Poster: First Performance Insights on Our Novel OFDM-based Vehicular VLC Prototype

Jörn Koepe*, Christian Kaltschmidt*, Marvin Illian*, Robert Puknat*, Pascal Kneuper†, Steffen Wittemeier†, Agon Memedi*, Claas Tebruegge‡*, Muhammad Sohaib Amjad*, Stephan Kruse†, Christian Kress†, Christoph Scheytt† and Falko Dressler*

*Heinz Nixdorf Institute and Dept. of Computer Science, Paderborn University, Germany
†Heinz Nixdorf Institute and System and Circuit Technology, Paderborn University, Germany
‡HELLA GmbH & Co. KGaA, Lippstadt, Germany
{jkoepe,ckaltsch,millian,rpuknat,pkneuper,wittemei}@mail.uni-paderborn.de,
claas.tebruegge@hella.com, {stkruse,kressc,cscheytt}@hni.upb.de,
{memedi,amjad,dressler}@ccs-labs.org

***Abstract*—In this poster, we present the first experimental results of our OFDM-based Vehicular VLC (V-VLC) prototype. Our Bit Error Rate (BER) measurements show that for lower Modulation and Coding Schemes (MCS), the performance of our hardware-setup roughly behaves the same as it does in simulation for AWGN channel. However, for higher order MCS with high PAPR, the BER performance gets degraded due to non-linear behavior of LEDs, and deviates further from AWGN performance as the MCS order is increased. The obtained results suggest that unlike RF-Communications, where the focus is usually towards linearity of the amplifiers, for V-VLC, linearity within the whole system is required to achieve optimal performance.**

I. Introduction

Recently, Visible Light Communications (VLC) has emerged as a viable communication technology for vehicular networking applications [1], [2]. The orthogonality to Radio Frequency (RF) communications allows its use as a complementary technology alongside RF-based vehicular networking technologies, like DSRC/WAVE [3] and C-V2X [4]. Additionally, VLC offers a huge license-free spectrum and has lower implementation costs – properties, which make it interesting for the vehicular networking community.

VLC enabling front ends for indoor communications are already available in the market (e.g., pureLiFi). Furthermore, multiple standardization efforts take place in the scope of the IEEE [5], [6]. Most of the research in the field has been concentrated on the physical layer design and the implementation of highly efficient and robust Modulation and Coding Schemes (MCS). Nevertheless, despite quite advanced research and the promising standardization efforts, many aspects from scalability to robustness to deployment of Vehicular VLC (V-VLC) in real-world application remain open topics.

In this paper, we present first experimental Bit Error Rate (BER) curves of our OFDM-based V-VLC prototype for vehicular use cases, which is building upon our earlier work in [7]. For performance comparison, we simulate our system in GNU Radio for an AWGN channel to obtain baseline BER curves. Our results show that for lower MCS, the BER performance in both simulations and experiments is roughly similar. However, the experimental BER performance gets worse with higher order MCS. The combined effect of both high Peak to Average Power Ratio (PAPR) in OFDM and the non-linear behavior of the Light Emitting Diodes (LEDs) inside the headlight are major reasons causing this performance degradation; and, thus, remain a major challenge for our research community.

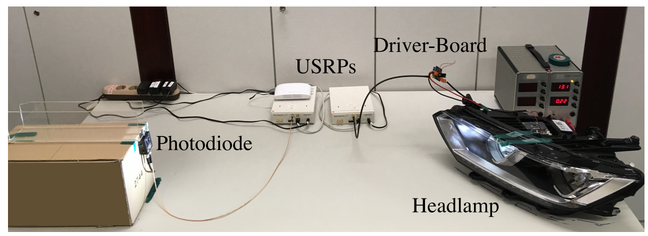

Figure 1. V-VLC prototype and experimental setup.

II. System Design

Our V-VLC prototype including the full experimental setup for vehicular communication is depicted in Figure 1. The prototype comprises of two parts: the VLC enabling front-ends and the digital signal processing part.

Our V-VLC front-end consists of a VLC transmitter circuit with a linear amplifier that is able to drive high power LEDs used in exterior automotive lighting. The design procedure of the linear amplifier is discussed in more detail in [7]. The low beam of an off-the-shelf LED headlight from VW is used at the transmitting end, coupled with the custom transmitter board. Similarly, an off-the-shelf Thorlabs PDA100A-EC photodetector is used on the receiving end. The LEDs in the headlight convert the current into an intensity modulated light signal, which is converted to current again through the photo-detector at the receiver side.

We used USRP Software Defined Radios (SDRs) on both ends of this VLC link for the signal processing, which is done in the GNU Radio signal processing framework. We implement an IEEE 802.11-based DC-biased Optical Orthogonal Frequency-Division Multiplexing (DCO-OFDM) system for Intensity Modulation and Direct Detection (IM/DD),

978-1-5386-9428-2/18/$31.00 ©2018 IEEE

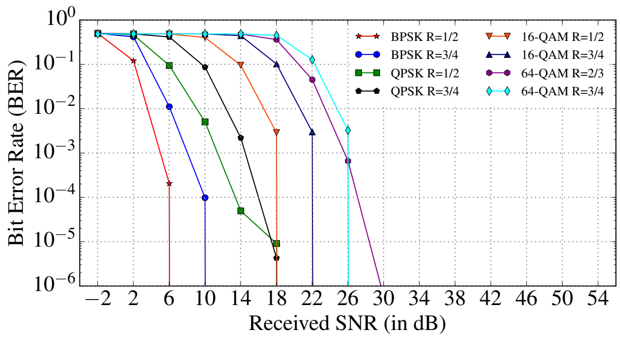

Figure 2. BER in simulation with LS equalizer; 'R' indicates the code rate.

