Real Experience with IPv6 Communications in Highways

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Abstract

Cooperative Intelligent Transportation Systems (C-ITS) are intended to improve safety and efficiency of roads worldwide. In the last ten years multitude of research works have served to reach ITS specifications within standardization organizations such as ISO, ETSI or IEEE. Platforms implementing such recent standards have bursted into the international ITS scene under the Field Operation Tests (FOT) nomenclature, however, many initiatives in this line have bet on pure ITS communication protocols, instead of thinking of the importance of interconnecting vehicles and the road infrastructure with the future Internet based on the Internet of Things (IoT) concept. IPv6 is essential in this framework, and not only because of interoperability, but also due to the advantages provided by Internet protocols in vehicular networks, such as global reachability, network mobility, auto-configuration, easiness of deployment or the use of extensively tested protocols, among others. For this reason, we present an IPv6-based communication platform considering both the ITS standardization and the Internet viewpoints. The key contribution of the work remains in the deployment of the network design in real highways under the umbrella of the FOTsis project, and its evaluation by using totally operational software and hardware units. The results show that the IPv6-based vehicular network performs correctly and is able to work with different communication technologies (3G and 802.11p), abstracting applications from network management duties.

Keywords: IPv6, Intelligent Transportation Systems, cooperative ITS, performance evaluation

1 Introduction

Cooperative Intelligent Transportation Systems (C-ITS) are ITS where participating entities (e.g. cars, charging stations, traffic lights, etc.) continuously communicate and exchange information among them with the objective of improving safety, sustainability, efficiency and comfort beyond the scope of standalone ITS. In other words, C-ITS magnifies the benefits offered by autonomous ITS, brings major social and economic benefits, and lead to greater transport efficiency and increased safety. C-ITS supports decreasing road fatalities, improving the capacity of roads, diminishing the carbon footprint of road transport, and enhancing the user experience during travels. Although there are many vehicular services envisioned for the short, medium and long term, these are usually categorized in the next groups [1, 2]:

- *Safety*. These services are intended to reduce accidents and safeguard vehicle occupants and pedestrians lives. Some examples are collision avoidance, accident notification or emergency vehicle approaching.

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- *Traffic efficiency*. In this group there are services that improve the road network capacity and reduce the travel time. Some examples are variable speed limit, dynamic management of road intersections, or congestion detection and mitigation.
- *Infotainment*. Mainly oriented to provide value-added comfort services, Internet access and multimedia. Some examples are context-aware touristic guidance, video under demand and video conferencing.

As a result of the great research efforts in cooperative ITS, we are now immersed in the phase of developing previous theoretical or simulated advances and getting preliminary results prior to the real operation of commercial services over real platforms. For this purpose, the European Union has recently financed projects for Field Operational Tests (FOT), such as DRIVE C2X[1] or FOTsis[2]. In parallel to these projects, additional efforts have been put on standardizing an interoperable communication architecture in vehicular cooperative systems. First, the ISO TC 204 released the Communications Access for Land Mobiles (CALM) concept, but the later created group ETSI TC ITS improved CALM based on the results of the COMeSafety European project[3].

Current lines of publicly founded projects are implementing communications stacks conforming with the previous standards. Some of these initiatives have shown an interest on IPv6 communications, since most of the foreseeable ITS services will be based on current Internet standards. However, essential issues such as global addressing or network mobility of nodes (i.e. hosts on vehicles) have not been considered in implementations until recent days. The ITSSv6 project[4], which concluded in 2014, worked on this line, proposing an implementation of a communications stack based on current standardized Internet protocols, which has been ported to several FOT initiatives such as FOTsis.

The maturity of 3G/4G and the more recent vehicular WiFi (IEEE 802.11p), together with the penetration issues that imply vehicle to vehicle (V2V) communications, implies that V2I communications are expected to be firstly exploited. It is in the V2I segment where novel traffic efficiency, comfort services and relaxed safety applications can be initially tested and deployed. For this reason, this research work, which is an extended version of [3], is framed in this communication domain and presents a comprehensive vehicular communications stack compliant with the ISO/ETSI standards that integrates a secure mobility solution by means of well-known and standardized Internet technologies such as Network Mobility (NEMO), Multiple Care-of Address Registration (MCoA), IP security (IPsec) or Internet Key Exchange (IKE), which favors its potential adoption by car manufacturers or road operators. Unlike existing works, this proposal not only presents a conceptual design, but also validates the proper operation of the communications stack through a deployment architecture and its application in a real test site in the Spanish A2 highway, in frames of the FOTsis project.

The paper is structured as follows. Section 2 places this paper in the research context, taking as reference a set of related cites in the literature. Section 3 introduces the reader in the context of this work: the FOTsis project, while Section 4 justifies the use of IPv6 in vehicular networks, which is a key part of the proposal presented in the paper. Based on that, Section 5 proposes an IPv6-based communication stack for vehicular scenarios. The general network deployment model is then presented in Section 6, which has been replicated in the reference test site evaluated in Section 6.2. Finally, Section 7 concludes this work with a set of final remarks and presenting our future research lines.

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[1] http://www.drive-c2x.eu

[2] http://www.fotsis.com

[3] http://www.comesafety.org

[4] http://itssv6.eu

2 State of the Art

The integral, realistic and experimental dimensions of the proposal presented in this work are non-frequent aspects in the literature. In the context of FOT projects one could find some articles in the line of supplying frameworks for vehicular integral communication. The authors of [4], for instance, present the testing framework for the DRIVE C2X project that, unfortunately, is not concerned with the use of IP-based communications, which are left out for management and testing purposes. A similar work about the simTD project is presented in [5], but it is specially focused on security and privacy.

In the terrain of using IPv6 technologies in vehicular communications, one of the most outstanding contributions has been provided by the ITSSv6 project. Research results achieved by this project have been published by authors in [6, 7] as well as by some colleagues in [8], where it is reported their experience performing packet delivery ratio tests using the 802.11p technology. Compared with these preliminary studies, the research work presented in this paper goes a step forward and deploys a real vehicular network that is tested to evaluate the communication performance.

