Dimming Support for Visible Light Communication in Intelligent Transportation and Traffic System

Seyhan Ucar*, Bugra Turan†, Sinem Coleri Ergen†, Oznur Ozkasap* and Mustafa Ergen**
Department of Computer Engineering*
Department of Electrical and Electronics Engineering†
Koc University, Istanbul, Turkey
Koc University / MiSONE Solution, Istanbul, Turkey **
{sucar, bturan14, sergen, oozkasap, mergen}@ku.edu.tr

***Abstract*—Automotive industry is under a major change and new vehicles are being enriched by the recent advances in communication. Not only business plans are changing due to connected and urbanized life style, but also transportation is becoming more intelligent with smart roads that connect smart cars. Technology coined as vehicular ad-hoc network (VANET) is harmonizing with Intelligent Transportation System (ITS) and Intelligent Traffic System (ITF). However, current ITS and ITF systems suffer from the scarcity of radio frequency spectrum. Visible light communication (VLC) that uses modulated optical radiation in the visible light spectrum is an alternative medium being researched. To date, majority of research on vehicular VLC was aimed at achieving high data rates provided that high lighting quality is achieved without any concern on dimmable LED lights. Auto-dimmable headlights gain attention due to danger caused by sudden glare on drivers at night conditions which makes dimming in VLC necessary. In this paper, we first present the latest concept of vehicular VLC on ITS and ITF systems and address dimming utility. We then demonstrate experimentally that dimming is a key parameter in VLC which affects data dissemination and received power signal strength.**

I. INTRODUCTION

Advances in automobile industry and urbanization make vehicles connected with each other as well as with city infrastructure. There exist more than 1 billion motor vehicles in worldwide and it is believed the number would get doubled within the next 10 to 20 years. Moreover, developments in wireless technology bring autonomous driver-less cars [1] into reality where vehicles are capable of cruising by themselves. As a result, VANET, a type of mobile ad-hoc network (MANET) of covering vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), is becoming one of the most relevant network technologies. In VANETs, vehicles communicate based on IEEE 802.11p, which forms the standard for Wireless Access for Vehicular Environments (WAVE). IEEE 802.11p provides data rate ranging from 6 Mbps to 27 Mbps at short radio transmission distance, around 300 m.

The enhanced vehicular connectivity in ITS and ITF aims to reduce traffic congestion, traffic accidents, energy waste and pollution by providing timely and efficient data dissemination about events like accidents, road condition and traffic jams beyond the drivers' knowledge. Although the investment on road construction may solve the traffic congestion to some extent, it is not feasible due to reasons of high construction cost and limited availability of land. For instance, traffic congestion costs more than 100 billion annually due to wasted fuel and lost time in USA [2]. Moreover, vehicle emission caused by traffic congestion has great detrimental effect on air pollution and haze in some large cities. On the other hand, ITS and ITF suffer from scarcity of radio frequency (RF) where the increased wireless data traffic from the rapidly growing wireless mobile devices is creating pressure on RF spectrum. This scarcity problem leads researchers to investigate alternative technologies such as VLC, which uses modulated optical radiation in the visible light spectrum to carry digital information in free space. VLC uses fast switching light emitting diodes (LEDs) as its source and provides both illumination and communication in indoor and outdoor scenarios.

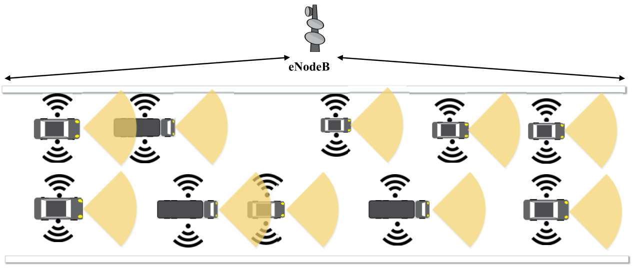

Fig. 1: ITS and ITF System Architecture

Fig. 1 demonstrates possible ITS and ITF architecture that mainly adopts Dedicated Short Range Communication (DSRC), Long Term Evolution (LTE) and VLC. A comparison of the key properties of both VLC and conventional RF-based (DSRC) technologies is presented in Table I. DSRC is usually omnidirectional and can work both in line-of-sight (LoS) and non-line-of-sight (NLoS) scenarios in licensed frequency band 5.8 - 5.9 GHz with high mobility. VLC, on the other hand, is highly directional and typically works in LoS scenarios in short range, around 50-100 meters, with high sensitivity to weather condition and ambient light. As a wireless communication technology, VLC is beneficial due to reasons such as; it has no health concern, it does not cause

