

# CAR-TO-CAR AND CAR-TO-INFRASTRUCTURE COMMUNICATION SYSTEM BASED ON NEMO AND MANET IN IPv6

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## ABSTRACT

A communication system is required for Intelligent Transportation Systems (ITS) applications. Given that vehicles will count by hundred millions and have a life expectancy of ten years or more and also that technologies are always involving, we believe that the communication system must be based on IPv6 and its associated protocols in order to scale and meet future needs. Recent work at the IETF and particularly on NEMO (Network Mobility) and MANET (ad-hoc networking) clearly support this belief. We are therefore embedding such mechanisms into our autonomous electric car developed at INRIA (CyCab). NEMO is used for vehicle-to-infrastructure (V2I) communications and MANET for vehicle-to-vehicle (V2V) communications.

## KEYWORDS

NEMO, MANET, V2V, V2I, IPv6, ITS

## ITS Telecommunication Requirements

Telecommunications will play an increasing role in the Intelligent Transportation Systems (ITS) era. Most ITS applications (road security, fleet management, navigation, traffic control, billing, multimedia, etc) and usages (private, public, logistic and safety vehicles) will rely on data exchanged between vehicles and the infrastructure and between vehicles themselves. This data exchange will have to meet a number of requirements. In particular, it must:

- be reliable and persistent (ubiquitous),

- be able to scale to several hundred millions vehicles and a large amount of data,
- be able to serve for the lifetime of the vehicle and be sufficiently flexible to sustain system improvement, unpredicted innovations and to accommodate a large panel of ITS applications and usages,
- require no or minimum human intervention and inquire minimum maintenance cost,
- be secure (third parties should not be able to corrupt the communication system),
- preserve human privacy (e.g. location, identity) and security (e.g. data corruption, system control),
- adapt to various national and service provider policies,
- must not be bound to a particular physical communication medium.

For all these reasons, the data exchange system will have to rely as much as possible on existing and open proven standards. Indeed, it became clear over the past few years that this exchange of data would be Internet-based and would use the underlying IPv6 protocols [7]. The IPv6 protocols already developed by the IETF, the standardization body of the Internet (Internet Engineering Task Force) meet most of the above listed ITS requirements, particularly its scalability (unlimited number of vehicles) and its flexibility (the protocol is extensible and any underlying technology could be contemplated, from GPRS to UMTS, M5, 802.11, 802.16, 802.21 and forthcoming 4G standards).

As discussed in [14, 13, 11], the basic functional requirements of an IPv6 communication system for ITS usages shall include:

- the ability to maintain Internet connectivity while vehicles are changing their point of attachment to the Internet topology (mobility support for V2I communications),
- the ability to deploy several IPv6 nodes interconnected through an in-vehicle network (network mobility support),
- the ability to use multiple access technologies simultaneously (multihoming),
- the ability to communicate with adjacent vehicles (ad-hoc networking for V2V communications).

## ITS-related Work in IPv6 at the IETF

### NEMO: Network Mobility in IPv6

The work conducted by the IETF NEMO (NEtwork MObility) Working Group [4] is going toward a direction that meets a number of our ITS requirements. The goal of the NEMO WG is to offer network mobility support in order to allow entire IPv6 networks (i.e. a *mobile router* and a number of connected devices such a sensors, servers, multimedia devices, etc) to change their point of attachment to the Internet topology. Cases of moving networks include networks of sensors deployed in vehicles, access networks deployed in public transportation (trains, buses, aircrafts, etc) and Personal Area Networks (PANs, small networks made of personal devices such as those found on firemen or wheelchairs, etc) . In-vehicle networks are the preferred use cases.

The NEMO Basic Support protocol (RFC 3963) [9] produced by this group is designed to maintain Internet connectivity between all the nodes in the moving vehicle and the infrastructure. This is performed without interruption nor failure of the data session under transmission, and transparently to the nodes located behind the mobile router embedded in the moving network. The mobile router is acting as a gateway between the moving network and the infrastructure. Other nodes are standard IPv6 nodes, i.e. they don't need to be upgraded with complex mobility management procedures to benefit from the Internet connectivity provided by the mobile router. *Network mobility support* is thus very easy to deploy, at a minimum cost.