Apart from specific project proposals, the work presented in [9] develops an experimental testbed to validate an on-board solution for providing vehicular communications through a “car gateway”, which is similar to the concept of mobile router. However, this solution is highly coupled with the vehicular platform and does not follow the ISO/ETSI guidelines. In [10] it is discussed the issue of using IPv6 mobility in vehicular communications, analyzing research directions and presenting a framework in which the present paper fits. The work presented in [11] is near the testbed presented in this paper, although a constrained communications stack is used for an experimental evaluation of a concrete routing and flow management subsystem using IPv6 with 3G and common WiFi. In [12] the Network Mobility (NEMO) protocol is evaluated in a real environment with two WiFi access points, however, the good results obtained in this work (no data looses during handovers) are non-realistic due to the limited testbed where a trolley is used to move the “on-board" equipment. This scenario is far from the real evaluation carried out in this paper in a real highway environment.

Another noticeable contribution of the present work relies on the development of an experimental validation of the IPv6-based communication stack over a real vehicular network and using a handoff scenario between 3G and IEEE 802.11p technology (ETSI G5), which is especially adapted to the conditions that arise in vehicular communications. To the best of our knowledge, there exist a few works dealing with this issue at network level. The evaluations performed in [8] reveal that the packet delivery ratio achieved by this technology is highly dependent on the distance between sender and receiver. These results are confirmed in [13], where it is also concluded that the vehicle speed does not imply a noticeable performance degradation in the communication. A similar evaluation is performed in [14], but this time carrying out a great testing campaign in a city. The most interesting analysis is the one attending to the impact of an environment with obstacles for the transmission of 802.11p signals. In the current work, these issues have also been demonstrated to play a key role in the expected performance of the considered mobile IPv6 network.

3 The FOTsis Project

FOTsis is a large-scale field testing initiative especially focused on close-to-market infrastructure services, involving 24 partners from eight European countries and having a budget of 13.8 million €. The recently finalized project has researched vehicle to infrastructure (V2I) and infrastructure to vehicle (I2V) technologies to enable the operation of services and assess their effectiveness and their potential for a full-scale deployment in European roads.

The project has put efforts on testing seven cooperative services in several European test sites, contributing to a safer, more intelligent and more sustainable road transportation system. The services considered are:

- Service 1: Emergency Management. This service supports the detection and alert of road incidents detected by either vehicles or road operators.
- Service 2: Safety Incident Management. This service provides real time information to drivers that warns them on any given situation that may reveal associated dangers or risks.
- Service 3: Intelligent Congestion Control. This service enables road operators to intelligently manage traffic in their roads by incorporating predictive algorithms that monitor traffic flows.
- Service 4: Dynamic Route Planning. This is an infotainment service for drivers providing optimized routes towards the destination taking into account factors such as weather conditions, road status, etc.
- Service 5: Special Vehicle Tracking. This service offers road operators a tool for monitoring special vehicles when driving through highways (e.g. when carrying dangerous goods).
- Service 6: Advanced Enforcement. This service monitors the drivers behavior in highways and either notifies infractions or enforce vehicles to obey driving rules.
- Service 7: Infrastructure Safety Assessment. This service gives road operators the opportunity of safety in their roads by analyzing information collected from either vehicles or other sources.

These services has been implemented by different partners of the project assuming an IP-like connection between a client side (an in-vehicle terminal) and a remote backend server. The University of Murcia group has been in charge of providing a service-agnostic network subsystem based on IPv6, which has been successfully validated with the different services in real test sites. In this paper this network architecture is presented and analyzed in terms of a real performance evaluation carried out in a real test site.

Regarding the different test sites considered in FOTsis, these are presented next by the involved country:

- Spain. Three highways have been considered: M-12 toll road, near the Madrid-Barajas airport; A2 highway 1st stretch, near Madrid in direction of Zaragoza; and A2 highway 3rd stretch, which is the segment of the A2 near Zaragoza.
- Portugal. Two highways are used: Baixo Alentejo and Algarve Litoral, both located in the south of Portugal.
- Germany. Three highways considered: A99, A9 and A92.
- Greece. The PATHE motorway is used.

In this work the A2 3rd stretch is considered as reference for evaluating the design presented, although this has been replicated and successfully tested in all the Spanish, Portuguese and Greek highways.

4 Rationale behind using IPv6 in vehicular networks

In an effort towards harmonization, the international ITS community agreed on the definition of a common ITS communication architecture suitable for a variety of communication scenarios (vehicle-based, roadside-based and Internet-based) through a diversity of access technologies (802.11p, infra-red, 2G/3G, satellite, ...) and for a variety of application types (road safety, traffic efficiency and comfort/infotainment) deployed in various continents or countries ruled by distinct policies. This common communication architecture is known as the *ITS station reference architecture* and is specified by ISO in [15] and by ETSI in [16]. As depicted in Fig. 1, the ITS station architecture follows an *Open Systems Interconnection* (OSI) like layered design: *access*, *networking & transport*, *facilities* and *applications*. Additionally, two cross-layer entities are defined: *ITS Station Management Entity* (SME) and *ITS station Security Entity* (SSE).

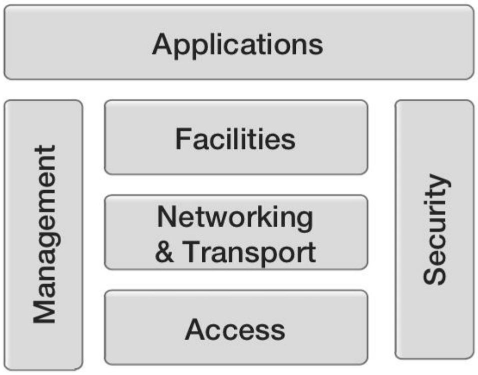


Figure 1: ISO/ETSI reference communications stack

There exists different types of ITS stations (ITS-S): *personal ITS-S* (e.g. smartphones), *vehicle ITS-S* (e.g. cars), *roadside ITS-S* (e.g. electric charging station) and *central ITS-S* (e.g. road operator control center). These are depicted in Fig. 2. ISO has recently called ITS Sub-systems to ITS Stations.

