Evaluation of a General Purpose Communication Unit for Two-Wheelers

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***Abstract*—Vehicular communications are a need in future smart scenarios, since people can spend hours on a variety of transport means in daily activities. However, most of the current research deals with the integration of telematics in light vehicles, while two-wheelers (or equivalent) present especial conditions that reveal a need for new communication units that allow integrating bikes and mopeds (among others) into vehicular networks. In this paper, this gap is solved with a new embedded design provided with IEEE 802.11p and cellular communications, which can work as a mobile router and presents a simple but effective interface for warning services. A key point of the proposal is the bet for IPv6 as the base network protocol, which will be the essential in all-connected environments following the IoT paradigm. The communication unit has been tested in a real driving scenario, and one-hop results using the 802.11p channel reveal communication delays bellow 2 ms, packet delivery rates above 50% within a road stretch of 400 meters, and a maximum throughput of 4 Mbps. These performance values are adequate for a number of safety, infotainment and exploitation services.**

Keywords*–*Communication unit; Two-wheeler; Performance evaluation; IPv6.

I. INTRODUCTION

Cooperative Intelligent Transportation Systems (C-ITS) are demonstrating to improve safety and mobility of common vehicles, as it has been reported in results of European projects like Drive C2X [1] or FOTsis [2]. These systems stretch the range of isolated systems powered with sensors to better maintain contextual information about the surrounding traffic, thanks to wireless communication technologies. Vehicular networks have reached a standardization stage and vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications are considered to save lives and improve travel experience in the near future. The USA government has stated its deployment strategy in this line [3], for instance. However, the work in this area focused on two-wheelers is still limited in the ITS context, even though European studies remarked the need for further research in the area of vulnerable road users (VRU) [4]. Bikes, mopeds and motorbikes have special constraints that make them a different vehicle group to be integrated in the Future Internet. Power source, mobility patterns, vehicle dimensions, communication range, positioning capability, human-machine interface (HMI) or electronics integration are some of these particular features. The potential of C-ITS in the two-wheel segment is clear, but a proper technological platform is needed to provide effective safety and mobility services.

For C-ITS to happen, a network that interconnects all the different elements of the road is necessary. In this field, different standardization bodies have defined its own reference communication architecture. IEEE have bet on Wireless Access in Vehicular Environments (WAVE), whose most relevant technology in the last years has been 802.11p, also called *Vehicular WiFi*, which provides the physical and access layers of the stack. ETSI and ISO propose an architecture with an exchangeable access technology, and propose different routing protocols. What is remarkable in these three proposals is the presence of the IPv6 protocol, although it has received a marginal interest and it is mainly considered by these organizations as a complementary network protocol mainly for infotainment applications. However, we understand IPv6 as an essential piece of a vehicular communication stack to integrate vehicular networks in the Future Internet.

The work described in this paper follows the objective of providing a communication unit adapted to the special needs of two-wheelers by also using IPv6 as a reference interconnection protocol. For this, the proposal raises from the synergy between current ITS standards (ISO/ETSI), Internet protocols (IETF) and IEEE technologies. The solution is an embedded communication unit for two-wheel vehicles integrating IEEE 802.11p and 3G wireless technologies in a small-factor computer, and running a communication middleware based on IPv6. Apart from the design, the work is especially focused on the prototype of the platform and the real communication performance tests.

The paper is organized as follows. Section II places this work in the research literature. Section III describes the design and development of the new communication unit for two-wheelers, while Section IV focuses on the IPv6 communication middleware integrated. Section V includes the experimental evaluation of the unit. Finally, Section VI concludes the paper and describes the next steps of our work.

II. STATE OF THE ART

A proper scientific knowledge supporting the application of C-ITS technologies in two-wheelers is limited in the literature. The authors in [5] have recently discussed the importance of communications for enhancing safety and efficiency of VRU and, particularly, the protection of two-wheelers. Several works in the literature already deal with road safety regarding pedestrians, which are the ones that barely cite two-wheelers in the area of vehicular communications. In [6], a review of systems to protect pedestrians reveals that until 2007 communications were rarely used to create cooperative systems, and vision, thermal, radar or laser sensors were used to avoid vehicle collisions with VRU. The proliferation of lower-delay cellular connections and the wide usage of WiFi contributed to the appearance of cooperative solutions around 2010. In [7], the base idea of exchanging localization data among pedestrian mobile phones and car on-board devices is presented. Here, a 3G link is mainly used, although it is also discussed the establishment of a WiFi connection between both

