PERFORMANCE EVALUATION OF V2LC SYSTEM USING LED TRAFFIC LIGHTS

Le Tung Hoa and Dang The Ngoc
Posts and Telecommunications Institute of Technology

Abstract— Vehicular visible light communication (V2LC) is a promising technology that enables intelligent transportation system (ITS). Recently, the classical light sources have been replaced by light emitting diodes (LEDs) on both vehicles and transportation infrastructure, such as traffic lights and road lights. Based on that fact, it makes easier and cheaper to apply V2LC on roads than any other technologies. In the paper, a LED traffic light is used to transmit data of the next road to vehicles. A two-lane one-way road is considered in order to calculate the values of signal-to-noise ratio (SNR), bit-error rate (BER) and throughput of vehicles at different positions on the road. We define a communication area where a vehicle can receive signal from the traffic light and then estimate the size of communication area based on BER.

Keywords— Vehicular visible light communication (V2LC), LED traffic light, communication area.

I. INTRODUCTION

Nowadays, road safety and traffic efficiency have concerned everyone because people have tended to spend more time in travelling. Consequently, a strong interest of the public, governments, industry exits to make vehicles safer and smarter. An intelligent transportation system (ITS), first introduced in 1980s, has been in response to this interest. To turn ITS into reality needs a wide variety of innovative technologies. And visible light communication (VLC) is the most promising key technology that plays an important role in a reliable component of data transmission for an ITS.

VLC is a technology that uses the visible light as a carrier to transfer data through wireless communications. VLC provides lots of advantages compared with the existing radio frequency (RF) [1]. Firstly, the visible light spectrum range doesn’t need to be registered while almost all RFs are controlled and provided by some organizations. Therefore, in the economy point of view, it is better to use VLC in order to reduce the cost of a system. Secondly, VLC is the electromagnetic spectrum that human eye can view. Therefore, VLC can be used for two purposes simultaneously that are lighting and transferring data. Furthermore, VLC, whose wavelengths are from 380 nm to 780 nm, offers around 1000 times greater bandwidth compared to the RF communications. It means that the wide available visible light spectrum enables any VLC systems to easily reach high data rates. Because of all above advantages, VLC has attracted lots of studies in both indoor and outdoor applications.

The opportunity of utilizing outdoor VLC for inter-vehicle or roadside-vehicle communication has been highly under consideration due to the trend of the lighting system and economical implementation of VLC on transportation system. Recently, the lighting industry has been replacing the classical light sources with light emitting diodes (LEDs). LEDs have high-quality characteristics of long-life, compact and low power consumption that is expected to be a future energy-saving light source. Therefore, LED-based vehicle lighting systems are popular in vehicle production. Moreover, most parts of the transportation infrastructure, such as traffic lights, road lights and traffic signs, also have changed to use LEDs. So, it is certain that LED-based lighting will be the important part of the transportation system, being installed in vehicles and also in the transportation infrastructure. The VLC technology will add LEDs more function besides lighting. In VLC, the data is transmitted into the instantaneous switching on-off LEDs, at speeds unperceivable by the human eye. In this case, the same LED system provides both illumination and data transmission [1]. The fact that a LED-based lighting system installed through all a road makes VLC implementation less complex and costly.

Recently, lots of papers have shown its attention to performance analysis of vehicular VLC systems. The authors in [2] researched a vehicular VLC system using road illumination. The shape of LED road illumination is introduced and then the system is evaluated by signal-to-noise ratio (SNR). On the other hand, the researchers in [3] implemented a vehicular VLC system using traffic lights. In [3], the design of service area is shaped by the decision of the vertical inclination and field of view of the receiver located in the center of vehicle’s front panel. Then, the service area is analyzed by SNR with different modulation schemes like on-off keying (OOK) and subcarrier binary shift keying (SC-BPSK). Moreover, in [4], the visible light vehicle-to-vehicle communication is taken into account. A 2×2 multiple-input multiple-output (MIMO) configuration from two lights in front and back

Corresponding author: Dang The Ngoc
Email: ngocdt@ptit.edu.vn
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of vehicle is utilized to maintain communication in some particular situations. The performance of the system is proved by average bit-error rate (BER) in different schemes of multiple-input single-output (MISO), single-input single-output (SISO) and MIMO. The work in [5] is slightly similar to [4] since, it also focused on vehicle-to-vehicle communication. However, the study in [5] implements headlamp beam on front of vehicle to transfer information through both light-of-sight (LOS) and non-light-of-sight (NLOS) links. The system BER performance is considered.