Each ITS station type implements a subset of the functionalities of the general ITS station reference architecture according to the played role. In the most general case, the functions of an ITS-S are split into a router (ITS-S router) and hosts (ITS-S host). The first one is a node comprised of routing functionalities that is used to connect two networks and forward packets, while the ITS-S host is a final node executing specific ITS applications. ITS-S hosts are attached to the ITS-S router via some ITS station internal network.

Despite the general architecture defined by ISO/ETSI supports ITS services under the same umbrella, currently there exist several ongoing efforts to define the operation of the different modules integrating the communications stack. In particular, a controversy remains about the protocols to be used mainly in the networking layer. So far, we can identify two main families of protocols being adopted by standardization bodies (and the academia): specific ITS protocols such as GeoNetworking [17], which is a multi-hop routing protocol oriented to the geo-dissemination of information in vehicular environments; and Internet Protocol version 6 (IPv6) technologies [18], based on the evolution of well-known Internet protocols defined within the Internet Engineering Task Force (IETF).

Although GeoNetworking offers more adapted functionalities for supporting vehicular communications, such as native geographical distribution or low packet overhead, IPv6 offers a more interoperable solution with the rest of the Internet. Moreover, IPv6 opens the door to perform an easy integration of vehicular networks with the foreseable Internet of Things (IoT) or Smart Cities, among others. In this sense, a number of well-known IETF protocols could be added for providing extra security, multicast,

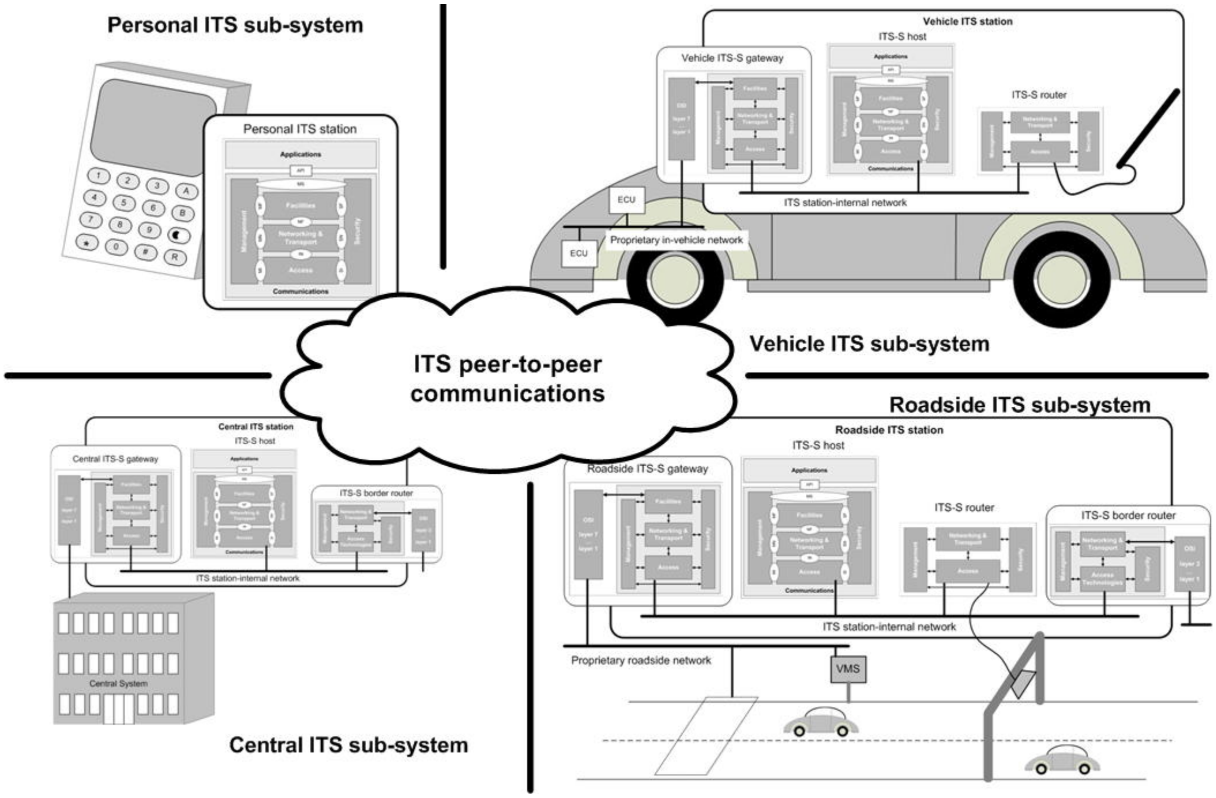


Figure 2: ITS Stations and interconnection (source ISO [15])

multi-homing, etc.

Apart from solving the IPv4 addresses depletion, IPv6 provides extra advantages that cover important needs in cooperative vehicular communications. First, IPv6 defines addresses of a fixed 128-bit length. This allows a very large address space that is considered sufficient for most ambitious deployment scenarios such as the vehicular one, where a number of vehicles and on-board devices should be addressed. Second, IPv6 makes easier the integration of mobile IP technologies, thus allowing the support of network continuity upon the change of point of attachment. Third, IPv6 also provides node auto configuration, which is useful for nomadic devices entering the vehicle. Finally, another advantage of IPv6 relies on its security capabilities. Unlike its predecessor, IPv4, IPv6 natively supports secure communications to assure information confidentiality, integrity and authentication.

As it is described in the next section, this work bets on integrating IETF-standardized technologies into a network architecture that implements ISO/ETSI specifications.

5 Proposed IPv6-Based Vehicular Communications Stack

As explained in the previous section, there exists an high interest in the development of a vehicular communications stack integrating IPv6-related technologies. Taking as reference the ISO/ETSI station architecture, in this work we present a novel communications stack that integrates relevant IPv6 technologies for implementing vehicular communications. The added value of this work is that the proposed stack has been implemented and deployed in a real scenario, in order to demonstrate its ability to support the different FOTsis services. In this section we describe the proposed vehicular communications stack. In the subsequent sections we will explain the deployed architecture together with a complete performance assessment.