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terminals to reduce communication delay. A similar system is presented in [8] and [9], although they analyze in more detail the implications of the communication technology used. The authors in [10] review a communication technology in the 700 MHz for pedestrian to vehicle communication, which is far from current USA and EU trend of working in the microwave band. The solution presented in this paper focuses on the use of vehicular WiFi technology in the 5 GHz band for short-range vehicular communications, whose potential for communications between cars and VRU is discussed in [11], and cellular networks for ubiquitous access to Internet when 802.11p is not available.

A recent work dealing with the integration of telematics in bicycles can be found in [12]. It is a preliminary system concept in which ZigBee is used to improve travel efficiency through cooperative cruise control in bikes. Although the communication system is apart from current vehicular standards, it shows an interesting equipment embedded in the bike with a haptic interface. In [13], a prototype of connected motorbike uses a communication device installed in the boot with vehicular WiFi (5 GHz). This is a reference research in the motorbike segment, although further work is identified in a protocol stack lacking support with current trendy standards in the segment and not considering Internet connection. The work in [14][15] is focused on light two-wheel vehicles, presenting a safety system to warn cyclist about the presence of other vehicles through a visual interfaced embedded in the helmet. However, as a difference with the present contribution, it is based exclusively on a 3G/4G connection through the mobile phone for the case of the bike. The work in [16] presents a system that also uses a mobile phone for a similar purpose, although the novelty in this case is found in the way that regular WiFi is used. Beacon messages are used to directly embed information about a safety service, thus avoiding the association. A drawback of this proposal is its narrow application perspective and the need of using this especial communication mode of WiFi. A work including standardized vehicular communication protocols is described in [17], where motorbikes are equipped with a unit using an ETSI-compliant communication stack, while bikes use a especial bluetooth low-power device. Although this work share with the present contribution the idea of connecting two-wheelers to the vehicular network, it is focused on especial protocols for vehicular networks, and thus it sets IPv6 aside. The proposal in [18] does not integrate up-to-date technologies in the vehicular segment, but proposes the usage of IPv6 in the bike domain as a proof of concept.

As can be seen, existent contributions that especially tackle two-wheelers connectivity are generally based on technologies and protocols far from dealing with the interconnection of these transportation means with the rest of the Internet. We think that IPv6 is the key piece of smart environments (e.g., smart cities) and, for sure, of Future Internet architectures and, for this reason, we present a communication unit able to integrate two-wheelers in IPv6 networks with a hardware adapted to this operation scenario.

III. HARDWARE PLATFORM

A new communication unit has been created for the case of two-wheel vehicles, including necessary communication technologies and providing a proper software host. The unit was initially presented in [19], considering a basic communication middleware for a constrained safety application, and presenting an initial prototype. The platform has been now improved to support IPv6 network mobility to act as mobile router and the prototype has been assembled in its final form, being totally operational, as it is demonstrated in Section V.

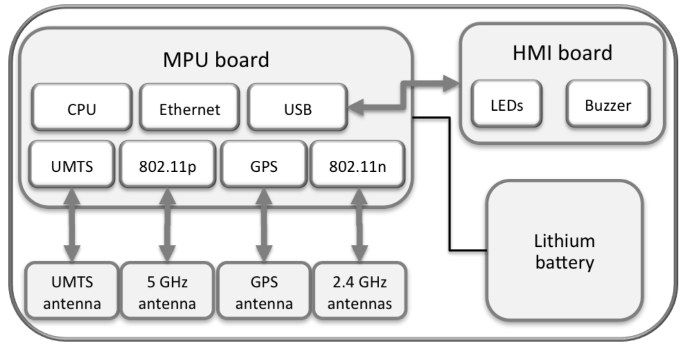

Figure 1. Hardware design of the communication unit

The general architecture of the unit is depicted in Figure 1. The microprocessor unit (MPU) board contains the base platform, with the CPU, USB, and communication modules supporting Ethernet, UMTS (3G), vehicular WiFi, GPS and regular WiFi, which is mainly used to connect with mobile devices installed on the two-wheeler or carried by the user(s). These modules are connected with an appropriate antenna. The main board is powered by a Lithium battery, given that the two-wheel vehicle could not include a power supply (e.g., bikes). A basic human-machine interface (HMI) is given by an extra board including LEDs and a Buzzer, which can be used to execute a basic services based on warnings or for testing purposes.