In summary, above-mentioned studies have taken some kinds of visible light communications for inter-vehicle or roadside-vehicle, but almost all are limited to calculate SNR and BER. However, the metrics of SNR and BER are not enough for evaluating the performance of vehicular visible light communication (V2LC) systems. Therefore, in this paper, we propose to determine the overall throughput of V2LC systems using the traffic light. Due to the fact that the traffic light cannot provide connection to the vehicles at every location, we define a communication area where a vehicle can receive signal from the traffic light and then estimate the size of communication area based on BER.

The rest of the paper is organized as follows. Section II introduces the system model. The performances of the given system will be analyzed in section III. Section IV demonstrates the numerical results and discussions. Finally, the study is summarized in Section V.

II. SYSTEM MODEL

The system model is divided in two main parts: (1) road model and transmitter-receiver model. The road model provides the specific road information, car position, car speed, and traffic road scheme. The following part concentrates on transmitter-receiver in terms of positions, modulation scheme and some important angle parameters.

TABLE 1. ROAD PARAMETERS

Distance in lane direction	x
Distance in width direction	y
Distance in height direction	z
Distance	d
Width of vehicle (m)	1.8
Width of lane (m)	3.5
Height of traffic light h_l (m)	5.3
Height of receiver h_r (m)	1.0

Firstly, our road model is a two-lane one-way road with a traffic light locating at the end of the road, which is an intersection. The width of a lane is 3.5 m. A three-dimensional space is applied on the road as shown in Fig. 1. In the space, the x-axis goes along the road, the y-axis shows the distance in the width direction and the z-axis points the height of attached position of transmitter or receiver. We assume that the traffic light is at the origin, the height of traffic h_l is 5.3 m. In the road, vehicles are the same in shape with 1.8 m width and they move at a constant velocity. A receiver is attached in the center of vehicle's front panel with the height of receiver h_r = 1.0 m. A vehicle on the first and second lanes locates in the position y = 0 m and y = 4.1 m, respectively. The traffic regime is assumed to be sparse, so that all vehicles always have LOS link between receivers and the LED traffic light as a transmitter. The specific road parameters are given in Table 1.

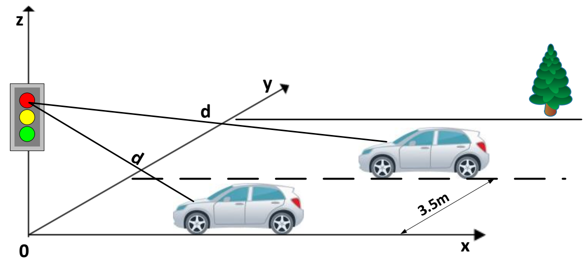

Fig 1. Road model.

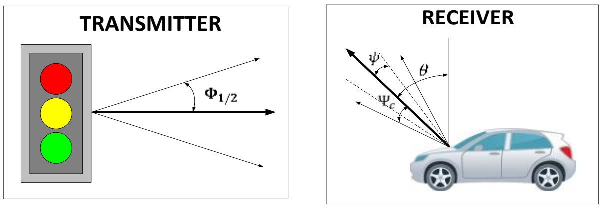

Fig 2. Transmitter and receiver in the system model.