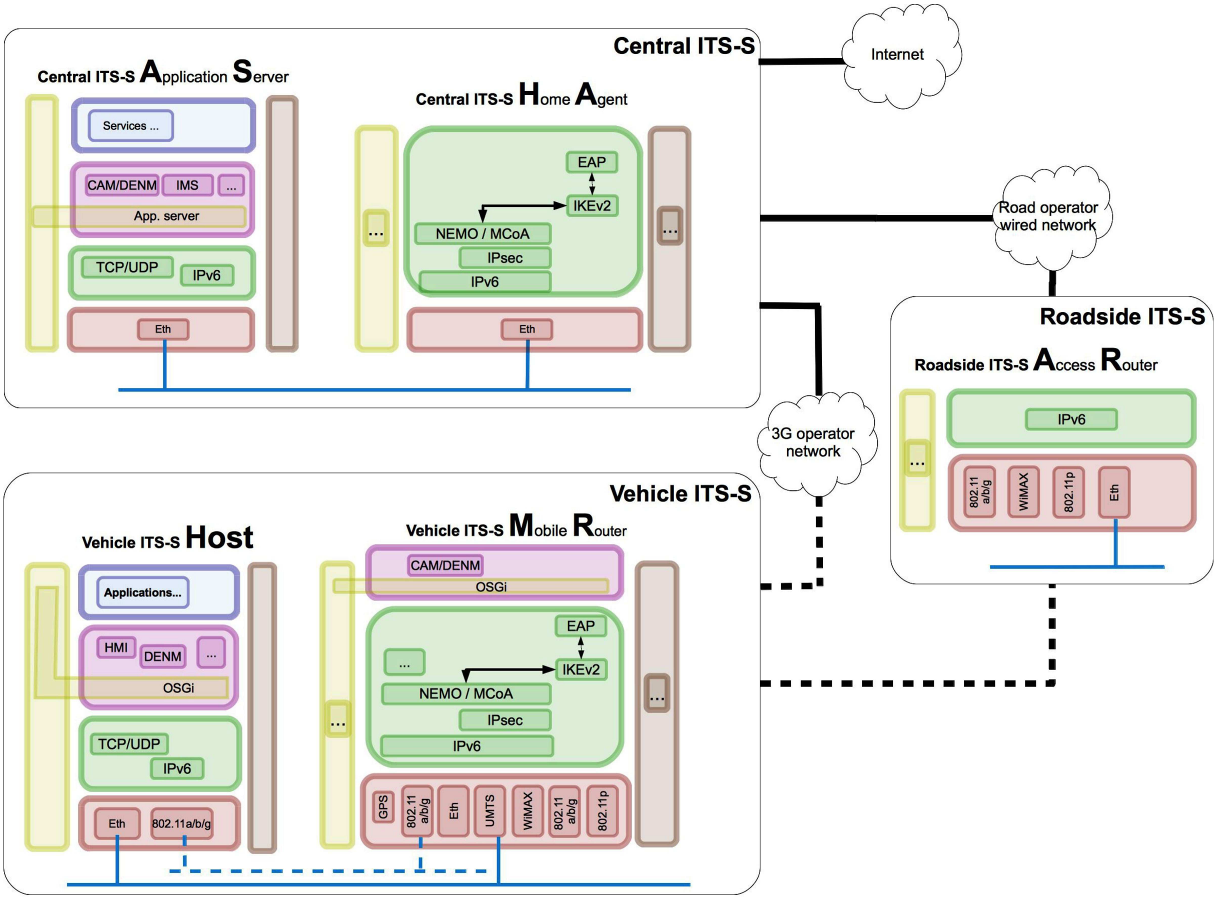


Figure 3: Overall design of the reference vehicular communications stack

Fig. 3 shows a simplified view of this platform, including three of the standard ITS stations: vehicle ITS-S, roadside ITS-S and central ITS-S. In the vehicle the stack functionality is split into the vehicle ITS-S host and vehicle ITS-S router (also known as Mobile Router - MR). The MR includes the needed functionalities to hide networking tasks to in-vehicle hosts, which could connect to the network by means of the MR through WiFi or Ethernet. To maintain external communications with roadside equipment and the control centre, the following communication technologies are integrated: 3G/UMTS, WiMAX, WiFi and 802.11p (ETSI G5-compliant). IPv6 connectivity is supported by the set of elements included within the networking and transport layer of the MR. On one hand, Network Mobility (NEMO) [19] is in charge of maintaining reachability for the whole in-vehicle IPv6 network. Additionally, to support the multi-homed configuration of the mobile router, the NEMO operation is assisted with Multiple Care-of Addresses Registration (MCoA) [20]. Regarding security, the mobile router is equipped with Internet Protocol Security (IPsec) [21].

The stack on the Vehicle ITS-S Host is in charge of executing final applications that could access remote services. As observed, this stack includes a common networking middleware based on the Transport Control Protocol (TCP) and User Datagram Protocol (UDP). The facilities layer, based on the Open Service Gateway Initiative (OSGi), includes CAM (Cooperative Awareness Message Service) and DENM (Decentralized Environmental Notification Message Service) messaging modules (apart from other functionalities) to make easier the implementation of applications.

The communications stack instantiated in the roadside ITS-S access router acts as network attachment point for vehicles using short/medium-range communication technologies. Similarly to the MR, the available wireless technologies to communicate with vehicles are WiFi, 802.11p and WiMAX.

Finally, in the upper part of Fig. 3 we can see the communications stacks for both the Central ITS-S Application Server (ITS-S AS) and the Central ITS-S Home Agent (Central ITS-S HA). The former hosts ITS services managed by the central ITS-S, while the latter is necessary for maintaining the connectivity of vehicles upon the change of point of attachment to the road, acting as NEMO Home Agent (HA). For this reason, the modules included in the network layer are equivalent to the ones included at the same layer in the MR. Since IPv6 security is applied between the MR and the mobility/security server represented by the HA, equivalent security modules are used in both entities.

6 Highway Deployment and Performance Evaluation

In this section we describe the general vehicular network architecture employed in the FOTsis project. We concrete the details of the deployment carried out in the Spanish A2 highway and show the evaluation results exhibited by our communications stack.