A reference prototype of the unit design has been implemented and installed in both a bike and a moped. Figure 2 shows the main parts of the hardware. An overall view of the platform is included in Figure 2a, where both the main unit (bottom in black) and the HMI board (upper in blue) are mounted on an electric moped. Figure 2b shows the hardware included in the main unit, which includes the functional modules of the MPU board described above. The unit is based on the Laguna LGN-20 platform from Commsignia. The communication board is visible on the top, from where different cables are connected to the 802.11p, regular WiFi (802.11n), GPS and 3G antennas. This system mounts an ARM11 300MHz SoC processor, 16 MB of Flash and 8 GB of internal storage, and 256 MB of RAM memory. The USB interface is used to connect with the HMI board. The power supply used is a 15 volts and 3500 mA lithium battery, which is able to maintain the unit up more than six hours in the operation modes used in the tests presented in Section V. The 802.11p antenna used is a 5.9 Ghz Taoglas Limited DCP.5900.12.4.A.02 (6 dBi), which has been affixed to the inner part of the unit enclosure, and it is visible on the upper right corner in Figure 2b. No 802.11n antennas have been used for the moment, and the cables are maintained in a foam piece, but communication with near devices has been possible without them. The 3G antenna is a common stick used for WiFi, and it is connected on the lower left corner of the unit.

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(a) Unit mounted on a moped (b) MPU board (c) HMI board

Figure 2. Prototype of the communication unit for two-wheel vehicles

The HMI board includes a set of LEDs and a buzzer. The prototype is showed in Figure 2c. One of the LEDs is used to inform about the whole unit status, while the others and the buzzer are left for application purposes, such as the safety service for two-wheelers described in [19]. The USB connector is used to connect the circuit to the main board, as can be seen in Figure 2a. The GPS antenna has been finally installed in the same enclosure used for the HMI in order to avoid interferences with the main unit electronics and improve the signal reception. This antenna is a PCTEL WS3917, which has worked correctly in the tests.

IV. Communication Stack

The communication stack of the new embedded unit for two-wheelers has been ported from the one used in the car mobile router presented in [20]. This stack follows the ISO/ETSI reference architecture specifications [21][22]. Its main design blocks are depicted in Figure 3. IPv6 connectivity is supported by the set of elements included within the networking and transport layer of the unit. Network Mobility Basic Support (NEMO) [23] is in charge of maintaining IPv6 reachability. Regarding security, the mobile router is equipped with the needed elements to secure mobility-related traffic by means of Internet Protocol Security (IPsec) [24]. Communication flows can be secured with IPsec once security associations are stablished with Internet Key Exchange Protocol Version 2 (IKEv2) [25].

The functionality provided by NEMO is useful to maintain Internet connectivity in C-ITS between all the nodes mounted on the vehicle and the infrastructure. Thanks to NEMO, mobile devices connected to the mobile router of the two-wheeler (e.g., a mobile phone), are reachable through the infrastructure at the same IPv6 address during the itinerancy of the bike or moped. Additionally, with the aim of supporting multihoming, Multiple Care-of Addresses Registration (MCoA) [26] has been included in our unit. This technology allows us to perform faster handovers, maintaining initial and target communication flows up during the transition. However, in order to better decide the most suitable network at every single location, we have also included modules from the IEEE 802.21 standard. As discussed in [20], with this technology it is possible to obtain seamless handovers by minimizing packet losses during the process.

