

# Experimental Investigation of Angle Diversity Receiver for Vehicular VLC

Daniel K. Tettey  
Research and Development,  
Ford Otosan  
Istanbul, Turkey  
dtettey@ford.com.tr

Mohammed Elamassie  
Electrical and Electronics Eng.,  
Özyeğin University  
Istanbul, Turkey  
mohammed.elamassie@ieee.org

Murat Uysal  
Engineering Division,  
New York University Abu Dhabi  
Abu Dhabi, UAE  
murat.uysal@nyu.edu

## ABSTRACT

In this paper, we explore the use of multiple photodetectors for vehicular visible light communication (VLC) systems with a focus on the so-called Angle-Diversity Receiver (ADR). ADR builds upon the principle of using multiple photodetectors oriented at different reception angles to enable multidirectional signal reception. With ADR, it is possible to receive light rays from the vehicle headlight in challenging mobility conditions such as in the cases of U-turn, left-turn, and right-turn. In our work, we present preliminary results of an experimental verification of ADR-based vehicular VLC system implemented using software-defined radio platforms. Our results demonstrate that a packet delivery ratio (PDR) of more than 99 % is achieved even for T-junction road scenarios where the link is likely to get lost in the case of conventional single transmitter/receiver configurations.

## CCS CONCEPTS

• **Applied Computing** → **Network Systems and Hardware**; • **Hardware** → **Emerging technologies**;

## KEYWORDS

Vehicular VLC, Angle-Diversity Receiver, Intelligent Transportation Systems, Software-Defined Radio.

### ACM Reference format:

Daniel K. Tettey, Mohammed Elamassie, and Murat Uysal. 2023. Experimental Investigation of Angle Diversity Receiver for Vehicular VLC. In *Proceedings of The 29th Annual International Conference on Mobile Computing and Networking, Madrid, Spain, October 2–6, 2023 (ACM MobiCom '23)*, 3 pages.

<https://doi.org/10.1145/3570361.3615755>

## 1 INTRODUCTION

To improve road safety and traffic efficiency, the automotive industry and governments are considering the adoption of Intelligent

Transportation Systems (ITS) where vehicles can coordinate and communicate to share safety-critical messages [1][2]. ITSs require ultra-reliable low latency wireless communication between the vehicles (V2V) and between road-side infrastructure and vehicles (I2V) to realize its full potential.

The ubiquity of light emitting diodes (LEDs) in the exterior lighting of recent vehicles and road-side infrastructures has prompted the consideration of VLC as an alternate and/or complementary connectivity solution to radio frequency systems in vehicular communications [3]. While most indoor LEDs have a Lambertian pattern, vehicular headlights exhibit asymmetrical intensity distribution which mainly aims to illuminate the road. Utilization of vehicular headlights therefore brings additional challenges in a vehicular VLC system which is supposed to work in highly dynamic and mobile conditions.

Initial works on vehicular VLC systems assumed perfect alignment between the LED emitter and photoreceiver. Such an idealistic scenario cannot be guaranteed under vehicle mobility as it rarely exists. To address the challenge posed by mobility in vehicular VLC, the authors in [4] investigated the use of multiple photodetectors (PDs) through an extensive simulation study with the aim of achieving omnidirectional coverage in various driving and mobility conditions. There have also been some experimental efforts highlighting the benefits of multiple PDs in vehicular VLC. In particular, the authors in [5] implemented a vehicular VLC system using software-defined radio platforms. The implementation employed two PDs: one positioned at the left-back and another at left-side of the vehicle. It was demonstrated through an outdoor experiment that vehicular VLC link can be maintained during driving on a curved road with PD located on the side of the vehicle.

In this paper, we explore the use of multiple PDs with a focus on the so-called Angle-Diversity Receiver (ADR). ADR builds upon the principle of using multiple PDs oriented at different reception angles to enable multidirectional signal reception. With ADR, it is possible to receive light rays from the vehicle LED headlight in challenging mobility conditions, i.e., U-turn, left-turn, right-turn. ADR has been explored for indoor VLC in [6–8] and later applied to vehicular VLC in [9]. The work in [9] is mainly limited to a simulation study of ADR in the context of vehicular VLC and uses the Lambertian model for the LED transmitter which does not hold for vehicular headlights.