According to Fig. 1, the distance d between the LED traffic light and the receiver at a vehicle is calculated as

$$d = \sqrt{x^2 + y^2 + (h_l - h_r)^2}\ . \qquad (1)$$

The second part explains in details of a transmitter and a receiver depicted in Fig. 2. In the system model, the transmitter is the traffic light and the receiver is PIN attached on each vehicle. At the LED traffic light, the optical signals are modulated by intensity modulations (IM) like OOK and SC-BPSK. In OOK modulation, ON-OFF keying is used with on-off alternatively while transferring bit "1" or "0". Besides, SC-BPSK utilizes subcarrier binary phase-shift keying in which the original data is modulated by a subcarrier and converted into optical intensity. Those IM schemes help to convey information by on-off LED at speeds unperceivable by the human eye. Loss of switching one color to the other color is ignored.

TABLE 2. TRANSMITTER AND RECEIVER PARAMETERS

Angle of irradiance	ϕ
Half-power semiangle	$\Phi_{1/2}$
Angle of incidence	ψ
Vertical inclination	θ
FOV of receiver	Ψ_c

All the parameters of the considering transmitter and receiver are given in Table 2. We assumed the light has the angle of irradiance ϕ and half-power semiangle of LED $\Phi_{1/2}$ is 15^0. At a receiver, there are three angles that are the vertical inclination θ, the field of view (FOV) Ψ_c, and the instant angle of incidence ψ. Based on the road model, we can calculate the instant angle of irradiance ϕ and angle of incidence ψ, respectively, as follows

$$\phi = \arccos\left(\frac{x}{y}\right)$$
$$\psi = \arccos\left(\frac{\sin\left(\theta + \arctan\left(\frac{h_l - h_r}{x}\right)\right)\sqrt{x^2 + \left(h_l - h_r\right)^2}}{d}\right). \quad (2)$$

III. PERFORMANCE ANALYSIS

This section is an in-depth introduction of LOS channel model and performance metrics such as the signal-to-noise ratio, BER, and throughput in the considering system.

A. LOS Channel Model

The traffic regime is assumed to be sparse enough to be able to have LOS links between receivers attached on vehicles and the transmitter, i.e., the LED traffic light. LEDs in traffic light are optical transmitters that follow the Lambertian model [6]. In the model, LED radiant intensity P_{tr} is given by

$$P_{tr}\left(\phi\right) = \frac{m+1}{2\pi} P_t \cos^m\left(\phi\right), \quad (3)$$

where P_t is the transmitted optical power and the order m is related to $\Phi_{1/2}$ by

$$m = -\frac{\ln 2}{\ln \cos \Phi_{1/2}}. \quad (4)$$

Considering the VLC link, a receiver with an optical band-pass filter of transmission $T_S(\psi)$ and a nonimaging concentrator of gain $g(\psi)$, the DC gain for a receiver located at a distance of d can be approximated as

$$H\left(0\right) = \begin{cases} \frac{\left(m+1\right)A}{2\pi d^2} \cos^m\left(\Phi\right) T_s\left(\psi\right) g\left(\psi\right) \cos\left(\psi\right), 0 \le \psi \le \Psi_c \\ 0, \quad \psi > \Psi_c \end{cases}. \quad (5)$$

An idealized nonimaging concentrator having an internal refractive index n achieves a gain

$$g\left(\psi\right) = \begin{cases} \frac{n^2}{\sin^2 \Psi_c}, & 0 \le \psi \le \Psi_c \\ 0, & \psi > \Psi_c \end{cases}. \quad (6)$$

B. Bit-Error Rate

The receiver SNR is usually expressed as below

$$\text{SNR} = \frac{S}{N}, \quad (7)$$

where S is the signal power, and N is the noise power. With the transmitted optical power (P_t), the received optical power (P_r), and LOS channel model, S can be calculated as

$$S = \Re^2 P_r^2 = \Re^2 \left[H\left(0\right) P_t\right]^2, \quad (8)$$

where $\Re$ is the responsivity of the photodetector.

