UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

THE SIXTH INTERNATIONAL CONFERENCE
TRANSPORT AND LOGISTICS

til 2017

VISIBLE LIGHT COMMUNICATION AS A SEGMENT OF THE INTELLIGENT TRANSPORTATION SYSTEMS

Aleksandra KOSTIĆ-LJUBISAVLJEVIĆ
Vesna RADONJIĆ ĐOGATOVIĆ
Branka MIKAVICA

University of Belgrade,
Faculty of Transport and Traffic Engineering

Abstract

Permanent improvement of the safety and efficiency of the transportation systems is necessary. Along with the individual safety mechanisms in the vehicle, there is a strong requirement for a complex system in which all the components contribute to the safety of the entire transportation system. With the advancement of Light Emitting Diodes (LEDs), Visible Light Communication (VLC) becomes an alternative to other existing wireless technologies in Inteligent Transportation Systems (ITS). VLC is a promising, cost-effective technology with a potential of large scale acceptibility.

Key words*: Visible Light Communication (VLC), Intelligent transportation system (ITS), vehicle-to-vehicle (V2V), infrastructure-to-vehicle (I2V) communication, light-emitting diode (LED)*

1 INTRODUCTION

The number of the vehicles using transportation infrastructure is continuously growing. Inteligent Transportation Systems (ITS) integrates different technologies in order to increase safety, efficiency of the transportation system and to reduce the gasses emissions, as well. Cooperation between vehicles themselves or with a road infrastructure is necessary in the heavy traffic density on highways or in city. In order to improve transport performances, specially safety, various modes of vehicular communication are considered: vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V) and infrastructure-to-vehicle [1]. The key role in ITS, as means of transmiting important traffic information, can achieve Visible Light Communication Systems (VLC).

This paper is organised as follows. After the introduction, in second section of this paper, some key features of VLC technology are presented. Third section presents possible VLC applications in Inteligent Transportation Systems. At the end of this paper, the concluding remarks are given.

2 KEY FEATURES OF VLC

Visible light communication is a developing wireless communication technology, which uses white or coloured LEDs in order to provide information through visible light as the communication medium. VLC transmits data using all the frequencies between 400 THz (750 nm) and 800 THz (375 nm) by intensity modulating the light sources faster than the pertinacity of the human eye. Recently, LEDs improvements in switching rates and brightness, as well as large scale diffusion, have led to great interest of researchers. Visible light has become a new communication medium which can be used to alleviate congestion in radio spectrum.

In some aspects VLC can be considered to be relative to infrared (IR) optical wireless communication (OWC). It had a slow but constant evolution during the last century. The infrared light is used in our daily life (for example, for the remote control of electronic domestic devices). However, until now, IR wireless communication has not evolved into broader scope as dependable alternative for broadband access networks and it remains less important compare to short range RF based technologies, such as Bluetooth [2].

VLC is without a doubt a subset of Optical wireless communication (OWC) that has become a separate technology because, in this case, the signal carrier can be seen by the human eye. While traditionally OWC has been concerned just with communications, VLC provides both illumination and communication. On the other hand, VLC systems must operate through illuminating devices with eye safety constraints and they also should be able to provide communication even when the illuminating light is dimmed or turned off.

The importance of potential use of the same device for simultaneous data transmission and illumination can be primely reflected through reusing the power and money already invested in providing illumination for facilitating high-data-rate communication between light sources and users. LED luminaries could act as network access points, making VLC to become a direct competitor to broadband radio technologies such as WiFi, fourth/fifth generation (4G/5G) systems and WiGig. The Visible light spectrum is unlicensed and has a great potential for communications since it is currently mostly unused for that purpose. The availability of this free spectrum creates an opportunity for low-cost broadband. Although, indoor hybrid systems, which comprises RF technology and VLC links, in which directional broadcast VLC channels are exploited to supplement conventional RF channels, there are still no estimated solutions for the seamless integration of VLC with conventional wireless networks. The design of VLC systems remains a challenge, because of new possibilities as well as the potential problems regarding systems applications.