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TABLE I: Comparison Of VLC and RF (DSRC) Key Properties

Type	**VLC**	**RF (DSRC)**
Communication Scenario	Typically LoS	Both LoS and NLoS
Transmission Range	Short Range and Highly Directional	Long Range and Usually Omnidirectional
Frequency Band	400 - 790 THz	5.8 - 5.9 GHz
Licensing	Free	Required
Cost	Low	High
Mobility	Medium	High
Weather Condition	Sensitive	Robust
Ambient Light	Sensitive	Not Affected

any electromagnetic interference, it is license free and it can easily integrated with existing LED equipped motor vehicles with low-cost additional on-board units. These distinguished characteristics make VLC attractive in both academia and industry where the IEEE 802.15 working group for wireless personal area networks (WPAN) standardized the PHY and MAC layer for VLC in the IEEE 802.15.7 task group [3].

In VANET settings, VLC is a suitable communication technology where most of the components that enable visible light communication are already equipped in vehicles. Any light emitting technology can be used as transmitter where modern vehicles have already started to use LEDs due to their long service life, high resistance to vibration, and better safety performance. LEDs are used in the stop lamps, brake lights, turn signals, and headlamps of many vehicles. On the other hand, VLC receivers are mostly either photo-diode (PD) [4], [5] or CMOS camera [6] which can be found in many vehicles as front or rear camera for lane tracking and parking purposes. In literature, vehicular VLC has been investigated for different purposes such as channel characteristics [7]–[10], handover capabilities [11], requirements [12]–[17] and feasibility in a hybrid architecture together with DSRC [18]–[20]. Proposed vehicular VLC schemes were studied either experimentally [7]–[9], [12], [14], [17] by using a LED in outdoor condition or via computer based simulations [10], [11], [13], [15], [18], [19] using Lambertian property of LEDs.

To date, a majority of research concerning vehicular VLC was aimed at achieving high data rates via analysing the channel characteristics. However, data rates with respect to lighting quality and its correlation with dimming utility had mostly been over looked. Moreover, auto-dimmable headlights gain attention due to danger caused by high, bright beam of headlights which create a sudden glare while driving at night condition [21], [22]. This sudden glare has crucial effect on driver where it causes a temporary blindness to a person resulting in road accidents. To prevent driver from this blindness in vehicular VLC system, dimming is proposed where the light sources are arbitrarily dimmed. Dimming is beneficial in terms of energy efficiency and life span where dimmed lamp requires less current and it produces less heat which extends its life time. However, achieving efficient dimming control in VANET-VLC link is difficult since dimming has an adversary effect on communication [23]. Due to fixed average intensity, achievable data rate is decreased. Dimming is provided via changing the forward current through the LED where forward current determines the brightness level. Lower brightness level has crucial effect on both signal-to-noise ratio (SNR) and bit error rate (BER) where at lower brightness the achievable data rate and SNR is low and BER is relatively high. Moreover, external weather conditions such that fog, snow and rain may cause dimming which are needs to be considered in efficient dimming utility. As a result, detailed analysis of vehicular dimmed VLC and proper dimming techniques or protocols must developed to provide the right trade-off between illumination and communication. Analysis of dimming functionality and efficient dimming techniques in vehicular VLC systems will contribute to the safety and allow vehicular system to have full control over the lighting output.

In this paper, our goal is to present the latest concept of vehicular communication on ITS and ITF system and provide detailed overview of trending VLC which involves headlights dimming utility. The original contribution of this paper is twofold. First, the characteristic of the vehicular VLC link in LoS is investigated with experimental scenarios. Second, the effect of VLC dimming utility in varying inter-vehicular distance and dimming level is analyzed. We then demonstrate experimentally that dimming is one of the key parameters in VLC that affects the data dissemination and received power signal strength.