Regarding noise power, we consider shot noise and circuit noise, which are denoted as σ^2_{shot} and σ^2_{cir}, respectively. Hence, the noise power N is given by

$$N = \sigma^2_{shot} + \sigma^2_{cir}, \quad (9)$$

The shot noise σ^2_{shot} depending on signal power and background current is expressed as

$$\sigma^2_{shot} = (2qRP_r + 2qI_{bg})BF_t, \quad (10)$$

where q is the electronic charge, I_{bg} is background light noise current, F_t is the noise factor and B is the noise bandwidth. Meanwhile, σ^2_{cir} mainly contains thermal noise and thus is calculated as

$$\sigma^2_{cir} = \frac{4kT}{R_F} BF_t, \quad (11)$$

where T is the absolute temperature and R_F is the load resistance.

We assume that SC-BPSK is used in the model. Therefore, BER is given by

$$\text{BER} = \text{Q}\sqrt{\frac{SNR}{2}}, \quad (12)$$

where Q(.) is Q function.

C. Throughput

The system throughput is calculated based on the following parameters: the packet size (L) and the transmission data rate R. The probability of receiving an error-free packet of length L bits denoted as p_c is expressed as

$$p_c = \left(1 - \text{BER}\right)^L. \quad (13)$$

Throughput is therefore given by

$$Throughput = Rp_c. \quad (14)$$

IV. NUMERICAL RESULTS

To prove the feasibility of our proposed system model, we have derived numerical performance results that are demonstrated in this section. All the system parameters are in Table 3.

TABLE 3. SYSTEM PARAMETERS

Detector physical area of PD A (cm^2)	0.79
Gain of optical filter $T_s(\psi)$	1.0
Refractive index n	1.7
Absolute temperature T (K)	298
O/E conversion efficiency $\Re$ (A/W)	0.35
Load resistance R_F (kΩ)	10
Noise factor F_t	10^2
Vertical inclination θ (degree)	79.1
FOV of receiver Ψ_c (degree)	7.6
Transmitted power P_t (OOK) (mW)	314
Transmitted power P_t (SC-BPSK) (mW)	126
Packet size L (bits)	50
Transmission data rate R (Mbps)	1

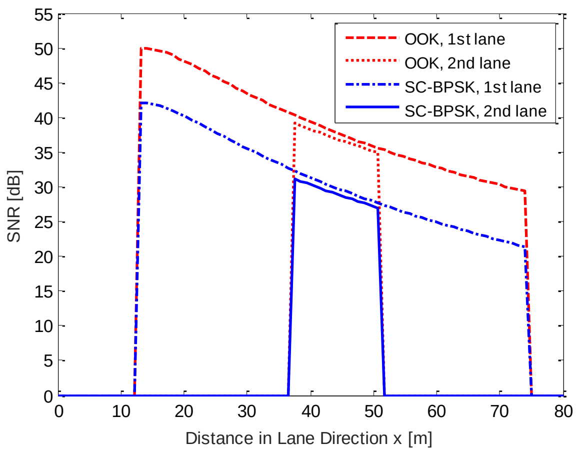

Fig 3. SRN in different modulation schemes and lanes.

Figure 3 investigates SNR versus the distance in lane direction x with two types of modulation scheme including OOK and SC-BPSK. According to the figure, SNR depends mostly on the lane of a vehicle in which the vehicle runs. Vehicles in the first lane always have better SRN than those in the second lane at the same lane direction x. The reason is that the angles of irradiance ϕ and incidence ψ of the second lane, described in Equations (1) and (2), are narrower than that in the first lane if both have the same x. When a vehicle runs closer to the traffic light, the SNR increases. However, when the vehicle is at the position too close to the traffic light, the transmitter is not in the FOV of the receiver and thus SNR becomes zero. In addition, the different modulation schemes, OOK and SC-BPSK, show fairly difference in the value of SNR. In the same lane and at the same lane direction x, using OOK performs better than SC-BPSK due to its higher transmitted power allowed according to the standard.

