast routing highly differs from unicast routing, this Home Agent forwarding mechanism based on the MNP does not serve the forwarding of multicast packets. The key reason is that multicast packets are sent to a multicast address that is unrelated to the prefixes of the networks where potential multicast receivers are located (e.g. the moving network prefix).

However, there are many use cases where the support of IP multicast for nodes inside moving networks is needed. Scenarios range from professional applications, such as remote-repair activities including mass software upgrade to embedded devices in a fleet of vehicles, to entertainment applications, for instance enabling passengers in a vehicle to participate in group communications, such as video conferencing.

Two approaches have been investigated in OverDRiVE. The first one suggests the use of the MR-HA bidirectional tunnel for the forwarding of multicast traffic too, in both directions, between the MR and its home link. By co-locating a multicast routing function on both the MR and its HA, multicast routing protocol messages can be exchanged over the MR-HA tunnel. This allows the creation of multicast branches from the Internet to receivers in the moving network, as well as from sources in the moving network to receivers in the Internet.

The second approach is an attractive alternative in situations where the first one is either not possible (e.g. due to MR or HA capabilities), or the network and radio overhead (i.e. sub-optimal routing, and encapsulating header) introduced by the MR-HA tunnel is not acceptable. It proposes to re-apply the Remote Subscription (RS) principle [8], inherited from mobile multicast hosts, to the case of a MR serving a moving network. As it moves, the MR uses Multicast Listener Discovery (MLD) [9] messages to re-subscribe to the ongoing multicast sessions through the local multicast router in the visited link. In case of the moving network, however, the MR must (1) be able to discover which multicast groups the nodes in the moving network are interested in, and (2) provide optimal multicast routing inside the moving network by avoiding flooding. The selected approach relies on the deployment of "MLD-based Multicast Forwarding (MLD-proxying)" [10] inside the moving network, in order to solve the two above mentioned issues. As illustrated in Figure 7, this allows group membership information to propagate router-by-router from the routers serving multicast receivers towards the MR. Each intermediate router learns group membership information from its downstream interfaces, aggregates this information and proxies it upstream. Similarly, it forwards multicast traffic, based upon that information, only to downstream interfaces in the direction of receivers. Such a configuration, combined with the use of Remote Subscription at MR, allows multicast support for moving networks, without the need to run a multicast routing protocol.

This approach also supports multicast sources located inside moving networks. Receivers in the same moving network will get the multicast packets thanks to the MLD-based forwarding mechanism. In order to reach receivers outside of the moving network, the MR intercepting the multicast packet from the local source should then forward this packet towards its home network, by taking advantage of the MR-HA tunnel.

The advantages of this approach include the capability to roam in any visited link in the Internet (irrespective of the multicast routing protocol locally deployed); optimal routing even in case of nested moving networks; optimization of network and radio resources; compatibility with some host-based seamless mobile multicast approaches [11]; and of course simplicity of use.

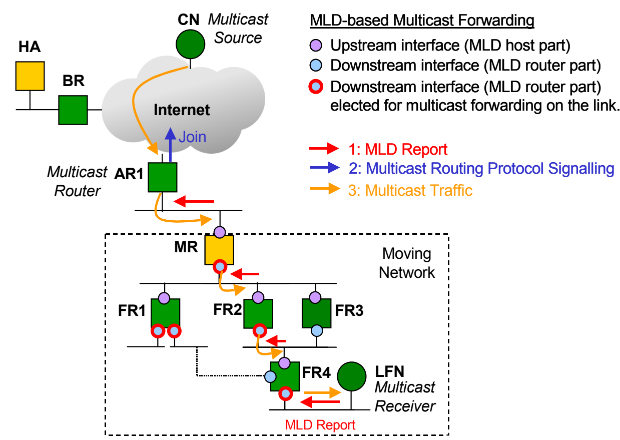

Figure 7 *Multicast for Moving Networks with MLD-based Multicast Forwarding*

Traffic Management

The OverDRiVE concept for Traffic Management originates from the field of AAA [12] and its application in mobile environments. First, Traffic Management mainly aims at not overstressing the wireless links between the MR and its AR. Additionally, it can be used as a basis for bandwidth reservation to ensure that important applications are granted a share of the bandwidth. In the scope of OverDRiVE moving networks, bandwidth reservation for an IVAN (i.e. between a MR and its HA) can involve multiple networks under the administration of different corporations. As the IVAN is mobile in terms of its point of attachment towards the Internet, handovers can imply frequent changes of network path characteristics.