Note that network mobility support using RFC 3963 is to be opposed to the earlier specification on *host mobility support* using Mobile IPv6 (RFC 3775, and specified by the IETF MIP6 WG) which provides Internet connectivity to a *single* moving host only. Mobile IPv6 is therefore inappropriate for most ITS use cases which usually consider more than one in-vehicle embedded CPU.

## MANET: Mobile Ad-Hoc Networking

The IETF MANET (Mobile Ad-hoc Networking) working group is specifying wireless routing protocols that could be used for vehicle-to-vehicle communications. It targets infrastructure-less networks of mobile nodes moving very dynamically. It could be applied to communications between people in conference rooms as well as to V2V communications between vehicles driving on the same lane (Vehicular Area Networks or VANET). OLSR (Optimized Link State Routing protocol) [16] is one of the protocols standardized by the MANET Working Group. It is classified as a *proactive* routing protocol where periodic control messages are broadcast in order to determine the network topology (it is a wireless adaptation of OSPF, the routing protocol the most commonly used in the fixed Internet). It differs from the other class of routing protocols where the routes between two nodes are computed on demand only (*reactive*).

## ITS Applicability of IETF Standards

Basically, the entire IETF community is devoted to produce the technical specifications required for all kinds of mobile communications (mobile phone usages, ITS usages, military and security forces usages, etc), from mobility management itself (e.g. NEMO Basic Support, Mobile IPv6, Fast Mobile IPv6), security (e.g. IPsec, IKEv2), access control and authentication (e.g. Diameter, PANA) to redundancy and multihoming (e.g. managing multiple access technologies simultaneously, as investigated by the MONAMI6 WG recently set up at the IETF).

The protocols specified at the IETF are usually implemented as they are specified, so implementations are available and protocols have been validated. Some of the implementations are publicly available (mainly on BSD variants and Linux) so they can be tested at an extensive level by anyone who wants to validate a particular usage of the protocol. The most difficult part is basically the integration of all the desired protocols into a system architecture that fits the needs of a particular usage. For instance, the Nautilus6 project hosted by the WIDE organization in Japan is working on such a system architecture with INRIA and other French partners [12].

While the IETF is defining the protocols, other standardization bodies such as 3GPP for the mobile operators or ISO for the ITS community are indeed defining the architecture

using the protocols defined by the IETF. At ISO, NEMO, Mobile IPv6 and other related protocols are parts of the CALM architecture currently under specification within the Technical Committee 204 Working Group 16 (TC204 WG16) [1]. This architecture is being implemented in Europe under the EC-funded CVIS project [5].

A few IPv6 experiments involving NEMO-enabled vehicles have already been performed. For instance, in Europe, the concluded OverDRIVE project financed by the European Commission considered NEMO as the underlying protocol to maintain Internet connectivity [17]. In Japan, the InternetITS consortium<sup>1</sup> gathering car manufacturers, mobile system vendors, software companies and operators is developing ITS applications and the necessary communication system based on NEMO for a number of years already.

The sudden interest in IPv6 for ITS usages, and particularly NEMO, can be witnessed from the growing number of papers and talks on this topic in ITS-related conferences such as VTC, ITST (particularly the edition held in France in June 2005 [18, 12]) and the WONEMO workshop (held in Japan in January 2006 and to be held again in 2007 [3, 8]). The WONEMO workshop is particularly interesting to ITS usages as it aims at both research, implementation, testing, validation, deployment and usages of network mobility.

## ITS Communications Activities at INRIA

INRIA (the French national institute for research in computer science and control) [6] has a long record of ITS-related experiments, both in the domain of Advanced Driver Assistance Systems (ADAS) and in the area of fully automated vehicles, known as cybercars. INRIA, and particularly the project team LARA (which was known as IMARA until its recent renaming) [2] is involved in several European projects dealing with car-to-car (V2V) and car-to-infrastructure (V2I) communications, such as CVIS [5], com2react, cybercars2. INRIA is also involved in the standardization process of the necessary communication protocols (IETF and ISO) and has pioneered network mobility [10]<sup>2</sup> and ad-hoc networking [16]<sup>3</sup>.