6.1 Deployed Architecture

On the basis of the previous stack design for the different entities involved in our V2I scenario, it is now possible to create a deployment architecture using real equipment. This is showed in Fig. 4. Initially, it is noticeable the direct mapping among the different entities included in this diagram and the communication nodes described in the previous section. For the sake of clarity, only two roadside ITS-S and one vehicle ITS-S are included. For a reference testbed it is not necessary to replicate the functionality of the central ITS-S Home Agent and Application Server in multiple servers.

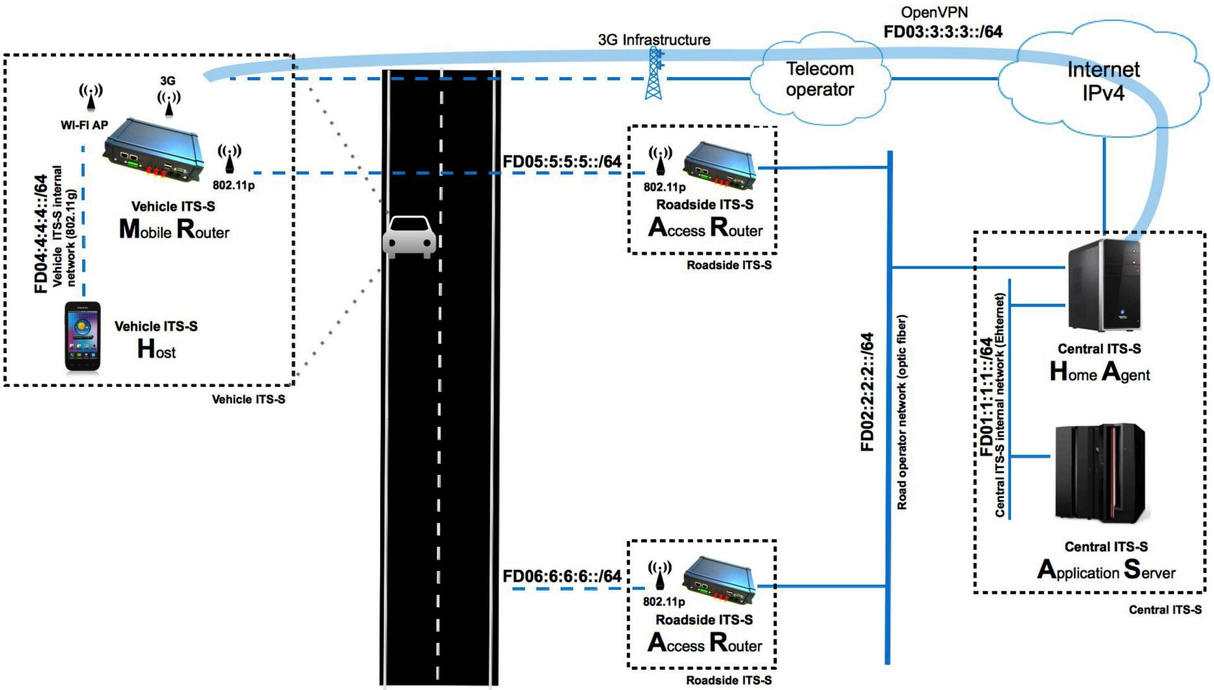


Figure 4: Deployment architecture of the vehicular network

Fig. 4 shows the two available communication routes between the vehicle and the central ITS-S: the 802.11p one, using the control channel of the ETSI G5 profile; and the one provided by using the 3G operator's infrastructure. A testing addressing scheme is also showed and, due to the 3G operator used does not provide IPv6 support, an OpenVPN tunnel over IPv4 has been used. A wired connection is used between the roadside ITS-Ss and the central ITS-S, which is supposed to be installed in the control centre premises of the highway. Here, the central ITS-S Home Agent acts as a border router, interconnecting the roadside network segment with the whole central ITS and the Internet. The wired connection between each roadside ITS-S and the central ITS-S is supposed to be established over the communication infrastructure of the road operator, which is usually a fiber optic channel.

In the test site later explained the roadside ITS-Ss are installed next to the road, using the available road infrastructure, while the vehicle ITSs are mounted in common vehicles. The 12-volts lighter connection is enough to connect the mobile router, which offers connectivity to in-vehicle hosts through a common WiFi connection based on IEEE 802.11g.

6.2 Test Site Deployment

The previous deployment architecture has been used in several test sites in frames of the FOTsis project, as described in Section 3. Without loss of generality, in this section we describe the deployment conducted (in December 2014) in the Spanish A2 highway (3rd stretch), near Zaragoza, which has been the last one equipped in the FOTsis project. The deployments carried out in the remaining test sites are quite similar to the one described here.

The exact test stretch is located in the A2 highway 3rd stretch, from KP 139 to KP 226, as indicated in Fig. 5. The Control Centre of this highway has been installed in Arcos de Jalón, located in the Soria province, and it can be found in the east of the the testing stretch, just 30 Kms away from Medinaceli (upper right corner of Fig. 5). Vehicles drive from one edge of the road stretch to the other, in a circular basis.

The equipment used in the test site is detailed in Table 1. The same base hardware is used for both the MR and the AR, in which the ITSSv6 software stack has been installed. It integrates the mobility and security services previously described. A stick antenna is mounted in each roadside ITS-S for 802.11p communications, and a roof antenna is used in each vehicle ITS-S, supporting 802.11p/3G/GPS. Both antennas are designed to improve the communication performance in terms of gain and radiation pattern.

6.3 Test Site Preparation

The roadside ITS-Ss have been installed at KP 139+00 and KP 146+00 of the A2 highway, as marked in Fig. 5, while the central ITS-S equipment is installed in the highway control centre. The HA and AS are wired to the control centre local network, which has external connection with Internet and the roadside ITS-Ss. As can be seen in Fig. 6, the two ARs have been installed in roadside cabinets used for electronic devices at the selected points of the road, where power supply and network connection is available. They are connected with an optic fiber to Ethernet switch also available in the cabinet. In order to enable IPv6 communications within the road operator network, a separated virtual local area network (VLAN) was set up with the switch ports used by each AR and the pair of terminating ports in a local switch available in the control centre.

A photo of the interior view of one of the roadside ITS-Ss can be seen in Fig. 7. Here you can see the switch acting as bridge between Ethernet and fiber optic technologies, which several devices connected with yellow cables. One of these is the AR, which can be seen in Fig. 8. The power supply provided by the cabinet and the Ethernet cables are clearly visible, while the connection with the one-pole external antenna is hidden in the image.

