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***Abstract*—The goal of Cooperative Intelligent Transportation Systems (ITS) is to enhance road safety, traffic efficiency, and comfort of road users based on Vehicle-to-Vehicle, Vehicle-to-Roadside, and Vehicle-to-Central communications over diverse media such as DSRC, Wi-Fi, 3G, WiMAX, and LTE. IPv6 is the most promising technology that enables a convergence of such different communications over diverse media. This paper is about investigating the issues regarding IP-communications over DSRC band. The investigation is made through field test experiments using communication devices equipped with hardware interfaces for different media as well as an IPv6 stack. Based on our field test results, we discuss the issues and some potential solutions towards achieving sufficient perfomance of IPv6 communications over DSRC band.**

***Index Terms*—Cooperative ITS, ITS Station Architecture, IPv6, IEEE 802.11p, experimentation.**

I. INTRODUCTION

Road safety, fleet control, Geo-localization, infotainment and other applications are new road services that need not only new control technologies for vehicles and the infrastructure (sensors capacity, high image processing, complex data handling...) but also efficient data transmission between vehicles and the infrastructure. A new vision of Intelligent Transportation Systems (ITS) is born: Cooperative ITS. The idea is based on conceiving and deploying a transportation system in which the roadside infrastructure, vehicles, and remote entities cooperate to enhance road safety, traffic efficiency and comfort of road users (drivers, passengers, pedestrians, fret carriers). With this new revolutionary concept of Cooperative ITS, the pure fiction of communicating vehicles is becoming a reality in which suitable communication forms, architectures and techniques are deployed to combine in an efficient way the internal control function of the vehicle with its external communication function.

In situations where the exchange of information has to transit through the Internet and considering today's Internet predomination in mostly all communication systems, Internet-based communication scenarios are crucial for vehicular communications in order to keep the whole system up to date with the new technological achievements in favor of the ubiquitous Internet. IPv6 takes its place within these new ITS communication architectures, thanks to its advantages like extended address space, mobility support and ease of configuration, in boosting new Internet and ITS usages [1]. While a much effort has been made to improve the capability of IPv6 including enhanced mobility management and embedded security, the cooperative ITS brings even higher challenges due to the underlying diverse communications media. This motivates our research and development activities that are to establish a cooperative ITS system enabling *Vehicle-to-Vehicle* (V2V), *Vehicle-to-Roadside* (V2R), and *Vehicle-to-Central* (V2C) communications using DSRC, 3G, and Wi-Fi media.

The IEEE 802.11p [2] is defined for ITS communications for safe and comfort driving support and it operates over DSRC band (5.9 GHz). IEEE 802.11p based communications for safe driving support has been taking much attention from academic and industrial sectors. Safe driving applications, including inter-vehicle collision avoidance, have strict requirements especially in terms of transmission delay. Adding to the delay requirement, because such applications often do not require Internet connection, the majority of the ongoing research on ITS over IEEE 802.11p targets non-IP communications [3], [4]. Thus, not much work has been done to answer the question "how IEEE 802.11p radio performance affects IPv6 communications?". This is an important and essential issue towards enabling cooperative ITS, since DSRC is one of the core underlying media of cooperative ITS. To this end, we have made extensive field tests to evaluate IEEE 802.11p performance and to analyze its possible impacts on IPv6 communications. In our experimental testings, we use a multimodal communication device, Laguna [5], which is developed especially for cooperative ITS. This paper introduces some of our experimentations and the insights achieved from the experimentation results.

The paper is structured as follows: Section II describes ITS station reference architecture, IEEE 802.11p access protocol, and introduces some of ITS applications that need IPv6 communications. Section III introduces Laguna multimodal communication device and Section IV presents our experimental results and the achieved insights. Finally, conclusion and perspectives are presented in Section V.