## 2 VEHICULAR VLC WITH ADR

Our V2V VLC experimental system set-up consists of one National Instrument's USRP 2930 on the transmitter side and two units of Ettus Research USRP x310 on the receiver side. These USRPs are

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from [permissions@acm.org](mailto:permissions@acm.org).

ACM MobiCom '23, October 2–6, 2023, Madrid, Spain

© 2023 Copyright held by the owner/author(s). Publication rights licensed to the Association for Computing Machinery.

ACM ISBN 978-1-4503-9990-6/23/10...\$15.00

<https://doi.org/10.1145/3570361.3615755>

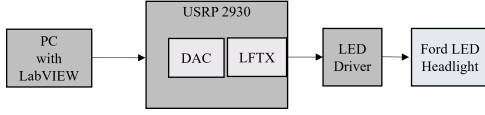


Figure 1: Vehicular VLC transmitter block diagram

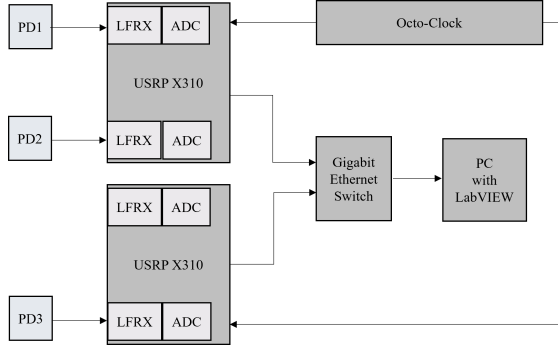


Figure 2: Vehicular VLC receiver block diagram.

modified for baseband signal transmission/reception by replacing the default RF daughterboards with the baseband cards, i.e., LFTX for transmission and LFRX for reception. Fig. 1 and 2 depict the block diagrams of transmitter and receiver experimental set-up, respectively. At the transmitter side, we generate on-off keying (OOK) modulated baseband signal according to a specified frame structure using LabVIEW software. The OOK baseband signal is fed to USRP 2930 via an ethernet cable. The output of the USRP is fed to the LED driver which consists of an amplifier, bias-tee, and DC power supply. The driver circuit gives 26 V DC bias to the amplifier output. The Mini-circuits ZFBT-GW+ Bias Tee is used to impose the modulated signal on the top of the DC bias. As the wireless transmitter, we use Ford F-MAX low-beam LED headlight with a measured 3-dB modulation bandwidth of 2.3 MHz.

At the receiver side, we use 3 PDs as shown in Fig. 2 and 3. Each PD connects to one receive channel on the USRP x310. The USRPs are connected to a personal computer (PC) via a gigabit ethernet switch. An Octo-Clock is employed to supply the two USRP x310s with a 10 MHz clock signal to ensure synchronous operation. The received signals are fed to USRPs for shifting back to baseband, digitization and forwarding to the gigabit ethernet switch. The gigabit ethernet switch forwards the baseband signal samples to the PC for receiver processing in LabVIEW software.

The three PDs are configured to support the ADR as shown in Fig. 3. The holder is 3D printed and custom-made. Its design is such that the center points of the active area of adjacent PDs are separated from each other by an angle of  $60^\circ$ . Each PD has an active area of  $75.4 \text{ mm}^2$  and a field of view (FOV) of  $53^\circ$ . Effectively, the ADR provides a wide FOV close to  $180^\circ$  which can enable receiving signal from multiple directions. The received signal strength of each PD is estimated, then the strongest received signal is selected for subsequent baseband processing and detection.

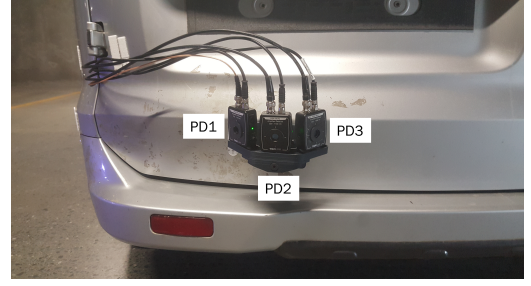


Figure 3: ADR attached to back of receiver vehicle.