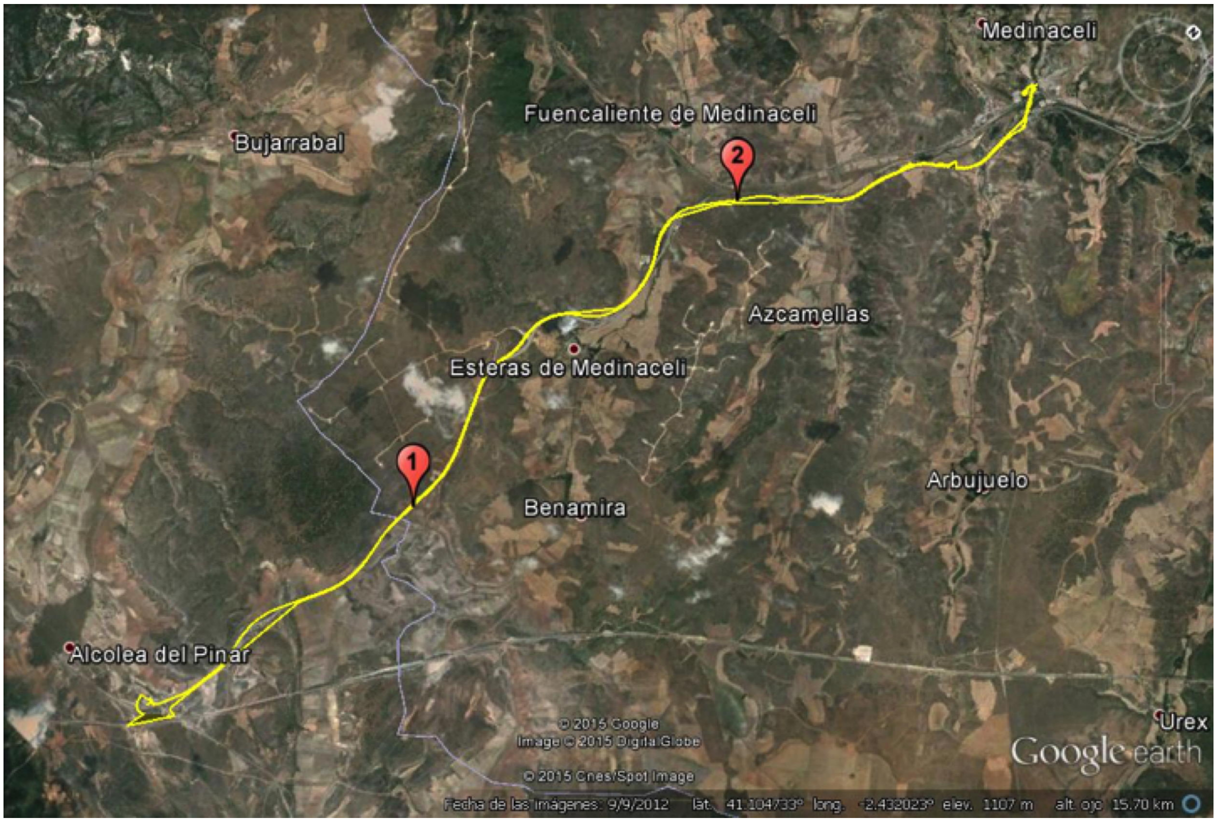


Figure 5: Deployment architecture of the vehicular network

Regarding the vehicle ITS-S, which can be seen in Fig. 9, it is installed in a common vehicle in the tests. In the image the MR is the upper box, which has a power supply connected to the vehicle 12-volts lighting connector, and it is connected with the exterior antenna. The tests conducted in this test site were also intended to evaluate services 5 (Special Vehicle Tracking), 6 (Advanced Enforcement) and 7(Infrastructure Safety Assessment) of FOTsis. Since the GMV company was the FOTsis partner responsible for implementing these services, we integrated as in-vehicle host an on-board unit provided by this company that used the connectivity offered by the vehicle MR. As can be seen in the photo, the connection of this unit with the MR is performed through a USB to serial adapter. Lastly, the MR is provided with two common WiFi antennas, since an 802.11n in-vehicle network is used to connect common hosts, as described above.

The combined antenna is affixed on the vehicle roof, as can be seen in Fig. 10. This antenna provides:

- An enhanced 3G cellular connectivity to the MR, since the coverage is improved with this set-up.
- GPS signal reception also improved thanks to the antenna design and placement.
- 802.11p communications with roadside ITS-Ss. In this case the improvement as compared with an in-vehicle antenna is even higher, since the line of sight requirements of this communication technology is quite higher than in the other cases.

Table 1: Hardware components used in the test sites

Network Nodes		
Node	**Hardware**	**Software**
MR	Laguna LGN-00-11/LGN-20	ITSSv6 stack
Host	Laptop, Intel i7, 4GB	Ubuntu 12.4
Host	Samsung Galaxy Tab II	Android 4.0.3
HA	Asus eeBox EB1501P	ITSSv6 stack
AS	PC Intel i5, 3.1Ghz, 3GB	Ubuntu 10.4
AR	LGN-20	ITSSv6 stack
Communication hardware		
Item	**Model**	
802.11p transceiver	Unex DCMA-86P2 mini-PCI in AR/MR	
Vehicle antenna	Omni-combined 3G/ 11p/ GPS 7dBi	
Roadside antenna	Omni-stick 12dBi	
3G modem	Ovation MC950D (only for LGN-00-11)	

Figure 6: Roadside ITS-S in the A-2 highway

6.4 Performance Evaluation

First of all, a set of general tests were performed to check geographically the 802.11p and 3G connectivity areas resulted when passing the roadside ITS-Ss. Fig. 11 shows the results obtained in one of the tests. The blue dots stand for 802.11p communication, whereas the orange ones pertain to the 3G connectivity.

Figure 7: Interior view of a roadside ITS-S in the A-2 highway

The 802.11p coverage was less than expected, covering only 1,35 and 1,20 Kms long for the first and second roadside ITS-S, respectively. For sure, the low height of the antennas was probably the main cause of this issue.