II. Preliminaries

A. ITS Station Reference Architecture

ISO TC204 WG16, known as CALM (Communications Access for Land Mobiles) is working for ten years on a communication architecture supporting a variety of media types (infrared, microwave, 2G/3G, ...), a variety of networking protocols (IPv6, FAST) for a variety of Cooperative ITS needs (communication profiles) and access network load. Such an interface management component requires input from various layers and is thus a cross-layer function. With such a cross layer function combined with IPv6 mobility support functions (NEMO, MCoA) [6], continuous Internet connectivity can be maintained over transient communication interfaces (i.e. not breaking ongoing communications after vertical handover from e.g. IEEE 802.11p to 3G) or transient access points (from one roadside ITS station supporting IEEE 802.11p to another one). This architecture has been developed, validated and demonstrated in the CVIS project for a number of Cooperative ITS applications.

In an effort towards harmonization, the European Commission's COMeSafety Specific Support Action issued an European ITS Communication Architecture which has then led to the definition of a uniform communication architecture known as the ITS station reference communication architecture (see Fig. 1) standardized at both the European level within ETSI TC ITS (Technical Committee for Intelligent Transport Systems) and the international level within ISO TC 204 WG16. Both ISO and ETSI architecture specifications [7], [8] are based on the same terminology and tend to converge although there are still differences between the two until all standards composing this architecture are revised and aligned.

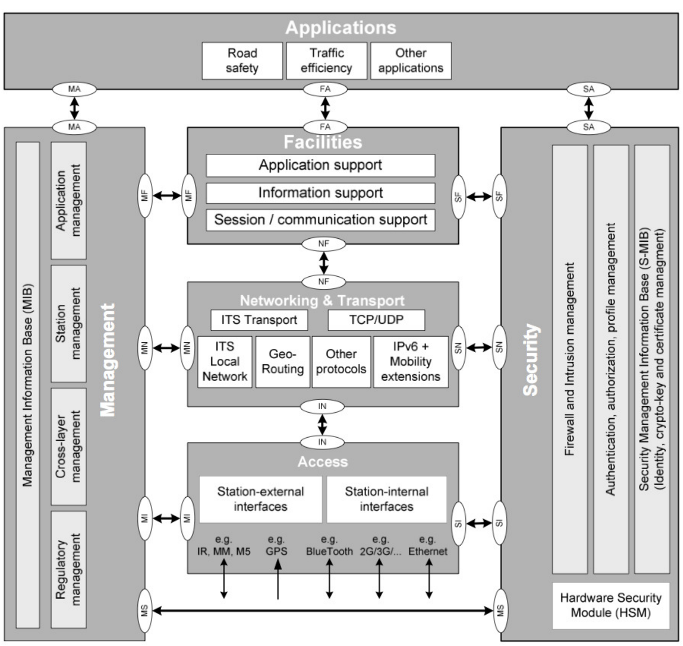


Fig. 1. ITS station reference architecture

The cross-layer design originally introduced by ISO TC204 WG16 is now clearly represented on the architecture diagram (*ITS station management* plane), though the cross-layer functions to be offered are still under discussion at the ETSI and ISO standardization level. Such an architecture would be deployed on various types of ITS stations involved in Cooperative ITS communications, but different features would be supported according to the type of ITS station, deployment environment and user needs.

B. Cooperative ITS Applications

Types of ITS stations include the *vehicle ITS station*, the *roadside ITS station*, the *personal ITS station* and *central ITS stations*. As a result, this ITS station architecture combines all types of communications: V2V and V2R, and V2C. As it can be seen in Fig. 2, vehicles are equipped with the IEEE 802.11p communication interface in order to organize the Vehicular Ad-hoc Network (VANET) between vehicles, and also between vehicles and the roadside. Vehicles can connect to the Internet via the roadside ITS Station dedicated to ITS. On the other hand, the ITS Station may be equipped with communication interfaces (*e.g.* 2G, 3G, Wi-Fi) that can connect to the general Internet infrastructure.

A Vehicle ITS Station consists of a router (Mobile Router, MR) which is in charge of the communication of the entire ITS Station and hosts that are running applications. With this concept, the ITS Station hosts are free from managing the communication beyond the link where the hosts connect to, since the router is responsible for managing the communication of the entire ITS Station.