The rest of the paper is organized as follows. Section II describes the experimental setup for vehicular VLC. Section III presents the experimental results. Section IV discusses the on-going work for an alternative dimming methodology. Finally, conclusions and future work are given in Section V.

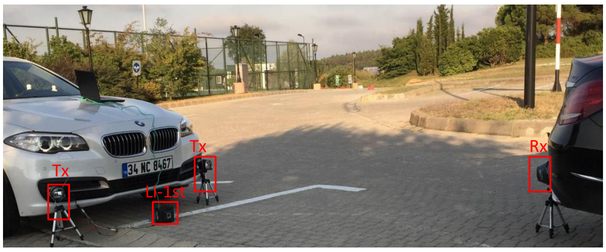

Fig. 2: Vehicular VLC Experimental Setup

II. EXPERIMENTAL SETUP

For the experiments of VLC system, two symmetrical LED fog lights [24] are connected to Li-1st [25] transmitter unit (Tx) and PD based receiver unit (Rx) as shown in Fig.2. Dual symmetrical LED fog lights are mounted on tripods with 36 cm height and 150 cm separation distance. In the experiments, automotive fog lights are preferred due to their wide and flat illumination pattern to minimize reflection by fog. Custom created 150 byte length data packets are transferred with the Li-1st Tx which is driven by LED fog lights. Tx utilizes Pulse Amplitude Modulation (PAM) scheme along with Reed-Solomon coding operating at a sample rate of 2.5 Mbps, allowing 5 Mbps data rate with 4PAM.

Received power is measured via OMM-6810B Optical Power Meter using OMH-6703B Si power head. Transmitted data is captured with Li-1st Rx. Both Tx and Rx are connected to computers for evaluating communication performance. Night time outdoor measurements are executed to compensate shot noise, sourced by diurnal variations. Rx and Si-power head of optical power meter is mounted on tripods with 36 cm height at the center of the leading vehicle's bumper. Both fog lights and Rxs are placed between vehicles in an outdoor environment to take into account the reflections from vehicles and road. Measurements emulated the following vehicle disseminating safety critical message (i.e. slip, lane change intention) with LED fog lights, to the leading vehicle proceeding on a curved path. Thus, receiver distance is changed from 1 to 5 meters while LED fog lights are fixed.

To analyse the dimming functionality in vehicular VLC, fog lights are driven in different dimming level changing from 0 to 9 where 0 and 9 represent minimum and maximum brightness levels, respectively. In all brightness level scenarios, experiments are performed to investigate the dimming effect on vehicular VLC. For all experimented scenarios, 100 packets are sent from Li-1st Tx unit to Rx unit.

III. PERFORMANCE EVALUATION

Performance evaluation of dimmable vehicular VLC system is done by analysing two metrics, namely data packet delivery ratio (DPDR) and Li-1st Rx unit received power in dBm. DPDR is defined as the ratio of the number of successfully received data packets to the total number of transmitted data packets. In experiments, Li-1st Tx brightness level is changed from 0 to 9 where this change is macroscopic and detected by eyes. Maximum distance, where the data is transmitted with Li-1st in dim level 9, is 10 meters.

Received power analysis at different distances with different dimming levels is demonstrated in Fig. 3. We observe that the received power exhibits similar degradation patterns with the increasing distance and dim level plays a critical role in the received power. Moreover, there is no major received power difference between the dim level 0 and 4. On the other hand, received power dramatically changes in dim levels 6 and 9 which affects the overall vehicular VLC system performance. Results indicate that knowing the distance from the leading vehicle with road information, vehicle can automatically change the dim level to ensure efficient data dissemination and prevent drivers from sudden glare at night condition.