The most important VLC features are: Line of Sight (LoS), unlicensed spectrum, healthy, absence of electromagnetic interference, security, high spatial reuse and ubiquitous computing [2].

LoS is a major issue for establishing an optical link between the transmitter and the receiver. It is particularly important in case of devices mobility or obstacles moving between transmitter and receiver that can disrupt communications, as well as in situations when natural and artificial lights add noise and interference to the channel. In addition, outdoor applications are affected by bad weather conditions such as rain, snow, fog etc.

Visible light covers huge unrestricted spectrum (400 THz wide) available worldwide, in contrary to infrared light (IR) or radio frequency (R/F) technologies, which are limited by law and limited in band, because many R/F frequencies are restricted for special applications, such as military, aircraft, etc. Unlike radio waves which are concerned to be dangerous to human body and infrared light which can be harmful to human eyes, visible light is completely safe for human health which allows transmission with high power.
VLC is resistant to electromagnetic noise and does not cause electrosmog, which makes it applicable in places where radio waves cannot be used, such as hospitals and areas around precision machines. Since visible light communication requires LoS, it does not penetrate through walls, thus limiting communication, contrary to radio frequencies. This characteristic can be useful for applications which need high level of security. Traditional wireless technology can hardly cope with situations where many devices compete for wireless medium access, which results in degraded performances. Since VLC is high directional, a single optical link could for example come from a lamp in the ceiling pointing directly to the floor, so that only a few users share the link. In that case spacial reuse allows accommodating larger number of VLC devices without interference, as in a case of using wireless technologies.

VLC can be used as a communications medium for ubiquitous computing, because light producing devices, such as indoor/outdoor lamps, commercial displays, traffic lights and other similar devices are used everywhere.
A typical VLC architecture, as shown in Fig. 1, consist of transmitter entities (TX) and receiver entities (RX), connected by modulated visible light. These entities can be end devices such as mobile personal devices, vehicles, and infrastructure lights. The VLC transmitter is an optoelectronic transducer that transmits information using visible light as the physical transmission medium. Usually high brightness LEDs are used. LEDs are modulated at such high frequencies that human eye cannot perceive any difference in lighting compared to that when there is not modulation. As a result, VLC transmitters can be used for lighting and data communication simultaneously. The VLC receiver can be composed of PIN or avalanche photodiode or CMOS sensor that receives information. Information that has been previously modulated in the visible light spectrum is then (at receiver end of the VLC link) converted into electrical signals that can be processed by a demodulator/decoder [2].

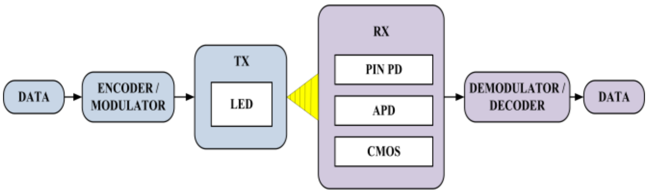

***Fig. 1** VLC Architecture*

There are three basic types of topologies that are possible for the VLC link: directed Line-of-Sight (LOS), non-directed LOS, diffused non-LOS, as shown in Fig. 2. The directed LOS allows the highest intensity of the received signal and thus it can achieve highest bitrate and the longest distance. These performances are obtained at the expense of strict demand of precise alignment. In the non-directed LOS the receiver has a wider field of view, the alignment is simpler, but the intensity of the signal is at medium level. Major consequence of this is that shorter distances are achievable together with high or medium bitrate. The diffuse non-LOS shows the lowest bitrate since it has no alignment issues, but it is suitable only in indoor applications.