The ITS applications running on the hosts are classified into three categories: traffic safety, traffic efficiency and infotainment. The definition of a Basic Set of Applications were defined in ETSI [9]. Among the applications, some of them highly require message delivery in real-time or message delivery guarantee (*e.g.* Emergency vehicle warning). In such case, IP may not be used. The non-IP approach puts more importance in the network performance such as delay, packet delivery ratio and so on by omitting the IP header and the processing at the IP layer. On the other hand, IPv6 is used for the other traffic efficiency and infotainment applications that needs connectivity to the Internet, such as "contextual speed limits notification" and "Media downloading".

C. IEEE 802.11p

The IEEE 802.11p [2] is a wireless medium access technology for V2V and V2R communications over the 5.9 GHz band. The IEEE 802.11p basically uses the same PHY as defined in IEEE 802.11a [10] but by default, it operates utilizing 10 MHz bands. Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), 16-Point Quadrature Amplitude Modulation (16-QAM), and 64-Point Quadrature Amplitude Modulation (64-QAM) modulation schemes are available allowing 27 Mbps data rate at maximum (see Table I).

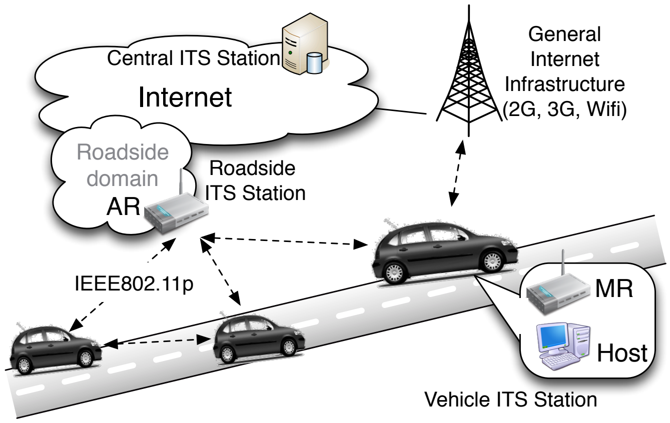


Fig. 2. ITS station reference architecture

TABLE I
MODULATION AND DATA RATE FOR A 10 MHZ CHANNEL

Modulation	Coding rate	Data rate [Mbps]
BPSK	1/2	3
BPSK	3/4	4.5
QPSK	1/2	6
QPSK	3/4	9
16-QAM	1/2	12
16-QAM	3/4	18
64-QAM	1/2	24
64-QAM	3/4	27

The IEEE 802.11p is adapted by ETSI (European Telecommunications Standards Institute) to European context through ITS-G5 standard [11]. According to the usages, ITS-G5 divides the band into three sub-bands ITS-G5A, ITS-G5B, and ITS-G5C, where 1 control channel (CC) and 5 service channels (SCs) are defined. The control channel, G5CC, is dedicated to road safety and traffic efficiency applications. It can also be used for ITS service announcements. The service channels G5SC1 and G5SC2 are for road safety and traffic efficiency applications. Finally, the service channels G5SC3, G5SC4, and G5SC5 are dedicated to other ITS user applications. All ITS-G5 stations (STAs) operating on ITS-G5A and ITS-G5B are treated equally disregard whether they are mobile or fixed. For operations in ITS-G5C, a distinction between mobile and fixed STAs is made for spectrum management based on distributed frequency selection (DFS) [11].

TABLE II
ITS-G5 CHANNEL ALLOCATION

Sub-bands	Channel type	Centre frequency	Channel number
ITS-G5A	G5CC	5900 MHz	180
ITS-G5A	G5SC2	5890 MHz	178
ITS-G5A	G5SC1	5880 MHz	176
ITS-G5B	G5SC3	5870 MHz	174
ITS-G5B	G5SC4	5860 MHz	172
ITS-G5C	G5SC5	5470 to 5425 MHz	

III. SYSTEM DESCRIPTION

We carried our research based on real world experimental testings using a multimodal communication device, Laguna [5]. Laguna is an all-in-one solution conceived for the design, integration and testing of communication protocols and solutions compliant with the latest development of vehicle and infrastructure communications worldwide. Laguna natively supports ITS communication architectures and standards developed by the joint efforts of ISO, CEN, ETSI and the IEEE. It aims at delivering services for hassle free implementation of experimental V2V, V2R and V2C communication scenarios, and as such, is an invaluable tool for test site development. The Laguna platform complies with the latest standardized ITS Station Architecture, which builds on top of the ISO CALM standards family. The platform delivers reference ITS architecture functionalities for personal, vehicle, roadside and central ITS sub-systems.