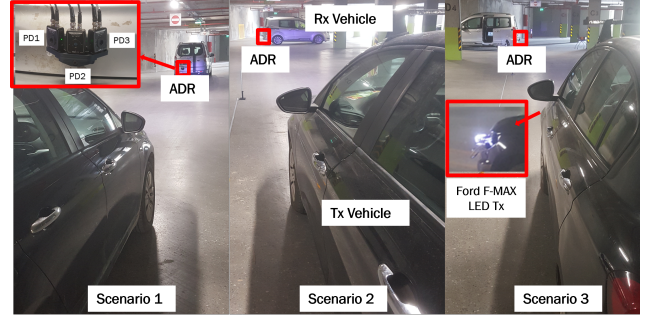


Figure 4: (a) Scenario 1 - Perfectly aligned (b) Scenario 2- Receive vehicle is making a right turn and (c) Scenario 3 - Receive vehicle is making a left turn.

### 3 PERFORMANCE MEASUREMENTS

In this section, we present performance evaluation of the ADR-based V2V VLC proof-of-concept system in terms of the received SNR and PDR. The measurements are recorded in real-time at a car park located in Ozyegin University campus. To demonstrate the effects of interference noise from ambient light, lighting systems were kept switched-on. In this preliminary experiment, the transmitter and receiver vehicles are stationary and located 20 m apart.

To evaluate the performance, we consider three scenarios presented in Fig. 4. In Scenario 1, the vehicles are perfectly aligned without any lateral shift. The other two scenarios can be considered as the worst cases for V2V alignment when one vehicle is following another at a T-junction. The received SNR for each PD in three scenarios are provided in Fig. 5. It is observed that PD 2 of the ADR (located in the middle) is selected for Scenario 1. For Scenario 2, as expected, PD3 is selected since it is the only one facing the transmitter vehicle while the receiver is making a right turn. Similarly, PD1 is selected for Scenario 3 due to the transmitter-receiver pair configuration.

In Fig. 6, we present the received SNR for the selected (primary) receiver for all three scenarios. The highest SNR is obtained in Scenario 1 when the vehicles are perfectly aligned. This is measured around 18.6 dB. For Scenarios 2 and 3, SNR of 13.24 dB and 12.02 dB are measured respectively. It can be noted that for OOK modulated signal, an SNR of 12 dB can provide theoretical BER of  $2.66 \times 10^{-4}$  which is below the forward error correction (FEC) limit of  $3.8 \times 10^{-3}$ .

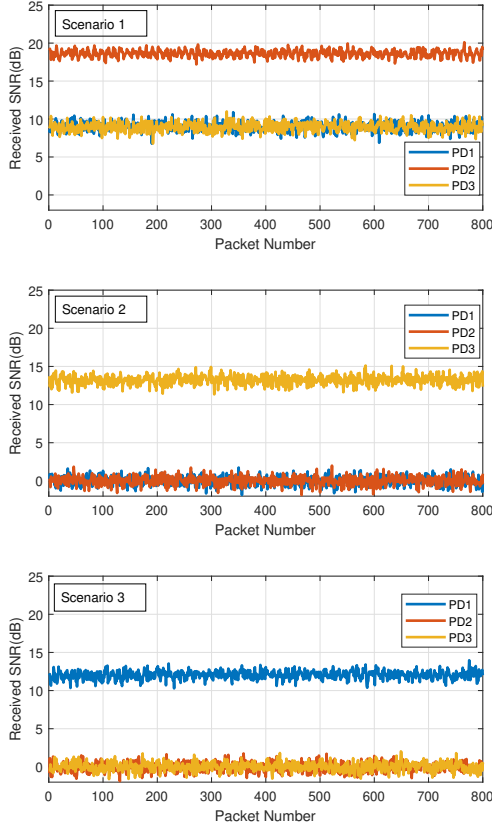


Figure 5: Received SNR in all scenarios.