The overall network performance was then tested to check its performance in terms of the throughput and delay. For measuring the network throughput, a constant data rate of 250 Kbps was generated from the central ITS-S HA to the vehicle ITS-S host, connected to the MR. The data rate was fixed to this value due to the 3G limitations checked in the area, which is attributed to a poor network deployment of the telecom operator. It is important to consider that this test site is quite far from big urban areas, and this could be the reason. The results can be seen in Fig. 12a. The vehicle has been driven at a speed between 80 and 100 Km/h, and the test complies a round trip in the road stretch described above. For this reason the roadside ITS-Ss are passed two times each. These are marked as “RSU1” and “RSU2” in the plots. Although a low data rate is used, the limitations of the 3G network and the impact of mobility is noticeable in the results. However, in the road segments where 802.11p is used the network throughput recovers.

A delay study was also performed by using the *ping* tool in the host to generate ICMP Echo Request messages and receive the correspondent ICMP Echo Replay messages. The round-trip delay time (RTT) results are showed in Fig. 12b. Since the car passes two times the two roadside ITS-Ss, four 802.11p connectivity periods are visible in the RTT results. As can be seen, the delay here is near 10 ms, while the 3G technology could imply RTT values of up to one second. Attending to the results, it is also noticeable a lack of connectivity just after the pass near the AR. This is due to the time needed for carrying out the handover back to 3G, which is performed when AR advertisements do not arrive through this link for a period of time configured in the NEMO software.

Figure 8: Access router connected in a roadside ITS-S in the A-2 highway

Figure 9: Vehicle ITS-S used in the A-2 highway

The effect of mobility is clearly noticeable in the results. Apart from the limitations in the 3G service, the 802.11p connectivity could be also improved if the location of the roadside ITS-S antennas were better, as said above. According to the coverage results, and based on our experience in other test sites, the performance of the 802.11p communications would be better with a higher installation point of

Figure 10: Vehicle antenna

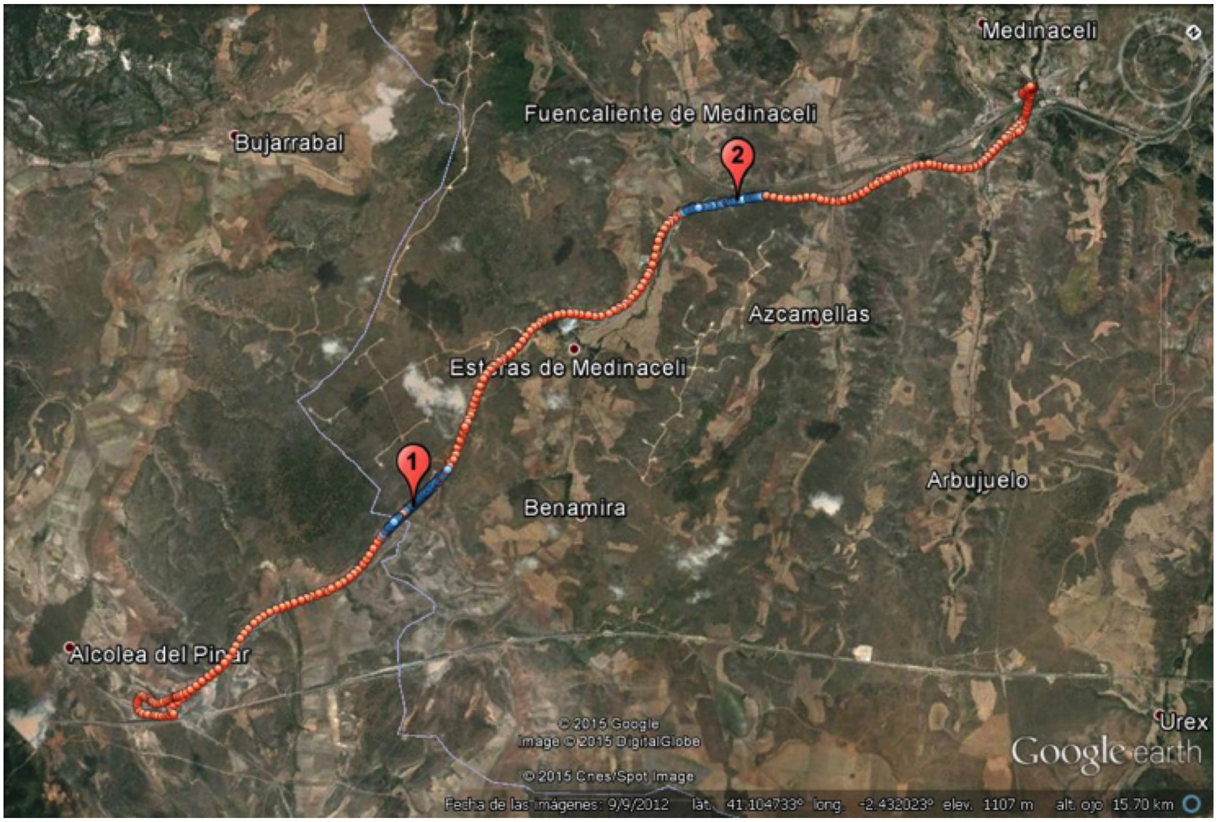
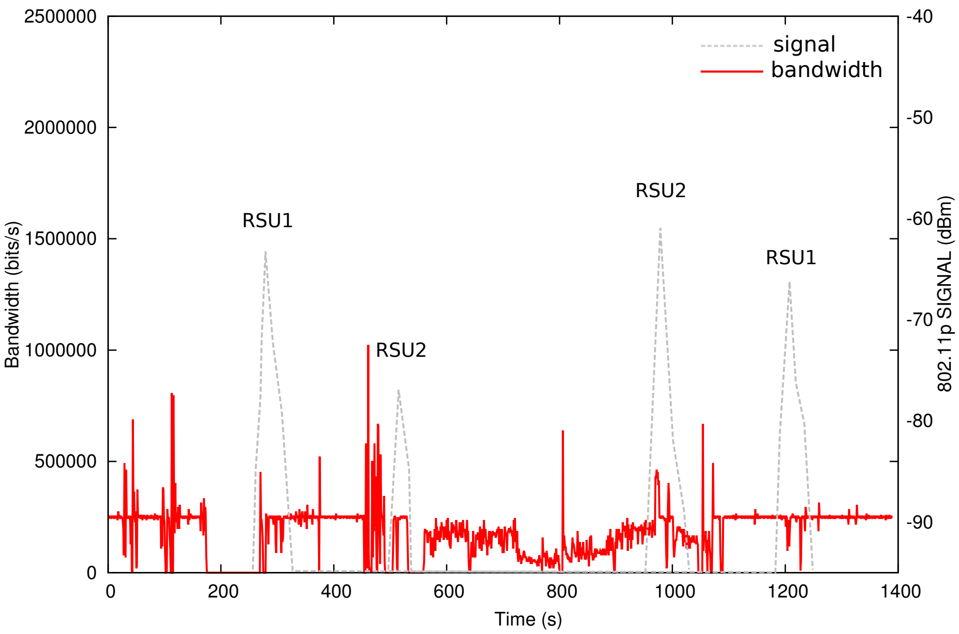
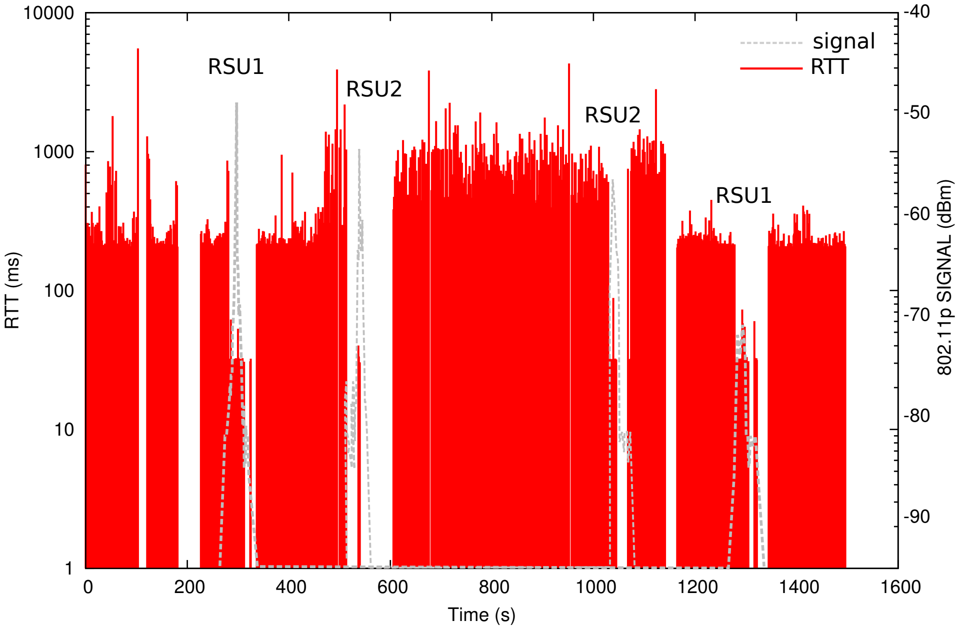