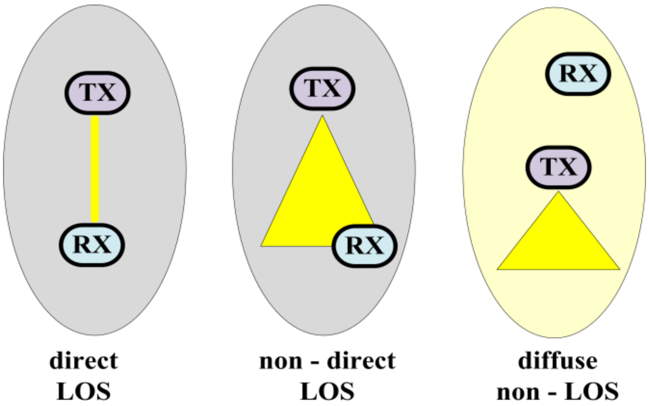

***Fig. 2.** Possible topologies of the VLC link*

VLC technology is promising solution for numerous LED based applications. Since radio frequencies can potentially influence aircraft safety, and LED-based cabin lights in airplans are already used, each of these lights could be VLC transmitters and thus provide both illumination and communication services for passengers. In addition, this can reduce the aircraft construction costs and its weight [3].
VLC could also enable indoor as well as improve city navigation where GPS signaling is weak or nonexistent due to position of very high buildings. Due to the simplicity of its front-end hardware, it can play a significant role in enabling the Internet of Things and machine-to-machine communications in general. Smart lighting with VLC provides the infrastructure for both lighting and communication and reduces the energy consumption. Other possible areas that stand to benefit from the practical implementation of VLC include museums, hospitals, and underwater communications. Museums could exploit the already present light fixtures to not only illuminate their exposition pieces, but also continuously transmit information about them. Hospitals could achieve ubiquitous networking without any detriment to equipment that is

sensitive to RF radiation. This should improve hospital care and reduce staff workload. Underwater communications stand likely to benefit most. RF and ultrasound communication are unable to provide fast wireless connectivity under water. Although VLC will also face challenges in that particular propagation environment, it should deliver significant data rate improvements when conditions allow, and otherwise fall back to existing technology to provide basic connectivity [4].

3 VLC in ITS

According to European Telecommunications Standards Institute (ETSI), Intelligent Transport Systems are systems to support transportation of goods and humans with information and communication technologies in order to efficiently and safely use the transport infrastructure and transport means (cars, trains, planes, ships). Elements of ITS are standardized in various standardisation organisations, both on an international level at e.g. ISO TC204, and on regional levels, e.g. in Europe at ETSI TC ITS and at CEN TC278. The term ITS communications (ITSC) denotes communications protocols, related management and additional functionality. ITS communication is a new type of communication system dedicated to transportation scenarios, e.g. as illustrated in Fig 3. ITSC is to a large extent independent from specific communication technologies and specific ITS applications. The ITSC architecture is intended to be an open systems architecture, i.e. an architecture that is open and not proprietary [5].
ITS applications make use of wireless communications: communications between mobile ITS stations (vehicles), and between mobile ITS stations and fixed ITS stations (roadside installations), with single-hops or multiple hops between the source and destination ITS stations; access to public and private (local) networks including the global Internet; and Infrastructure and satellite broadcast. ITSC is based on two domains: ITS domain and Generic domain. "ITS domain" refers to all elements of ITSC which are specified in ITS/ITSC standards. "Generic domain" refers to other elements used for ITS/ITSC. Data available from vehicles and road side units (RSU) can be either utilized locally in the boundary of a geolocalized network or transmitted to a server for central processing.

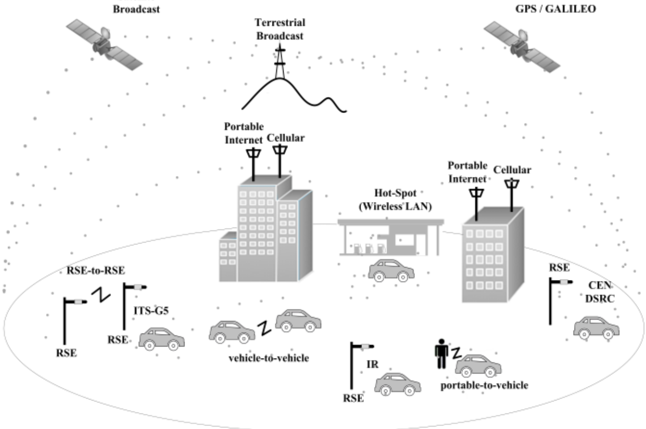

Fig. 3. *Ilustration of ITSC*

These data can be used to detect events such as traffic accidents, road works, traffic jam, approaching emergency vehicle, etc. Such data are processed in order to produce driving recommendation dedicated to a single or a specific group of drivers and transmitted wirelessly to vehicles [2].