A. *Hardware Description*

Laguna multimodal communication device has integrated GPS receiver, two IEEE 802.11p ETSI G5 communication modules, which enables simultaneous communication on up to 2 DSRC channels. The device can also be equipped with a 3G communication module and with IEEE 802.11 a/b/g/n modules. Fig. 4 shows the RSU and vehicle rooftop antennas.

Fig. 3. Laguna multimodal communication device

(a) Vehicle rooftop antenna

(b) RSU antenna

Fig. 4. Vehicle rooftop and RSU antennas

B. *Software Description*

The Laguna ITS software stack builds on top of the latest ITSSv6 software distribution, by integrating and consolidating the latest results from other ITS projects such as CVIS, GeoNet, while keeping the platform open for any 3rd party development efforts. The software includes an IPv6 ready networking stack, enhanced by the latest security and mobility features provided by members of the Mobile IPv6 protocol family (MIPv6), *i.e.*, Network Mobility (NEMO) [12], Multiple Care-Of Address (MCoA) [13] and secured by IPsec IKEv2 [14].

IV. Experimentation

We conducted field tests using an Access Router (AR, Roadside Unit) and a Mobile Router (MR, Vehicle), which are equipped with Laguna multimodal communication device. The experiments are carried out on appx. 1.6 km line of sight straight road at Satory, Versailles test site. Fig. 5 shows a snapshot of the fields tests and Fig. 6 illustrates the road scenario and the positioning of the AR. As Fig. 6 shows, the vehicle runs from the start point to the end point at a given speed and communicates with the AR which is fixed at 400 meters from the start point. Assuming a traffic efficiency application, such as contextual speed limit notification, the AR is set up to periodically broadcast packets. The packet reception performance is then measured at the MR. In the test, we paid more attention on the impacts of the receiving signal quality (RSSI), the data rate, the distance between the MR and the AR, and the speed of the vehicle.

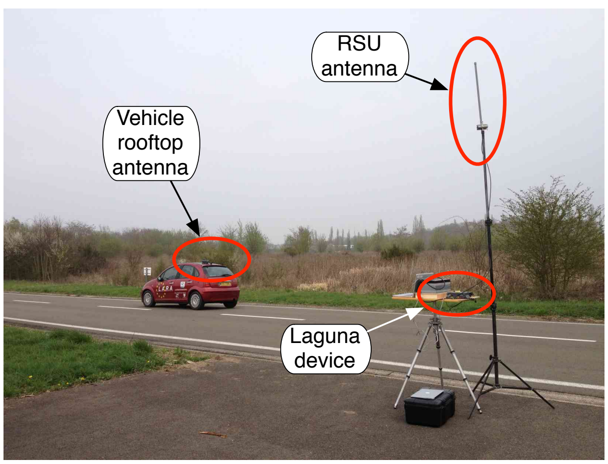


Fig. 5. A snapshot of the experimental testing

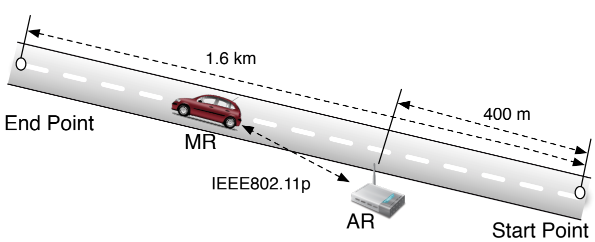


Fig. 6. Road scenario

The parameters settings is shown in Table III. Using the Iperf[1] tool, the AR could generate IPv6 link-local multicast packets that contain UDP frame with 200 Bytes of message. To get results of packet delivery ratio (PDR) and RSSI, we dumped packets from a monitor interface which has the capability to get MAC layer parameters (*e.g.* RSSI, frequency, data rate) on the MR. Besides, results were gathered at 1 second intervals.