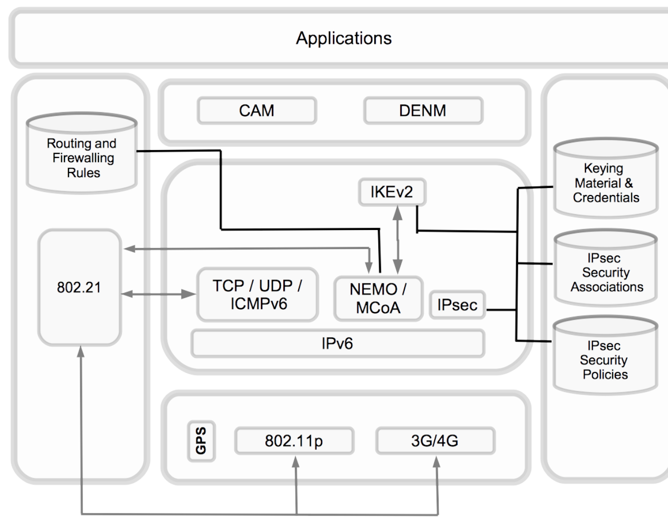

Figure 3. Design of the mobile router with extended IPv6 mobility support

CAM [27] and DENM [27] messages are supported by the communication stack. They can be used to develop ITS applications, such as the safety application for two-wheelers presented in [19]. In this work, CAM messages are encapsulated in UDP datagrams over IPv6, which are sent to the all-nodes multicast IPv6 address in a direct V2V fashion.

V. Experimental Evaluation

The communication unit for two-wheelers has been tested to assess its performance in real driving settings. Given its relevance for vehicular applications, the evaluation has been focused on the 802.11p channel, through a set of one-hop tests.

A. Testbed

The testing scenario was set in the surroundings of the University Centre of Defence at the Spanish Air Force Academy. For the sake of simplicity, we preferred to move a mobile router in a car, and maintain static the two-wheeler node, since the last one has a battery and it is not necessary an external power supply. Figure 4a shows the open road where the tests were performed, in which there is direct line of sight between

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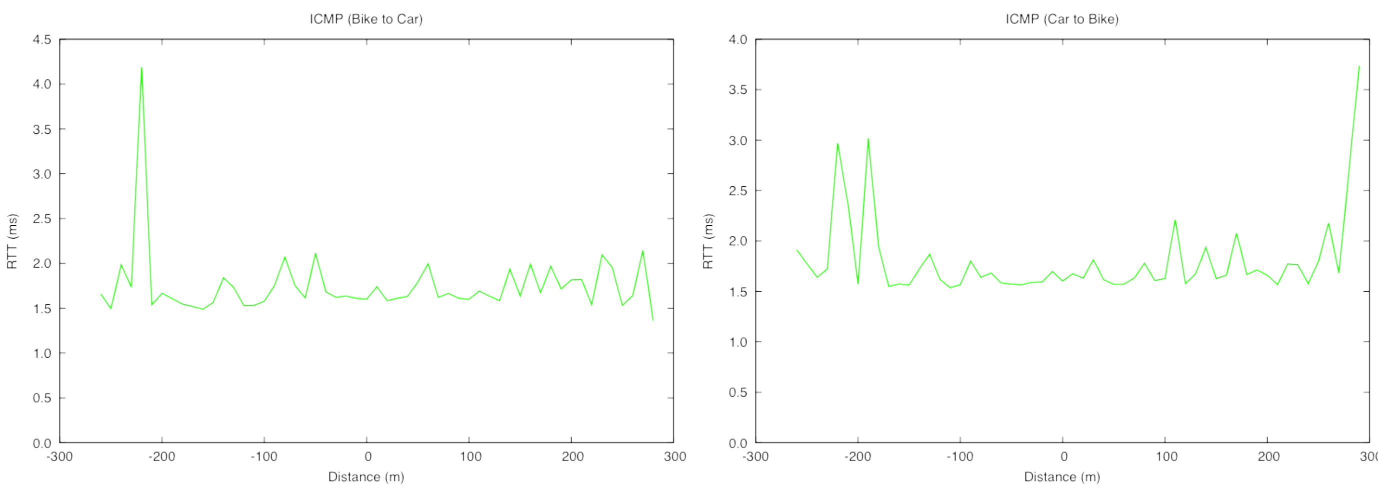
(a) Testing location (b) Two-wheeler communication node (c) Mobile router used in the car

Figure 4. Scenario for testing one-hop communications using 802.11p



(a) Two-wheeler to car (b) Car to two-wheeler

Figure 5. Delay tests using one-hop communication with 802.11p

the two-wheeler unit and the car mobile router. The new embedded node was detached from the moped and placed in a box on the sidewalk, next to the road and elevated 10 cm, as can be seen in Figure 4b. The HMI board (blue box) was connected just to check the correct operation of the unit through one of the LEDs, while the GPS antenna was necessary to geo-localise the unit. The box was placed at the middle of the road stretch showed in Figure 4a. The mobile router mounted on a common car is showed in Figure 4c. This is a Laguna LGN-20 from Commsignia, running a communication stack equivalent to the one included in the two-wheeler node. The antenna used is a combined omnidirectional 3G/11p/GPS 7dBi, which was attached on the vehicle roof with a magnetic base.