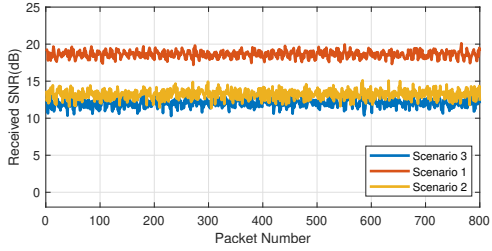


Figure 6: Received SNR for the primary PDs

The PDR of the three scenarios considered is further provided in Table 1. To measure PDR, we transmitted 800 packets for each scenario. Each packet has a length of 1024 bits. A packet delivery is successful if it is received without a single bit error. The PDR is therefore defined as ratio of packets received without error to total packets sent. It is observed that PDRs of 100 %, 99.5 %, and 99.12 % are obtained for scenarios 1, 2 and 3 respectively.

Table 1: Packets delivery ratio (PDR) of all scenarios

Scenario	Primary PD	Packets Delivered	PDR (%)
Sc. 1	PD 2	800	100
Sc. 2	PD 3	796	99.5
Sc. 3	PD 1	793	99.12

## 4 CONCLUSION AND FUTURE WORK

We have presented a proof-of-concept vehicular VLC with ADR. Our preliminary experimental results demonstrate the potential of ADR for reliable vehicle-to-vehicle transmission, particularly for vehicle platoon applications. PDR above 99 % is achieved with ADR even for T-junction road scenarios where link is likely to get lost in the case of conventional single transmitter-receiver configurations. Future work will further test this prototype under different vehicular mobility scenarios and weather conditions.

## ACKNOWLEDGMENT

This work was funded by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska Curie grant agreement ENLIGHTEN No. 814215.

## REFERENCES

- [1] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin, and T. Weil, "Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions," *IEEE Commun. Surv. Tutor.*, vol. 13, no. 4, pp. 584–616, 2011.
- [2] P. Papadimitratos, A. D. La Fortelle, K. Evensen, R. Brignolo, and S. Cosenza, "Vehicular communication systems: Enabling technologies, applications, and future outlook on intelligent transportation," *IEEE Communications Magazine*, vol. 47, no. 11, pp. 84–95, 2009.
- [3] M. Uysal, Z. Ghassemloooy, A. Bekkali, A. Kadri, and H. Menouar, "Visible light communication for vehicular networking: Performance study of a v2v system using a measured headlamp beam pattern model," *IEEE Vehicular Technology Magazine*, vol. 10, no. 4, pp. 45–53, 2015.
- [4] H. B. Eldeeb, S. M. Sait, and M. Uysal, "Visible light communication for connected vehicles: How to achieve the omnidirectional coverage?" *IEEE Access*, vol. 9, pp. 103 885–103 905, 2021.
- [5] B. Aly, M. Elamassie, and M. Uysal, "Vehicular vlc system with selection combining," *IEEE Transactions on Vehicular Technology*, vol. 71, no. 11, pp. 12 350–12 355, 2022.
- [6] A. Nuwanpriya, S.-W. Ho, and C. S. Chen, "Angle diversity receiver for indoor mimo visible light communications," in *2014 IEEE Globecom Workshops (GC Wkshps)*, 2014, pp. 444–449.
- [7] Z. Chen, N. Serafimovski, and H. Haas, "Angle diversity for an indoor cellular visible light communication system," in *2014 IEEE 79th Vehicular Technology Conference (VTC Spring)*, 2014, pp. 1–5.
- [8] H. B. Eldeeb, M. Hosney, H. M. Elsayed, R. I. Badr, M. Uysal, and H. A. I. Selmy, "Optimal resource allocation and interference management for multi-user uplink light communication systems with angular diversity technology," *IEEE Access*, vol. 8, pp. 203 224–203 236, 2020.
- [9] S. Yahia, Y. Meraihi, A. B. Gabis, and A. Ramdane-Cherif, "Multi-directional vehicle-to-vehicle visible light communication with angular diversity technology," in *2020 2nd International Workshop on Human-Centric Smart Environments for Health and Well-being (IHSH)*, 2021.