While modifications to the MR and its HA are possible, it was a design premise to not apply any changes to the AR [13]. The MR-HA tunnel as an alternative allows for limiting the data rates sent to and from the MR. However, shaping the MR-HA tunnel calls for the knowledge of the capacity of the network path between the MR and its HA in both directions. Although the MR-HA tunnel is bidirectional, it is not necessarily symmetric in terms of capacity, e.g. most radio technologies provide asymmetric transport services to accomplish the requirements of web browsing, video streaming, etc.

An estimation of the capacity of this tunnel by a simple traffic monitoring approach to incoming and outgoing traffic at the MR or a capacity estimation based on the network hardware of MR's wireless links in combination with a propagation of results to the HA and nested MRs seems not sufficient. The OverDRiVE solution uses packet dispersion techniques [14][15] in order to estimate the capacity of the network paths between the MR and its HA. There are two fundamental techniques to estimate the path capacity: sender and receiver based packet pair techniques. Sender based technologies need neither measurements at nor status reports from the receiver. Instead, small echo packets are triggered. The arrival times of these echo packets are then measured at the sender. However, this approach does not disburden the receiver from resource intensive measurement tasks as both directions need to be monitored. Instead, an additional source of error is introduced, as not only the probing packets are subject to error due to cross traffic, but the echo packets as well. In addition, the ratio of echo packet sizes to probing packet sizes determines the maximum asymmetry of the network path that can be measured.

OverDRiVE's Traffic Management uses a receiver based packet pair technique to estimate the path capacity. The receiver does the measurements and sends status reports to the sender. The sender can perform traffic shaping based on these results. The probing packets are sent actively. However, data tunnelled between MR and HA can be used as a further source for capacity estimation. Furthermore, probing packets can either be sent on the same interface that is used to maintain the MR-HA tunnel or on the virtual MR-HA tunnel interface itself. Sending probing packets via the tunnel interface ensures on the one hand that the probing steam is not treated differently at routers on the network path. If encryption is used, these packets cannot be identified by their content, which may help to increase security. On the other hand, when using the tunnel interface, packet pairs are subject to the same tunnelling effects, i.e. delays due to encryption and fragmentation, as data traffic. This ensures meaningful measurement results.

Based on the results gathered from the measurements a scheduling mechanism is needed at the MR and its HA to share the tunnel capacity between the nodes on each side. An approach for implementing a fair queuing strategy has been published in [16] where an efficient way of realizing fair queuing by Deficit Round Robin (DRR) has been proposed.

4 Validation and Trials

OverDRiVE dedicated an important amount of efforts to trials and demonstrations of the protocols developed within the project. The foremost goal was to validate the findings by implementing the key aspects of the solution and performing tests in lab and real-life environments. At several places like in Paris, Bonn, Budapest and Turin testbeds consisting of at least a IPv6 backbone, GPRS, and WLAN access systems were established. Figure 8 depicts the demonstration setup at the HyWiN 2003 in Turin (http://www.ist-overdrive.org/HyWiN2003). To further visualize the benefits of the mobility management protocols, dedicated applications like video streaming, remote car control and software download to the car were realized. Details of all the testbeds, trials and applications can be found in [17]. Findings of the trials were also fed into the IETF NEMO group [18].

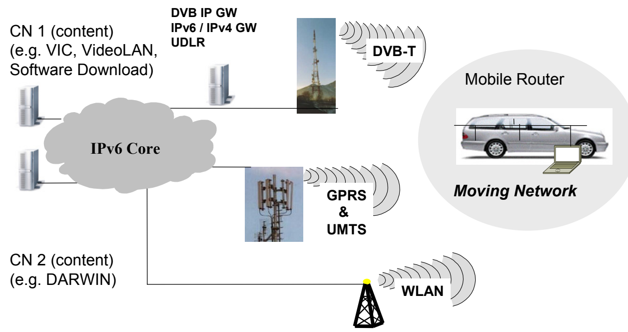

Figure 8 *Field Trials Setup at the HyWiN 2003 in Turin*

Summary

The OverDRiVE project successfully investigated and developed mechanisms to support network mobility based on Mobile IPv6 solutions. Such mobile networks may be found in future vehicles such as trains, cars, ships, etc. The work had significant impact on the scientific community by actively contributing to IETF NEMO working group and publications by all project partners on various conferences and workshops.