The tests have been carried out with three different protocols:

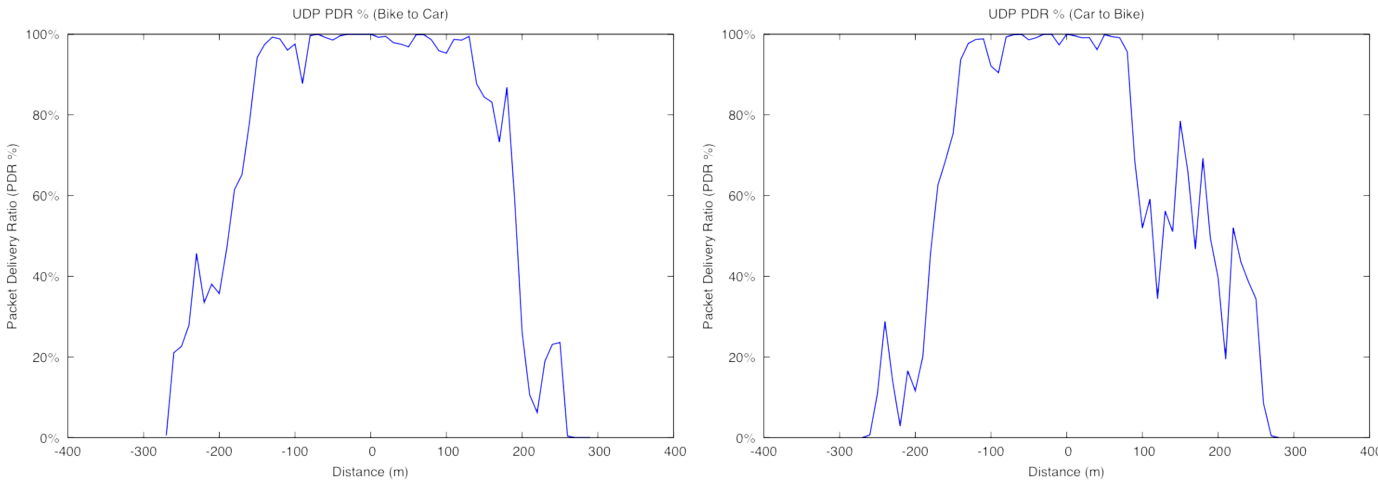
- ICMPv6, to check the delay of the communication link. A continuous check of the link using the *ping6* tool at a rate of 1 Hz and with a payload of 56 bytes has been performed.
- UDP, to study packet losses. It has been chosen a transmission rate of 1 Mbps, sending 1230 bytes of data in each datagram. The *iperf* tool has been used to generate this UDP traffic.
- TCP, to study the maximum achievable throughput. The *iperf* tool has been used for this again.

Each transmission type was used to pass six times with the car near the two-wheeler node, and different tests were carried out to check the car to two-wheeler transmission direction, and the two-wheeler to car one. Each record of the test was geo-located by marking it with the GPS position. This way the results obtained have been averaged in a 10 meter basis, computing the distance from the car to the two-wheeler node.