Figure 4 demonstrates the relation between BER and the distance in lane direction x for the case of SC-BPSK. The communication area is defined as the range of distances, where BER is lower than 10^{-6}. In the first lane, the communication area extends from 10 m to 74 m on the x-axis. Meanwhile, in the second lane, the communication area is within 36 m to 51 m on the x-axis. It is clear that the communication area in the first lane is larger than the second lane. It means that the vehicles in the first lane can receive more information than the vehicles the second lane with the condition that these vehicles move at the same velocity.

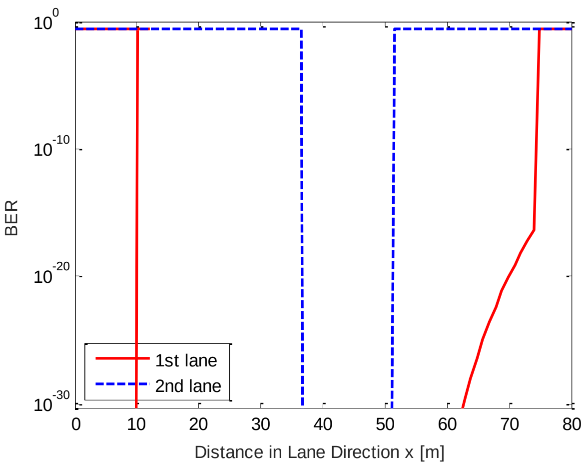

Fig 4. BER in different lanes.

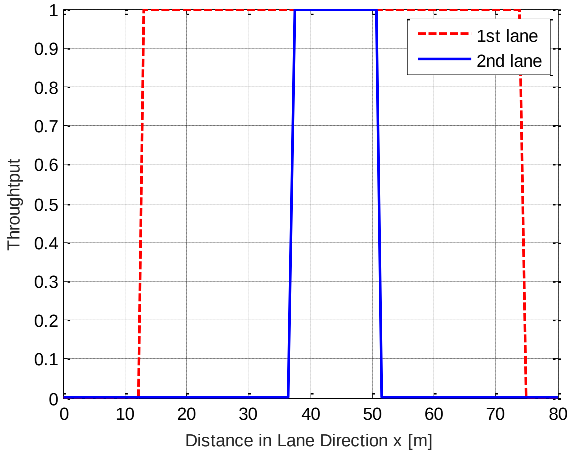

Fig 5. Throughput in different lanes.

The system throughput is investigate versus the distance in lane direction x in Fig. 5. The figure shows that the system throughput reaches the maximum value of 1 Mbps when the vehicles are at the communication area. This is due to the fact that the system provides error-free in communication.

The vertical inclination θ shows the angle of sensor attached on front of a vehicle to receive information from the LED traffic light. Different vertical inclinations will affect angle of incidence ψ and consequently change communication areas. As shown in Fig. 6, at the same first lane, communication areas achieve three different values where we use three different vertical inclinations.

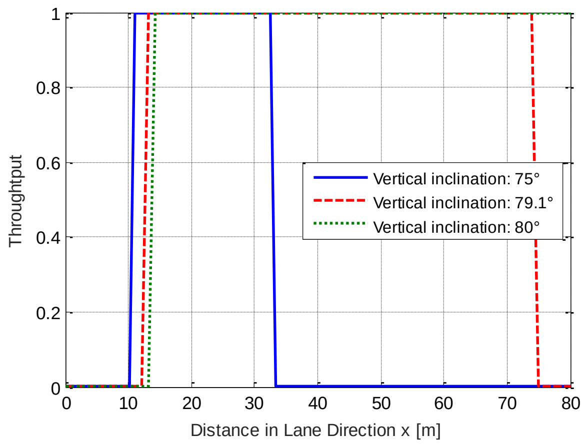

Fig 6. Throughput in 1st lane with different vertical inclinations.

When we increase the value of vertical inclination θ, the start points and end points of the communication areas are further to the LED traffic light and communication areas consequently are wider. However, if we consider more traffic light sections, the overlapping of communication areas will create inter-section interference. So, we need to estimate the best vertical inclination θ which satisfies our desired communication area and avoids inter-section interference.