Figure 11: Connectivity with 3G and 802.11p through the A2 road stretch

the antennas. Unfortunately, this issue was detected a posteriori, since we visited the test site once the roadworks had ended.



(a) UDP throughput from the host perspective



(b) Network delay

Figure 12: Network throughput in the A-2 test site (Spain)

6.5 Discussion

In the road segments where 802.11p connectivity is available, it can be seen in the results how NEMO works correctly, by changing the data flow to use a proper communication channel. As expected, the throughput is better with 802.11p, covering the requested data rate, although the maximum achievable bandwidth can exceed 5 Mbps, according to our previous research [7]. The delay improvement is even greater than with throughput, as compared with 3G. RTT values bellow 10 ms have been gathered, which is a performance similar to common WiFi networks.

A key performance point is the time needed to come back to 3G once the 802.11p connection is lost. As said before, this is due to the current mechanism used to leave the 802.11p channel, which is based on the lack of router advertisement received from the ARs. A timeout is configured here to wait several seconds before changing to another potential communication interface, which supposes a temporal data link loss each time a roadside ITS-S is passed.

Considering the previous results, services deployed over a network like the one presented cover a wide range of possible traffic efficiency applications, such as route guidance, dynamic speed limit, congestion avoidance and mitigation, or road traffic monitoring. Moreover, in the area of comfort and entertainment, the possibility of accessing directly to the Internet offers many possibilities to our model. Regarding safety, delay-relaxed applications such as notification of road accidents, or incidents in general, could be supported, but others requiring direct low-delay communications between vehicles, such as forward collision avoidance, fall out of the network model analyzed. However, it is important to remark how V2V communications are possible in the network architecture exploited in this work, since all communication nodes in the network are IPv6-addressed.

7 Conclusion

The work presented in this paper addresses four main objectives: first, it justifies the usage of IPv6 communications in cooperative ITS; second, it describes a network architecture with a proper communications stack based on ISO/ETSI standards and IETF technologies to present an IPv6 access to future telematic services; third, it creates a deployment architecture of the proposal prepared to be installed in real scenarios; and fourth, it sets up and evaluates a reference testbed in a highway.

The results gathered from the experiments validate the correct operation of the network architecture and allow us to assess the performance of the solution. The network has been able to route data packets using alternatively 3G or 802.11p thanks to the NEMO technology. This has been performed in a real highway with vehicles moving at common speeds. Nevertheless, we have checked that some parts of our system could be improved through several parallel research lines. The work described in [7] envisages how the IEEE 802.21 specification can improve the handover operation diminishing the network transition time, above all when passing from 802.11p to 3G. This idea is also discussed in [22], and it is a research area in which we are actively working these days. Another line is focused on the security aspects in IPv6 vehicular communications, further evaluating the use of IPsec and IKE. A third line is the authentication to access vehicular networks and, especially, the ones provided by road operators. A vehicular authentication framework is being designed and developed solving this issue, based on EAP (Extensible Authentication Protocol) and PANA (Protocol for Carrying Authentication for Network Access).

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