[1]http://iperf.sourceforge.net

TABLE III
Experimental setup

Parameters	Description/Setting
Road length	1.6 km
Antenna height	3 m for AR, 1.5 m for MR
Speed	20, 40, 60, 80 km/h
Transmission power	24 dBm
Data rate	3, 12, 27 Mbps
Message generation rate	2 Mbps
Message size	200 Bytes

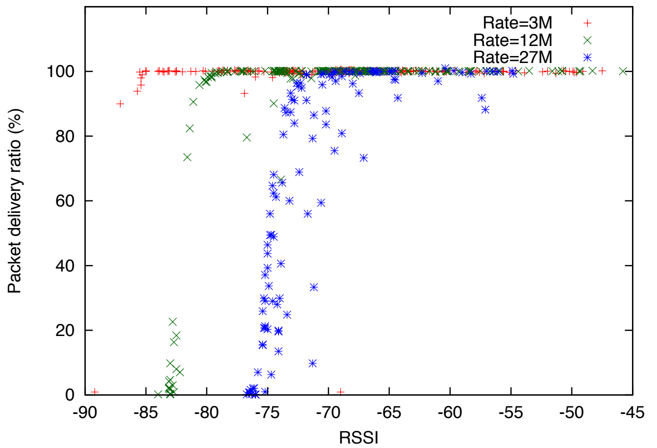
A. Results

Fig. 7 shows PDR performance for the case when the vehicle's speed is 20 km/h. As it can be seen in Fig. 7(a), the PDR performance sharply degrades when RSSI is below appx. -70, -80, -85 dBm for 27, 12, 3 Mbps data rate, respectively. An interesting point to be observed is that the larger the data rate, the more the PDR deviates from the average value. This characteristic is even clearer in Fig. 7(b), which shows the relation between PDR and the distance. The insights we achieved from the results are as follows: There is no doubt that in order to achieve stable communications, especially if the vehicle(s) is far from the AR, a use of a low data rate is required. However, when the vehicle is close to the AR, a high data rate can be used with a support of a technique that takes advantage of *e.g.*, path diversity. The latter is maybe preferable for applications *e.g.*, in which moving vehicles need to download a large amount of data preferably in a short amount of time.

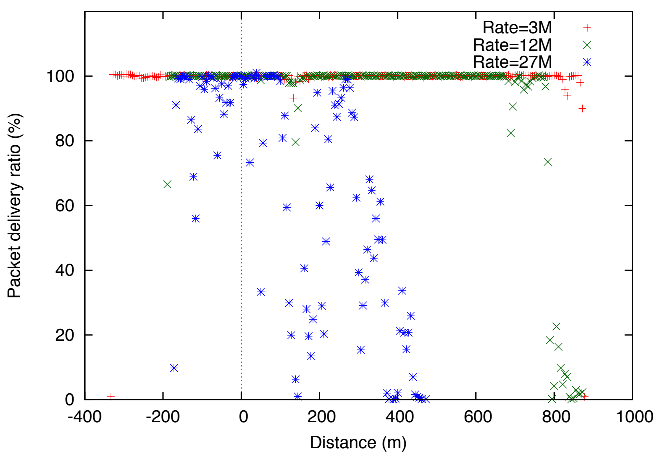
Fig. 8 shows PDR performance for different speed of the vehicle. Although the impact of the speed is not as drastic as that of data rate, we can obverse, especially in Fig. 8(a) (where data rate is fixed to 3 Mbps), the random performance degradation for higher speed. Apparently the reason behind is the doppler shift. However, the impact of the doppler shift is more difficult to see if a higher data rate is used (Fig. 8(b)). Conceivably, this is because the data rate has a dominant impact compared to the doppler shift.

