Challenges and Opportunities of VLC Application in Intelligent Transportation Systems

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INTRODUCTION

Visible Light Communication (VLC) is a developing wireless communication technology, which uses visible light (380 - 780 nm) for data transmission. It offers significantly greater bandwidth compared to the radio frequency (RF) communications. VLC exploits the low-cost and highly efficient Light-emitting Diodes (LEDs) used for both illumination purposes and wireless communications. LEDs are characterized by numerous advantages, including long lifespan, compact form factor, reduced usage of harmful materials in design and low heat generation even after long period of usage. Another important benefit of LEDs is the capability of switching to different light intensity levels (undetectable to human eyes). Furthermore, VLC is safe for human health and it does not affect the functionality of the sensitive electronic systems. It is also characterized by a high directivity and a predictable channel, which reduces the sources of interference and a high-security level is guaranteed due to the inherently reserved channels. These benefits make VLC a very promising technology for numerous applications. However, the high directivity requires the existence of the Line-of-Sight (LOS), which limits the use of VLC. Relative mobility in establishing communication links between vehicles or between vehicles and infrastructure can disrupt LOS. In addition, natural and artificial light also degrades performances of the VLC systems, especially the sunlight which adds noise and interference in the channel.

VLC enables wireless communications with high data rates wherever there is artificial lighting, indoor and outdoor. Thus, VLC has great potentials in vehicular communication applications. It can easily be incorporated into Intelligent Transportation Systems (ITS). The aim of ITS is to increase safety, the efficiency of the transportation system and to reduce the gasses emissions. Numerous studies show that VLC can satisfy the requirements imposed on vehicular networks. Various modes of vehicular communication can be established: Vehicle-to-Infrastructure (V2I), Vehicle-to-Vehicle (V2V) and Infrastructure-to-Vehicle (I2V). Considering the communications between infrastructure and vehicles, and vice versa, most of the existing systems are oriented towards the communication between LED-based traffic lights or street lighting system and vehicles. The high power of traffic lights allows relatively long communication distances. On the other hand, the short distance between the street light and vehicle, along with the high power implied, assures high data rates and increases the communication stability. Based on the LED lighting systems integrated into vehicles in headlamps, brake lights or signal lights, the VLC communication between vehicles is enabled. Besides communication, VLC enables positioning superior to the Global Positioning System (GPS) with lower costs than existing systems. In this chapter, the

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comprehensive analysis of VLC technology and applications in ITS are provided. Main characteristics of VLC in ITS in terms of architecture, modulation and standardization are analyzed. Benefits and possible challenges of VLC application in ITS scenarios are also addressed.

BACKGROUND

Transportation systems play an important role in modern life. The advancements in communication technologies and their application in transportation systems have led to the introduction of the concept of Intelligent Transportation Systems (ITS). A subset of the ITS, in which participants communicate and share information is called Cooperative Intelligent Transportation Systems (C-ITS).C-ITS aims at improving safety, sustainability and efficiency. C-ITS consists of the following four entities: personal, vehicle, central and roadside (ETSI EN 302 655 v.1.1.1, 2010). Personal entity enables access to ITS applications using personal devices, such as Smartphone with location-based applications. Vehicle entity consists of the vehicle on-board equipment (on-board unit, OBU) which hosts ITS applications. These vehicular ITS applications gather information about the vehicle and its environment and provide partial or full control over the vehicle in critical situations. Central entity comprises the equipment used to maintain, monitor and provide functionality to ITS applications. Finally, roadside entity, also referred to as Roadside unit (RSU), provide the equipment placed along the roadside which hosts ITS applications. The roadside ITS applications communicate with the vehicular ITS sub-systems together information about road environment, traffic conditions and control roadside equipment. A Multi-tier ITS architecture is proposed by Lin, Wang and Ma (2017). This structure provides guarantees in terms of interconnection, operation and service. It consists of the physical layer, the communication layer, the operation layer and service layer. Physical layer comprises vehicles, infrastructure and end users. Communication layer enables data transmission between ITS elements. Communication options provided by the communication layer include Field-Vehicle Communications (communications between vehicles and infrastructure), Fixed Point-Fixed Point Communications (communications between stationary entities), Vehicle-Vehicle Communications (short-range communications between vehicles) and Wide Area Wireless (Mobile) Communications (communication between vehicles and end user mobile devices). In general, ITS applications rely on Vehicle-to-Infrastructure (V2I), Vehicle-to-Vehicle (V2V) and Infrastructure-to-Vehicle (I2V) communications. There are three main classes of ITS applications: Road/Traffic Safety, Traffic Efficiency and Value-added applications (ETSI EN 302 655 v.1.1.1, 2010). Traffic safety applications aim at minimizing the risk of undesirable situations and reducing the damage of unavoidable accidents. The improvement of traffic conditions (in terms of travel time and traffic congestion) is a primary goal of traffic efficiency applications. Traffic information is usually gathered by roadside infrastructure and transmitted to the user. Value-added applications include providing Internet access, travel information and planning. The goals of these applications are comfort and convenience for the end users.

ITS involves cooperative wireless communication technologies to provide data exchange between vehicles or between vehicles and infrastructure. Current ITS research activities, products and standardization are mainly based on radio frequency (RF) communication technologies. Due to numerous advantages, VLC is considered as a promising candidate technology for vehicular communications (Khan, 2017). The primary advantage of VLC is the possibility of deployment in vehicular environments using existing infrastructure, which makes VLC a low complexity and low-cost technology. Highly directional Line-of-Sight (LOS) enables positioning with high precision. The positioning error is up to tens of centimetres, which is more accurate than the RF-based positioning technology (Armstrong, Sekercioglu