The demonstrations and trials provided valuable input to the project in order to validate the concepts and to identify further working areas.

References

[1] T. Ernst, A. Olivereau, L. Bellier, C. Castellucia, H.-Y. Lach, "Mobile Networks Support in Mobile IPv6 (Prefix Scope Binding Updates)", IETF Internet Draft, draft-ernst-mobileip-v6-network-03.txt, (Work in Progress), March 2002.

[2] V. Devarapalli, R. Wakikawa, A. Petrescu, P. Thubert, "Network Mobility (NEMO) Basic Support Protocol", Internet Draft, IETF, draft-ietf-nemo-basic-support-02.txt, Work in Progress, December 2002.

[3] A. Petrescu, ed., "Issues in Designing Mobile IPv6 Network Mobility with the MR-HA Bidirectional Tunnel (MRHA)", Internet DRAFT, IETF, draft-petrescu-nemo-mrha-03.txt, Work in Progress, October 2003.

[4] M. Pilz (editor), "Functional Description and Validation of Mobile Router and Dynamic IVAN Management", OverDRiVE Deliverable D17, March 2004.

[5] T. Narten, E. Nordmark, and W. Simpson, "Neighbour discovery for IP version 6 (IPv6)", RFC (Standards Track) 2461, IETF, December 1998.

[6] D. Johnson, C. Perkins, J. Arkko, "Mobility Support in IPv6", RFC (Standards Track) 3775, June 2004.

[7] IST-2000-28584 MIND, D2.2: MIND protocols and mechanisms specification, simulation and validation; http://www.dit.upm.es/~ist-mind/deliverables

[8] C. Janneteau, Y. Tian, S. Csaba , T. Lohmar, H.-Y. Lach, R. Tafazolli, "Comparison of Three Approaches

Towards Mobile Multicast", IST Mobile Summit 2003, Aveiro, Portugal, 15-18, June 2003.
[9] R. Vida and L. Costa, "Multicast Listener Discovery Version 2 (MLDv2) for IPv6", draft-vida-mld-v2-08.txt, work in progress, December 2003.
[10] B. Fenner, H. He, B. Haberman and H. Sandick, "IGMP/MLD-based Multicast Forwarding (IGMP/MLD Proxying)", draft-ietf-magma-igmp-proxy-06.txt, work in progress, April 2004.
[11] C. Simon, R. Vida, P. Kersch, C. Janneteau, G. Leijonhufvud, "Seamless IP Multicast Handovers in OverDRiVE", IST Mobile Summit 2004, Lyon, France, 27-30 June 2004, (accepted for publication).
[12] J. Vollbrecht, P. Calhoun, S. Farrell, L. Gommans, G. Gross, B. de Bruijn, C. de Laat, M. Holdrege, D. Spence, "AAA Authorization Framework", RFC (Standards Track) 2904, IETF, August 2000.
[13] C. Janneteau (editor), "Scenarios, Services, and Requirements", OverDRiVE Deliverable D03, September 2002.
[14] Prasad, Dovrolis, Murray, Claffy, "Bandwidth Estimation: Metrics, Measurement Techniques, and Tools", IEEE Network, November/December 2003.
[15] Dovrolis, Ramanathan, Moore, "What do packet dispersion techniques measure?", IEEE Infocom, April 2001.
[16] M. Shreedhar, G. Varghese, "Efficient Fair Queuing using Deficit Round Robin", IEEE/ACM Transactions on Networking, Vol. 4, No. 3, June 1996.
[17] T. Leinmüller (editor), "Description of Demonstrator for Mobile Multicast and the Vehicular Router", OverDRiVE Deliverable D14, February 2004.
[18] H.-Y. Lach, C. Janneteau, A. Olivereau, A. Petrescu, T. Leinmüller, M. Wolf, M. Pilz, "Laboratory and Field Experiments with IPv6 Mobile Networks in Vehicular Environments", draft-lach-nemo-experiments-overdrive-01 (work in progress), October 2003.

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