B. Discussion and Future Work

Enabling a sufficient communications quality, especially in terms of throughput, has always been the main objective of communications technologies. Additionally, in IPv6 communications, due to the control overhead and increased latency, frequent handovers are often not desirable. As our results show, it is possible to maintain stable communications between a MR and an AR for longer than one kilometer of distance in line of sight scenario using a combination of a high power and a low data rate. Moreover, such a combination of power and data rate is yet preferred for highly mobile scenarios (vehicles are running at a high speed). However such a setting of power and data rate might be undesirable for

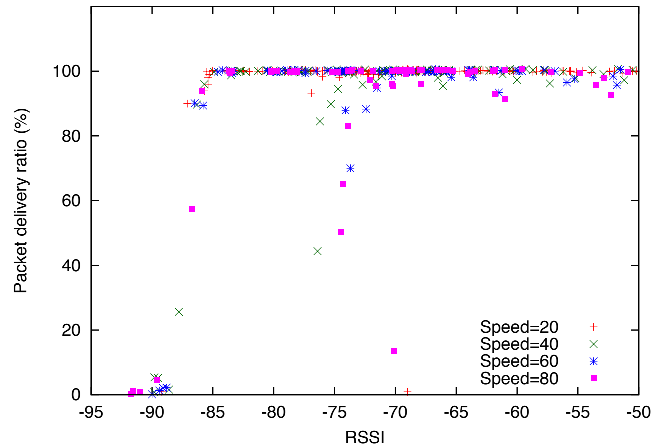


(a) PDR vs RSSI

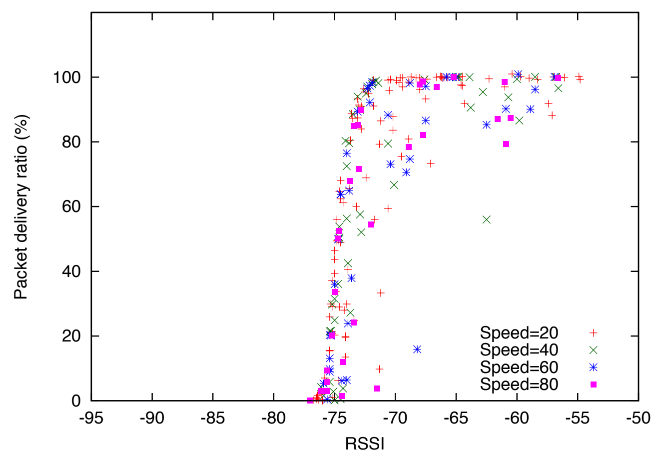


(b) PDR vs Distance

Fig. 7. Impact of RSSI, distance, and data rate (velocity: 20 km/h)



(a) Data rate: 3 Mbps



(b) Data rate: 27 Mbps

Fig. 8. The impact of vehicle's speed

throughput improvement, since low data rate directly results in low throughput and high transmission power results in a large amount of interference, which can hamper the total throughput of the network. Therefore, in our future work, we will make further investigations targeting more challenging radio and networking scenarios. Then based on our investigations, we intend to design intelligent power, data rate, and handover algorithms for IPv6 communications over IEEE 802.11p.

V. Conclusions

IPv6 is at the heart of enabling convergence of V2V, V2I, and V2C over diverse communications media including DSRC, 3G, WiMAX, and Wi-Fi for cooperative ITS. With a motivation of developing cooperative ITS, we have been conducting field tests to study the radio performances of wireless media and their impacts on the performance of IPv6 communication. This paper introduces some of the experimentations on IEEE 802.11p using a multimodal communication device, Laguna. The results reveal that a use of low data rate is referred for stable and long-range communications. If the application requires communications at high data rate, some efforts need to be made to improve the performance of communications taken at high data rates. The results also show that communications can be negatively affected by the doppler shift but the impact is less drastic compared to that of data rate if the relative speed is up to 80 km/h. Our future work includes additional field tests targeting more challenging road scenarios including tunnels, and designing intelligent power, rate, and handover algorithms for seamless IPv6 communications by taking account the application requirements and the road scenario.

Acknowledgment

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