We now present our experimental framework for the development of integrated communications. We are testing communications using the 4G access cube, a Linux MIPS Box from 4G Systems (Fig. 1) which can be re-programmed. The access cubes are installed on four wheeled electric vehicles which have robotic abilities, i.e. they can drive fully autonomously: the CyCabs (Fig. 2). Each box has 2 wireless LAN cards (802.11b), one for the mesh network and the other acting as a base station. The base station function is important if we want to monitor the traffic performance without disturbing the mesh network or if we want to connect regular devices (e.g. PDA, Smart Phones or wireless sensors).

We are currently testing V2V communications based on ad hoc networking using routing protocols defined in the IETF MANET WG. For this purpose, we use the OLSR [16] protocol contributed by INRIA. There is also a possibility to communicate with a central server, and to communicate with the in-car devices. Our goal is to build networks that can automatically organize themselves with moving vehicles. Ad hoc networking is the answer for the V2V communication, but we need more if we want to enable communications

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<sup>1</sup>InternetITS: <http://www.internetITS.org>

<sup>2</sup>The IETF NEMO WG has largely been set up based on this research work initiated by INRIA's PLANETE project team in collaboration with Motorola Labs Paris.

<sup>3</sup>This protocol designed by INRIA's HIPERCOM project team was standardized within the IETF MANET WG.

between in-car devices (such as a PDA or a sensor) to a device located in another vehicle or the Internet. For such a communication, the right answer is NEMO Basic Support.

Our current activity is therefore the integration of NEMO Basic Support with OLSR. The easiest way, from a development point of view, is to use NEMO Basic Support on a standalone mobile router embedded in the vehicle. The NEMO-enabled router would serve for V2I communications and the 4G access cube for V2V communications.

Interestingly, two paths to the Internet may be available to the vehicle: one directly from the NEMO-enabled router, and one through another vehicle through the 4G access cube. This way, a more reliable Internet access could be provided to the vehicle, but such configurations bring a number of issues, such as how to detect paths to the Internet, which path to use and how, and how to redirect traffic from one path to an other. These are *multihoming* issues also investigated at the IETF on which INRIA contributes [15, 19].

## Conclusion

IPv6 is the underlying communication protocol that will be deployed for ITS applications. The IPv6-associated concepts of network mobility (NEMO), ad-hoc networking (MANET) and other mechanisms meet the ITS communication system architecture requirements. We are therefore integrating such communication protocols within our autonomous vehicles (CyCabs) in order to study the efficiency of the communication system and to demonstrate the benefits of V2I and V2V communications for ITS applications. NEMO Basic Support is used for V2I communications whereas V2V communications is ensured by the OLSR ad-hoc routing protocol.

## References

- [1] CALM - Medium and Long Range, High Speed, Air Interfaces parameters and protocols for broadcast, point to point, vehicle to vehicle, and vehicle to point communication in the ITS sector - Networking Protocol - Complementary element. Draft ISO/WD 21210, ISO, Technical Committee 204, WG16, December 2005. <http://www.calm.hu> and <http://www.sae.org/technicalcommittees/tc204wg16.htm>.
- [2] Project Team IMARA: Informatique, Mathématiques et Automatique pour la Route Automatisée". Activity report, INRIA Rocquencourt, December 2005. Available from [http://www.inria.fr/rapportsactivite/RA2005/imara/imara\\_tf.html](http://www.inria.fr/rapportsactivite/RA2005/imara/imara_tf.html) or the IMARA Home Page: <http://www-rocq.inria.fr/imara/lara2>.
- [3] WONEMO: the international Workshop on Network MObility. Web page, January 2006. Program 2006: <http://www.icoi.org/icoi2006/program.html> and CFP 2007: <http://www.nautilus6.org/events/wonemo2007/>.
- [4] IETF Network Mobility (NEMO) Working Group Charter. Web page, As of November 2005. <http://www.ietf.org/html.charters/nemo-charter.html>.
- [5] CVIS: Cooperative Vehicle-Infrastructure Systems. Web page, Last Visited August 2006. [http://www.ertico.com/en/activities/efficiency\\_environment/cvis.htm](http://www.ertico.com/en/activities/efficiency_environment/cvis.htm).
- [6] INRIA: French national institute for research in computer science and control). Web page, Last Visited August 2006. <http://www.inria.fr>.