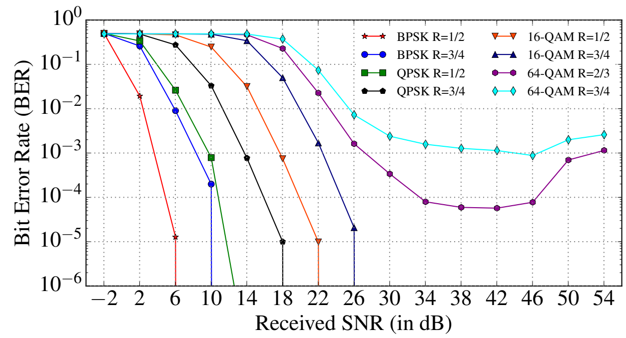

Figure 3. BER in experiments with LS equalizer; 'R' indicates the code rate.

where the implementation of OFDM is done in GNU Radio and the DC biasing is performed through hardware. The system is based on the work by Bloessl et al. [8]; more implementation details can be found in that article.

We consider multiple MCS with different coding rates and investigate the BER performance of those MCS. GNU Radio allows to play with these MCS both in simulation (e.g., using an AWGN channel) as well as in experiments. We make use of this functionality and evaluate the system in simulation and in a controlled lab environment.

III. Evaluation

Our OFDM implementation supports four different modulation schemes (BPSK, QPSK, 16-QAM, and 64-QAM), each with two distinct code-rates. Additionally, the receiver implements four different equalization techniques out of which the results obtained from Least Square (LS) equalizer are discussed here, which outperformed all others.

The hardware is supported by a 13.5 V power supply. As a compromise between data rate and reliability, the sampling frequency of the USRP is chosen to be 1 MHz. All presented BER curves are obtained by averaging five runs, each consisting of 10 000 messages of 200 B each.

In order to establish a baseline performance of the OFDM implementation, we first simulated it in AWGN channel (fading effects are not present in our small scale lab environment). Figure 2 shows the achieved BER for increasing Signal-to-Noise Ratio (SNR)-values with each MCS. We then assessed the performance of our VLC setup (shown in Figure 1) in a controlled lab environment. Figure 3 presents the BER curves obtained with the experimental setup. The initial descend of all curves for each MCS in both figures follows the same pattern up till a BER of 10^{-2}. Afterwards, there seems to be a none to major deviation in the curves depending upon the MCS. Additionally, the BER computed with the hardware setup is roughly similar to BER obtained in simulation at lower MCS, however, it is getting worse at higher order MCS, and in the case of 64-QAM, the BER seems to even saturate after certain SNR level. This behavior could be explained by distortion due to the high PAPR of higher order MCS forcing the LEDs to operate in the non-linear region.

With this experimental setup (also validated through simulations), data rates ranging from 0.3 Mbit/s for BPSK to 1.5 Mbit/s for 16-QAM can be achieved. However, due to high BER, 64-QAM in hardware-setup (with a simulated bitrate of 2.7 Mbit/s), did not produce reliable results.

IV. Conclusion

We presented some first performance insights of our novel OFDM-based VLC prototype for vehicular communication. Our system is capable to operate the full low beam of a headlight. As shown, the highly linear headlight driving circuitry in combination with the GNU Radio OFDM implementation offers a highly flexible environment to investigate V-VLC for different MCS. However, we also observed performance limitation, especially at higher order MCS, such as 64-QAM, where the deviation is due to high PAPR and non-linear behavior of the LEDs. Indeed, the amplification and the operation point was optimized to work reliably for Quadrature Phase-Shift Keying (QPSK). Thus, in contrast to RF-Communication, the focus must not only be on the amplifier to reach high linearity, but the whole system has to been taken into consideration. In future work, we plan overcoming the PAPR problems by using pre-equalization at the transmitter. This can be achieved by first measuring the nonlinear transfer function at the transmitter, and then, applying the inverse of that transfer function to the signal, resulting in extended region of linear behavior.

References

[1] C. B. Liu, B. Sadeghi, and E. W. Knightly, "Enabling Vehicular Visible Light Communication (V2LC) Networks," in *ACM VANET 2011*, Las Vegas, NV: ACM, Sep. 2011, 41–50.

[2] A.-M. Cailean and M. Dimian, "Impact of IEEE 802.15.7 Standard on Visible Light Communications Usage in Automotive Applications," *IEEE Communications Magazine*, 2017.

[3] IEEE, "Wireless Access in Vehicular Environments," IEEE, Std 802.11p-2010, Jul. 2010.

[4] "Architecture enhancements for V2X services," 3GPP, TS 23.285 v14.7.0, Jun. 2018. [Online]. Available: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3078.

[5] "IEEE Standard for Local and metropolitan area networks – Part 15.7: Short-Range Wireless Optical Communication Using Visible Light," IEEE, Std 802.15.7-2011, Sep. 2011.

[6] "Multi-Gigabit per Second Optical Wireless Communications (OWC) with Ranges up to 200 meters)," IEEE, Std 802.15.13, Jun. 2017.

[7] S. Kruse, C. Kress, A. Memedi, C. Tebruegge, M. S. Amjad, C. Scheytt, and F. Dressler, "Design of an Automotive Visible Light Communications Link using an Off-The-Shelf LED Headlight," in *ANALOG 2018*, Munich, Germany: VDE, Sep. 2018.

[8] B. Bloessl, M. Segata, C. Sommer, and F. Dressler, "An IEEE 802.11a/g/p OFDM Receiver for GNU Radio," in *ACM SIGCOMM 2013, SRIF Workshop*, Hong Kong, China: ACM, Aug. 2013, pp. 9–16.