Vehicle-to-vehicle communications may be one of the first implementation scenarios as manufacturers are beginning to make a move toward solid-state lighting solutions. Given that traffic lights and many vehicles use LED-based lights, the possible application is that vehicles are able to communicate with each other in order to prevent accidents. Also traffic lights can send information to the car to ensure road safety.
It is well known fact that wireless communication has been identified as essential technology supporting ITS. With the advancement of LED, VLC becomes an alternative to other existing wireless technologies in ITS. The LEDs outperform the classical lighting sources in terms of energy efficiency, reliability and life-time. In order to utilize numerous advantages of LEDs, the automotive industry had begun to replace the halogen lamps by LED lighting systems. LED-based VLC systems can be deployed in ITS using existing infrastructure, such as LED-based traffic lights. These new traffic lights are characterized by low maintanance costs, long life-time, low energy consumption and better visibility. Therefore, road illumination will be able to provide communication possibilities, as well. VLC systems enable broadcasting of information related to safety traffic, thus supporting reduction of road accidents and smoothing traffic flows. This is a promising, cost-effective technology with a potential of large scale acceptability [6].
In this broad and more general framework it can be identified a number of applications where the unique characteristics of VLC systems can be exploited in more effective ways as compared to traditional radio frequency technology. However, it is worth emphasizing that compared to the mature RF based technology, VLC is still in the introductory phase and substantial efforts are needed before it can be widely deployed for short-range ITSs applications [2].
The combined lighting and switching feature of LEDs has a great innovative potential which will generate important applications [7]. For example LED-based traffic lights and vehicular VLC systems can become an integrated component of ITS and play a key role in road safety applications by broadcasting traffic information in advance to drivers running vehicles which will incorporate low cost VLC receivers, as shown in Fig. 4.
Traffic lights are gradually changing from electric light bulbs to LED lights because of their many advances energy

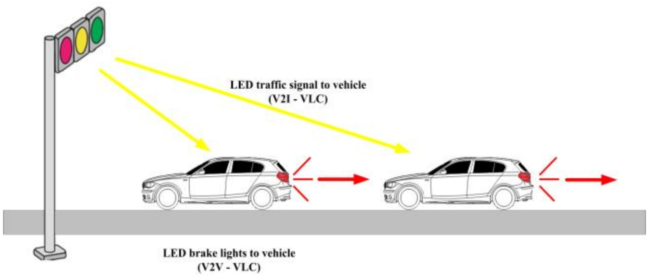

Fig. 4. *Example of I2V and V2V communication using VLC*

eficiency, long life, low maintenance cost, better visibility and low temperature production. These new lights have the potential to be used as transmitters, with signals transmitted by infrastructure lights and detected by receivers mounted in vehicles (I2V communications). RSUs such as LED-based traffic lights are appropriate for information broadcast in vehicular communication systems in I2V mode. Traffic safety related information can be continuously broadcasted without extra power usage, enhancing smooth traffic flow as well as reducing traffic accidents. Since light goes straight on, high directional communication is possible. That is specialy convenient for such applications that demand that different information has to be transmitted for every lane of a road. It is also possible for vehicles to exchange data with adjacent vehicles (V2V communication), using head, tail and brake lights. In a V2V scenario example, a vehicle in front of a traffic light receives the information and relays it using the brake lights to the vehicle running behind. From the perspective of the vehicular ad-hoc network, VLC can be seen as a new access channel. Potential applications of V2V systems are the same as those for RF channels, including active road safety, traffic efficiency, local services and Internet based services. Obviously the latency and reachability constraints for data exchanges are tighter for safety critical applications respect to the other kinds, but recent studies showed that they can be fitted by VLC also with off-the-shelf components.