- [7] BETTSTETTER, C. Toward Internet-based Car Communications: On Some System Architecture and Protocol Aspects. In *EUNICE Open European Summer School* (Twente, Netherlands, September 2000).
- [8] BOURNELLE, J., VALADON, G., BINET, D., ZRELLI, S., AND LAURENT-MAKNAVICIUS, M. AAA Considerations Within Several NEMO Deployment Scenarios. In *1st International Workshop on Network Mobility (WONEMO)* (Sendai, Japan, January 2006). <http://www.ico.in.fr/wonemo>.
- [9] DEVARAPALLI, V., WAKIKAWA, R., PETRESCU, A., AND THUBERT, P. Network Mobility (NEMO) Basic Support Protocol. Request For Comments 3963, IETF, January 2005.
- [10] ERNST, T. *Network Mobility Support in IPv6*. PhD thesis, Université Joseph Fourier, October 2001. Available from <http://www.inria.fr/rrrt/tu-0714.html>.
- [11] ERNST, T. The Information Technology Era of the Vehicular Industry. *ACM SIGCOMM Computer Communication Review (CCR) Volume 36*, Issue 2 (April 2006). <http://www.acm.org/sigs/sigcomm/ccr/archive/2006/april/p49-ernst.pdf>.
- [12] ERNST, T., KUNTZ, R., AND LEIBER, F. A Live Light-Weight IPv6 Demonstration Platform for ITS Usages. In *5th International Conference on ITS Telecommunications (ITST)* (Brest, France, June 2005), pp. 61–66. Available from the Nautilus6 web page: <http://www.nautilus6.org/doc.php>.
- [13] ERNST, T., AND UEHARA, K. Connecting Automobiles to the Internet. In *ITST: 3rd International Workshop on ITS Telecommunications* (Seoul, South Korea, November 2002). Available from <http://www.nautilus6.org/~thierry>.
- [14] KELLERER, W., BETTSTETTER, C., SCHWINGENSHLÖG, C., AND STIES, P. (Auto) Mobile Communication in a Heterogeneous and Converged World. *IEEE Personal Communications* 8, 6 (December 2001), 41–47.
- [15] NG, C., PAIK, E., ERNST, T., AND BAGNULO, M. Analysis of Multihoming in Network Mobility Support. Internet Draft draft-ietf-nemo-multihoming-issues-06, IETF, June 2006.
- [16] P. JACQUET, P., MUHLETALER, P., MINET, P., QAYYUM, A., LAOUITI, A., CLAUSEN, T., VIENNOT, L., AND ADJIH, C. Optimized Link State Routing Protocol. Request For Comments 3626, IETF, October 2003.
- [17] PETRESCU, A., LACH, H.-Y., JANNETEAU, C., WOLF, M., LEINMULLER, T., BARZ, C., PILZ, M., FRANK, M., AND TONJES, R. IPv6-based OverDRiVE Moving Networks: Mobility Management and Testbed Implementation. In *IST Mobile Summit* (Lyon, France, June 2004). <http://www.comnets.rwth-aachen.de/~drive/publications.html>.
- [18] SUCIU, L., BONNIN, J.-M., GUILLOUARD, K., AND ERNST, T. Multiple Network Interfaces Management for Mobile Routers. In *5th International Conference on ITS Telecommunications (ITST)* (Brest, France, June 2005), pp. 347–351. Available from <http://www.nautilus6.org>.

- [19] TSUKADA, M., ERNST, T., WAKIKAWA, R., AND MITSUYA, K. Dynamic Management of Multiple Mobile Routers in Network Mobility. In *IEEE International Conference in Networks (MICC-ICON)* (Kuala Lumpur, Malaysia, November 2005).



Figure 1: The 4G access cube



Figure 2: The CyCab vehicles