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Visible light communications as a complementary technology for the internet of vehicles

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ABSTRACT

The paradigm of connected vehicles is moving from research to implementation, thus enabling new applications that start from safety improvement and widen to the so called Internet of vehicles (IoV). The candidate enabling technologies in the radio frequency (RF) bands are cellular and short range technologies. However, the limited bandwidth shared among several applications pushes researchers to look at new technological solutions. To this end, an option is provided by visible light communication (VLC). Based on the use of the light emission diodes (LEDs) that are already available on the majority of vehicles, VLC would enable short range communication in large, unlicensed, and uncongested bands with limited costs. In this work we first highlight the main properties of VLC in vehicular networks and revise the state of the art focusing on both the IEEE 802.15.7 standard and on the performance demonstrated by field tests that have been conducted worldwide. Then, we discuss the limitations of using VLC for pure vehicular visible light networks (VVLNs) and its application as complementary technology, to be implemented with other wireless standards in future heterogeneous vehicular networks. Finally, we show numerical results provided by simulations in a realistic urban scenario focusing, as a case study, on the crowd sensing vehicular network application with VLC added to short range IEEE 802.11p technology. Results demonstrate that the addition of VLC improves the performance of a conventional vehicular network based only on IEEE 802.11p.

1. Introduction

In the next few years, connected vehicles will travel on the roads exchanging information one with each other and with the infrastructure; the collaboration will permit safer travels, more efficient traffic management, and new services for drivers and passengers. The first steps towards this horizon are being taken in many Countries around the World. In the United States US, it is August 2014, when the National Highway Traffic Safety Administration NHTSA, one of the main agencies in the field of transportation, issues an Advance Notice to proceed with standardization of vehicle to vehicle communication for light vehicles [1]. This means that new vehicles in the US will soon be equipped with the WAVE protocol suite for short range communications, based on IEEE 802.11p at the lower levels of the protocol stack [2,3] and using the dedicated short-range communications DSRC frequency bands.

In the European Union EU, even if there is still no mandate from governments, important activities are being carried out. In particular, the so called Release 1 of the set of standards for cooperative intelligence transport systems (C-ITS) was issued in February 2014 by the European Committee for Standardization (CEN) and the European Telecommunications Standards Institute (ETSI) [4]. Differently from US, various technologies are envisioned as enabler of connected vehicles, and particular attention is being posed on cellular technologies. In the EU, the long term evolution LTE technology can thus be considered as another key enabler of connected vehicles [5,6].

The availability of wireless communications will enable the creation of vehicular networks with a wide range of new applications [7–11]. Great attention is obviously devoted to safety improvement, thanks to neighbor discovery and tracking and the immediate warning of critical events, like accidents in the proximity. In addition, connected vehicles will also form, with fixed road side units RSUs as gateways, the so called Internet of vehicles (IoV), with other data services that include traffic management improvement or entertainment applications.

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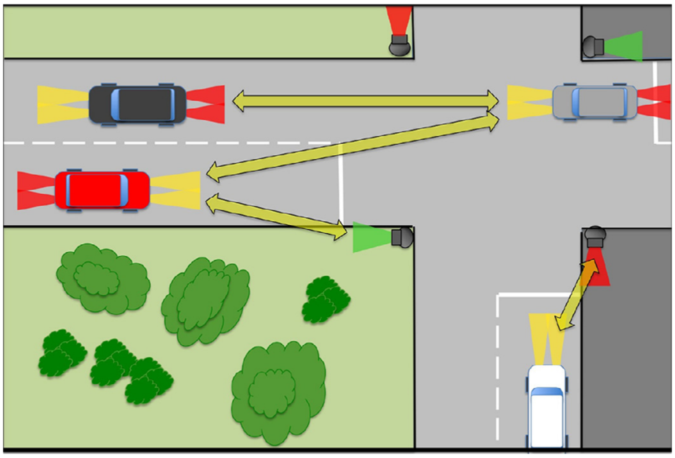

Fig. 1. Vehicular visible light networks.

Whereas presently the fight is tackled in the radio frequency RF band, with short range communications (with the IEEE 802.11p standard in the DSRC band) and cellular communications (mainly focusing on LTE), a new option is keeping the attention of researchers and engineers: visible light communication VLC. VLC exploits the low cost and high efficient light emitting diodes LEDs used for illumination purposes to also provide wireless communications.

The enormous spread of the LEDs and its huge communication potential, led in fact VLC to the introduction in the family of standards for wireless communications, by 2011, in the IEEE 802.15.7 specifications [12]. Exploiting the already mounting LED lights, VLC could be used in several application scenarios (such as underwater communications [13] or localization and tracking [14]), and also vehicles could be connected to each other to create the so called VVLNs (a.k.a. V^2LC networks [15]), as represented in Fig. 1.