V. CONCLUSION

In the paper, the simple system model of two-lane one-way road for V2LC is considered. In different lanes, the first and the second lanes, the values of SNR, BER, and throughput are calculated. These values prove that vehicles in the first lane always have better performance metrics than those in the second lane due to the fact that the angles of irradiance ϕ and incidence ψ of the second lane are narrower than that in the first lane if both have the same position on x-asix. A communication area is defined as a range of road where vehicles can receive successfully signal from the traffic light. Then, this area is identified based on BER.

This research will be easily extended if we consider more complex road models which involve two-way directions and a real cross road with more than one traffic lights. This paper is limited to use only VLC between a traffic light to vehicles, but in fact, V2LC can be applied on both inter-vehicle and roadside-vehicle communications. The traffic regime is mostly ignored by assumption of low-density traffic which always enables LOS channel. Therefore, researchers can develope the research to fulfill the real traffic situation.

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ĐÁNH GIÁ HIỆU NĂNG CỦA HỆ THỐNG V2LC SỬ DỤNG ĐÈN GIAO THÔNG LED

Tóm tắt- Truyền thông bằng ánh sáng nhìn thấy (V2LC) là một công nghệ tiềm năng nhằm hiện thực hóa hệ thống giao thông thông minh (ITS). Ngày nay, các nguồn sáng truyền thống đang dần được thay thế bởi điốt phát quang (LEDs) trên cả phương tiện giao thông và cơ sở hạ tầng giao thông như là hệ thống đèn giao thông và đèn đường chiếu sáng. Dựa trên thực tế này, việc triển khai sử dụng V2LC trên đường trở nên dễ dàng và kinh tế hơn nhiều so với bất kì công nghệ nào khác. Trong bài báo này, đèn giao thông LED được sử dụng để truyền tải thông tin của tuyến đường tiếp theo đến các phương tiện giao thông. Mô hình đường một chiều hai làn được khảo sát nhằm tính toán các giá trị của tỷ số tín hiệu trên tạp âm (SNR), tỷ lệ lỗi bit (BER) và thông lượng của các phương tiện giao thông tại các vị trí khác nhau trên đường. Bên cạnh đó, chúng tôi cũng định nghĩa vùng truyền thông nơi một phương tiện giao thông có thể nhận tín hiệu từ đèn giao thông và sau đó tính toán kích thước của vùng truyền thông này dựa trên tham số BER.

Từ khóa- Truyền thông bằng ánh sáng nhìn thấy (V2LC), đèn giao thông LED, vùng truyền thông.

Le Tung Hoa received B.E. from Posts and Telecommunications Institute of Technology (PTIT), Vietnam, in 2007, and M.E. degree from University of Electro-communication, Japan, in 2010, both in telecommunication engineering. Now, she is a lecturer at Faculty Telecommunication 1 of PTIT. Her research interests include wireless communications, VANET, Vehicular VLC and cognitive radio.

Dang The Ngoc received the B.E. degree from the Hanoi University of Science and Technology, Hanoi, Vietnam in 1999, and the M.E. degree from the Posts and Telecommunications Institute of Technology (PTIT), Hanoi, Vietnam in 2005, both in electronics and telecommunications; and received the Ph.D. degree in computer science and engineering from the University of Aizu, Aizu-wakamatsu, Japan in 2010. He is currently an Associate Professor/Head with the Department of Wireless Communications at PTIT. He was also an invited/visiting researcher at FOTON-ENSSAT Lab., Universite de Rennes 1, France, in 2011 and Computer Communications Lab., The University of Aizu, Japan in 2012, 2013, 2015, and 2017. His current research interests include the area of communication theory with a particular emphasis on modeling, design, and performance evaluation of optical CDMA, RoF/FSO, optical wireless communication, and QKD systems. He is a member of IEEE.