VLC links used in outdoor environment depend on the existence of an uninterrupted line of sight (LOS), so high concentration of vehicles on the streets or highways would enlarge the number of links between vehicles. This could improve data flow since multiple paths become available as more vehicles get connected within optical links. On the other hand, in such a situation, RF communications are likely to get into performance issues due to broadcast storms, disrupting real-time safety-critical applications and signal propagation [7].

Outdoor mobile optical networks, like VLC based networks, have some technical issues and challenges: relative mobility between vehicles or between infrastructure and vehicles is likely to disrupt LOS links; VLC is largely affected by natural and artificial lights, mainly sun light, which adds noise and interference to the received signal. The first issue could be addressed by optimizing fixed and mobile (on vehicle) lighting positioning, while interference may be minimized by using optical filters and optimized electronics. However, these problems induce an effective limit on the communication range. Some of experimental results and simulations show that a reliable communication is possible when a VLC transmitter and a VLC receiver are no further than than 40–50 m [1].

Being a relatively modern technology, there are many challenges that VLC systems are currently facing. Apart from the nonlinearity and limits of LED bandwidth, aspects such as signal modulation, power delivery to the transceiver, and multiple access cause difficulties for the immediate increase of VLC applications. However, since such technical challenges have already been conquered in RF through decades of research, VLC is well equipped to go along a similar but much accelerated path. Furthermore, while the current large quantity and development of RF communications may delay the commercialization and standardization of VLC technologies, there is no doubt that VLC will be needed in future communications generations [4].

4 CONCLUSION

Integration of visible light communication systems in intelligent transportation systems architecture can play significant role in improvement of various transport and traffic features. Using unlicensed spectrum and existing and more implemented LED lightning (in infrastructure and also in vehicles) VLC can provide energy efficient, low cost and sufficiently high bitrate data flow.

ACKNOWLEDGMENT

The paper is a part of the research done within the project No. TR 32025 from the Ministry of Education, Science and Technological Development of Serbia.

REFERENCES

1. Kumar, N., Lourenco, N., Terra, D., Alves, L. N., Aguiar, R. L., 2012, *Visible Light Communications in Intelligent Transportation Systems*, Proc. Intelligent Vehicles Symposium, Alcala de Henares, Spain
2. Falcitelli, M., Pagano, P., 2016, *Visible Light Communication for Cooperative ITS*, Intelligent Transportation Systems, 52, pp. 19-47
3. Cailean, A., Cagneau, B., Chassagne, L., Topsu, S., Alayli, Y., Dimian, M., 2013, *A Robust System for Visible Light Communication*, Proc. IEEE 5th International Symposium on Wireless Vehicular Communications WiVeC, Dresden, Germany
4. Burchardt H., Serafimovski N., Tsonev D., Videv S., Haas H., *VLC: Beyond Point-to-Point Communication*, IEEE Communication Magazine, July 2014, pp.98-105.
5. Intelligent Transport Systems (ITS); Communications Architecture, 2010, ETSI EN 302 655 v.1.1.1. Available: http://www.etsi.org/deliver/etsi_en/302600_302699/302665/01.01.01_60/en_302665v010101p.pdf
6. Cailean, A., Cagneau, B., Chassagne, L., Topsu, S., Alayli, Y., Dimian, M., 2013, *Visible Light Communications Cooperative Architecture for the Intelligent Transportation System*, Proc. 20th IEEE Symposium on Communications and Vehicular Technology in the Benelux SCVT, Namur, Belgium
7. Luo, P., Ghassemlooy, Z., Le Minh, H., Bentley, E., Burton, A., Tang, X., 2014, *Fundamental Analysis of a Car to Car Visible Light Communication System*, Proc. 9th International Symposium on Communication Systems, Networks & Digital Sign CSNDSP, Manchester, United Kingdom

Contact address:
Branka Mikavica,
Univerzitet u Beogradu, Saobraćajni fakultet
11000 BEOGRAD
Vojvode Stepe 305
E-mail: b.mikavica@sf.bg.ac