Differently from RF, the visible light spectrum offers large portions of unlicensed and uncongested bands. In addition to the potentially high throughput guaranteed by the low congested frequencies, the large bandwidth, and the optimal spatial reuse, VLC is also characterized by a high directivity and a predictable channel; these aspects allow high accurate neighbors positioning without use of other technologies [16], reduce the sources of interference [17], and guarantee a high security level due to the inherently reserved channels [18,19].

The high directivity also implies, however, the need for almost clear line of sight that limits the use of VLC to the applications where no obstacles must be overtaken and only single or multiple hops between vehicles that are traveling on the same road are needed. Besides pure VVLNs, anyway, VLC can be foreseen in heterogenous vehicular networks as an addition to the RF technologies to increase the overall capacity.

The scope of this paper is thus to introduce the paradigm of VVLNs and to highlight the improvement allowed by its integration in future heterogenous vehicular networks. To this aim, results are shown focusing on the example application of CSVNs, where data collected by sensors on board of vehicles are delivered through single or multiple hops to RSUs, which act as gateways towards a remote control center. The strategies for the selection of the technology to be used is also discussed and a congestion-adaptive algorithm is proposed.

The paper is organized as follows: in Section 2, the peculiarities of VLC applied to vehicular networks, the IEEE 802.15.7 specifications that focus on VLC, and the performance demonstrated in vehicular networks by real testbeds around the world are discussed; Section 3 focuses on the use of VLC as a single technology or as a complementary technology in heterogenous vehicular networks; in Section 4 the adaptive algorithm for the technology selection is proposed and numerical results are provided; finally, in Section 5 the conclusion is drawn.

2. Vehicular visible light networks

In this section we provide an overview of the VLC technology applied to vehicular networks; after highlighting its peculiarities, the present state of the art is discussed focusing on standardization and real experimentations.

2.1. VLC peculiarities

VLC significantly differs from the reference DSRC and LTE technologies in many aspects, including the use of unlicensed and uncongested frequencies, lower coverage and high directivity, and reuse of devices that are already deployed for other scopes. These characteristics are hereafter discussed in details and summarized in Table 1.

Unlicensed and uncongested bands. One of the main advantages of VLC is that it uses an unlicensed and uncongested bandwidth, located between 380 and 800 THz. It is known that DSRC bands around 5.9 GHz have been reserved to the short range use in vehicular networks in most Countries worldwide; however, there are strong concerns and long discussions about what happens when the small number of channels provided by DSRC are used by hundreds of vehicles under congested conditions [20–22]. This issue is also present with reference to LTE, with possible hundreds of vehicles sharing resources of a single cell [23,24]. In the case of cellular networks, there is also the additional aspect of the participation of a telecom operator, with issues on who would undertake the operating costs.

Short range, high directivity and need for line of sight. The range of VLC in vehicular scenarios obtained in today experiments is in the order of the tens of meters [16,25,26]. These ranges are significantly smaller than those obtainable with DSRC and will never enable the ubiquitous coverage of cellular systems. Compared to RF technologies, VLC propagation is also more sensible to rain and fog, and even the sun position can influence the performance [15]. Furthermore, other aspects make VLC very different from the other technologies: the high directivity and low penetration capabilities. These characteristics, on the one hand require that nodes are well aligned and without obstacles in between, but on the other hand imply low interference from neighboring devices and thus lead to high spatial reuse. In addition, these peculiarities also permit high accurate positioning [16] and highly secure communications [18,19]. An interesting advantage, which is a direct consequence of the high directivity, is also that full-duplex communication with concurrent transmissions in the two directions are easily achieved in VVLN, as shown for example in [15,27]. The full duplex capability also makes the receiver able to provide an acknowledgment during the transmission, enabling a collision detection mechanism. Differently, full duplex transmissions are still a hard task for researchers in the case of RF [28,29].

Use of available LEDs as transmitters. LEDs are already available on new vehicles and they are natural transmitters for VLC. This differs from RF technologies, where optimized antenna systems [30] must be designed and implemented. Concerning the VLC receivers, various options are possible. In fact, whereas photodiodes are the most obvious solution, also LEDs themselves or cameras can be used. The use of LEDs as receivers reduces the necessity of additional components and makes the system more robust against interference from external sources (sun, lampposts) due to a narrower operational bandwidth [27]. Cameras appear instead the best option in terms of achievable throughput, which is significantly increased at the cost of an higher expense [16,26,31].