B. Results

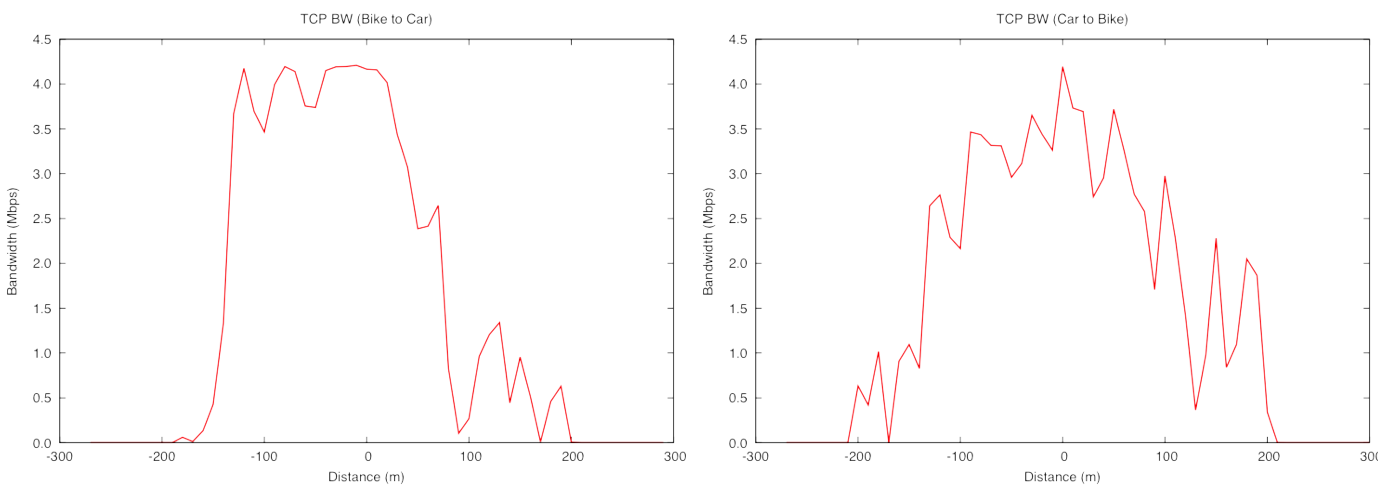
The delay results obtained in the tests are showed in Figure 5. As can be seen, a good performance is obtained within a communication range of near 600 meters. The round-trip time value obtained in most of the stretch is between 1.5 and 2 ms. Delay peaks are obtained at the edges of the road stretch until the communication is broken. As can be seen in the plots, the results gathered in both communication directions are equivalent, given that the *ping6* generates packets that reach the destination and then come back.

The study of the packet delivery ratio (PDR), which is measured in percentage of packets that reach the destination successfully, is showed in Figure 6. As expected, a similar communication range is obtained here and, although the distance with the two-wheeler node affect the performance at



(a) Two-wheeler to car (b) Car to two-wheeler

Figure 6. Packet delivery tests using one-hop communication with 802.11p



(a) Two-wheeler to car (b) Car to two-wheeler

Figure 7. Throughput tests using one-hop communication with 802.11p

distant points, good PDR results are obtained in general within the road stretch. It can be observed that the two-wheeler to car case performs better. This is due to the better reception sensibility of the antenna used for the case of the car.

TCP results are plotted in the two graphs included in Figure 7. The first noticeable difference with the previous tests is the communication range decrease. This is attributed to the features of the communication protocol used, since TCP needs a successful connection establishment stage prior to start the transmission. After that, the transmission rate is adapted according to the detected performance of the link. Again, it is observed that in the two-wheeler to car case, the link performs in a steadier way. In any case, the maximum throughput obtained reaches 4 Mbps in both transmission directions, which is a good value.

The results obtained indicate a good performance of the 802.11p communication link. The delay and PDR results assure a good operation of the network for safety services requiring direct V2V communications. Moreover, the good throughput of the link enables the cellular network offload for services, such as video transmission or file downloading, always when a near roadside unit is available. Nevertheless, it must be considered that, first, the expected performance when driving near multiple vehicles using 802.11p would be impacted by the congestion of the communication channel; and, second, urban scenarios would imply additional signal reception issues, due to the rest of vehicles and buildings.

VI. Conclusion

The paper describes the work carried out to develop a communication unit for two-wheel vehicles and its evaluation under real settings. The design of the unit has been adapted to the distinguishing features of two-wheelers, such as the need of a battery and the space/interface limitations. The hardware provides cellular and short-range communications, while a proper middleware has been added to support IPv6 networking. Both Internet-based and direct V2V communications are possible and, due to the inclusion of IPv6 protocols, the unit is ready for novel Future Internet environments, such as smart cities.

The performance tests carried out with short-range communications demonstrate the capabilities of the unit for connecting with road-side units or nearby vehicles. The results obtained indicate that the communication channel presents an RTT delay of 2 ms for delivery packets, a PDR above 50% within a road stretch of 400 meters, and a maximum throughput of 4 Mbps. Given the embedded design of the new unit, these are good results that assure the operation of the unit for a number of potential services.

At the moment, we are further evaluating the unit considering the network mobility capabilities, and our plans consider the integral adoption of all means of transport in smart environments powered by IoT technologies. For this to be done, especial IoT protocols will be adapted for the vehicle domain and research efforts are being identified for homogenizing data recovery and processing.

Acknowledgments

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