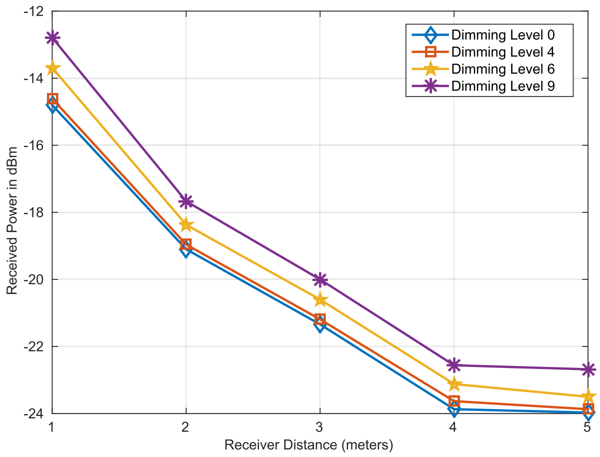

Fig. 3: Received Power With Varying Dimming Level

Fig. 4 shows the DPDR performance of vehicular VLC system in different dim levels and distances. From DPDR analysis, it is observed that as the distance increased, the dim levels determines the DPDR value of system whereas lower dim scenarios have lower DPDR values compared to high dim cases. For example, in scenario 5 meters where the dim levels are 0 and 4, the DPDR value is 0 where the light brightness is insufficient. Similar to dim level 0 and 4 , dim level 6 cannot transmit data after 5 meters whereas dim level 9 can transmit data up to 10 meters with 100% delivery ratio. Moreover, at short distances as the dim level increases, DPDR values also increases. Thus, dimming has crucial effect on the DPDR performance of vehicular VLC system where an adaptive dimming protocol is required to determine the desired DPDR value in safety applications.

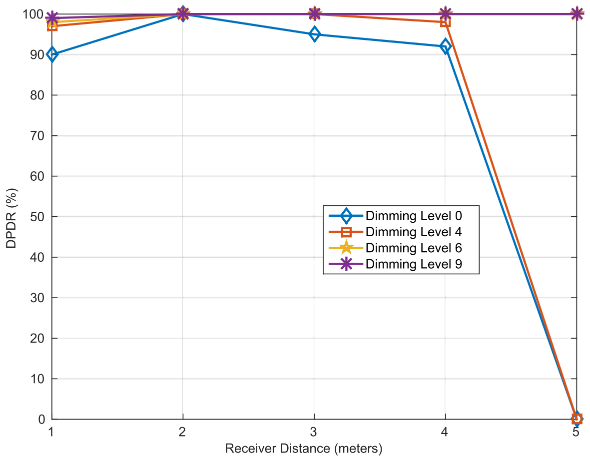

Fig. 4: DPDR Performance of Different Dimming Level

IV. ON-GOING WORK

VLC gains popularity due to its benefits in ITS and ITF. In the near future, vehicles will be much smarter where driver switched headlights are replaced with auto-dimmable lights which make adaptive dimmable system crucial. We are currently working on adaptive vehicular dimmable VLC protocols where the dimming level of headlight is autonomously changed based on vehicular metrics as follows. To protect drivers from sudden glare, vehicle adjusts its headlight dim level based on the front vehicle observation. In this type of communication, vehicles use hybrid communication model where each vehicle is equipped with VLC and DSRC component. Vehicles periodically share awareness messages with each other and rear vehicle can use these awareness messages to adjust its headlight dim level to ensure efficient message dissemination and prevent sudden glare caused by high beam of headlight.

V. CONCLUSION AND FUTURE WORK

Vehicular VLC is an alternative technology that offers low cost, directional and jam-free communication for ITS and ITF. To date, majority of research concerning vehicular VLC was aimed at high data rates. However, data rates with respect to lighting quality and its correlation with dimming utility had mostly been overlooked. Sudden glare caused by high beam makes auto-dimmable headlight crucial in terms of data dissemination and safety. Considering the requirement of VLC and vehicular dimmable light, we analyzed the limitation of dimming utility in outdoor experiments. Based on the experiments, we demonstrate that dimming utility has detrimental effect on vehicular VLC where in lower brightness level at high distances, communication is not possible. Moreover, dimming level plays critical role in DPDR. As the dimming level increases, DPDR also increases. As part of future work, we aim to analyse different vehicle related parameters including; field of view that is angle between the light line and the receiver, another light interference during the data transmission and vibration of vehicles. Based on the experimental analysis of vehicular parameter, we target to propose a realistic simulation platform for vehicular visible light communications.

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