Vehicular Visible Light Communications for Automated Valet Parking

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Abstract—Visible light communication (VLC) is a promising Optical Wireless Communications (OWC) scheme which is demonstrated to provide secure, line-of-sight (LoS), and short distance vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Recently, automated driving applications, supported by V2I links are proposed to increase the reliability of the autonomous vehicles. To this regard, we propose a VLC based V2I scheme to increase the V2I communication redundancy of autonomous valet parking (AVP) applications, through jam-free and location based characteristics of VLC. In this paper, we propose a novel architecture to support indoor parking garage online-map update with vehicle on-board data transmissions and location based map update dissemination through bi-directional VLC communications. The proposed system yields error free LoS transmissions with Direct Current Biased Optical OFDM (DCO-OFDM) up to 33 m transmitter - receiver distance enabling vehicle CAN Bus data, infrastructure camera video and LIDAR point cloud data sharing in an indoor parking garage.

I. INTRODUCTION

VLC is proposed as a complementary technology to radio frequency (RF) based V2V and V2I communication systems, utilizing readily available Light Emitting Diode (LED) lights of vehicles and infrastructure as the transmitter with optical detectors as the receiver. Since VLC offers RF interference and jam-free secure LoS communications, VLC systems are foreseen to complement RF based vehicular communication schemes for short distance, mission critical and precision oriented applications, such as platooning and AVP.

AVP allows drivers to drop off and pick up their autonomous vehicle in front of a parking lot without taking care of parking. AVP applications aim to provide numerous benefits, including refueling, cleaning and recharging of the vehicles, without human intervention \cite{1, 2}. Current AVP implementations\cite{3} mainly rely on vehicle on-board perception sensors and pre-loaded offline maps to navigate where cellular connectivity is utilized to reserve the parking spot. However, the reliability issues of vision and LIDAR sensors is a concern, since vehicle vision sensors are challenged by the low illumination and highly reflective environment due to shiny road surface whereas LIDAR sensors suffer from the non-reflective surface and specular reflections.

Since AVP implementations solely based on vehicle perception sensors, vehicle lacks real time infrastructure sensor information regarding maneuvering vehicles and pedestrians beyond its perception sensor range. Moreover, the infrastructure lacks immediate vehicle information to guide the vehicles in the parking garage. Therefore, an online-map, constantly updated through sensor-equipped infrastructure and vehicle on-board information is key to enhance the reliability of the application. Furthermore, real-time online-map sharing with the relevant maneuvering vehicles helps to increase the navigation performance, with the prior knowledge of dynamic objects beyond sensor perception range.

In this paper, we present a VLC based V2I communication scheme to increase the reliability of AVP, and evaluate its bit-error-rate (BER) performance through real world measurements. The focus is on the integration of VLC based communications into the indoor parking garage, which provides location based, need-to-know basis information to the vehicle and infrastructure to generate and share highly detailed online parking garage maps supporting AVP. The proposed VLC based scheme takes charge of sending location based vehicle on-board information to the infrastructure, and streaming up-to-date map information including pedestrian and maneuvering vehicle. The proposed scheme is foreseen to be a low cost, low complexity, and scalable communication solution to increase the reliability of AVP applications.

\textsuperscript{1}https://www.bosch.com/stories/automated-valet-parking/
II. SYSTEM OVERVIEW

The VLC based V2I communications system is based on VLC- on-board unit (OBU) , VLC- road-side unit (RSU), optical detectors and LEDs. The system architecture is depicted in Fig.[1]

The vehicle transmits on-board data through VLC-OBU driven LED lights. Moreover, the infrastructure information is captured and conveyed to the vehicle maneuver planner by the VLC-OBU of the vehicle.

The online-map of the parking space is created with camera, LIDAR, and vehicle on-board information. The map server of the infrastructure is responsible to fuse and disseminate the online-map updates through infrastructure LED lights driven by VLC-RSU. VLC-RSU also captures vehicle on-board information by optical receivers.

VLC provides a unique advantage of location based transmissions due to its LoS characteristics. Therefore, only the relevant part of the online-map is transmitted from the infrastructure LEDs. On the other hand, even though vehicle continuously transmits information through its LED lights, the optical receivers deployed on the infrastructure capture vehicle data only at certain locations, constrained by the detector’s LoS and field of view (FoV). Therefore, the VLC based V2I communications enables location specific information exchange between vehicles and infrastructure, decreasing on-board computation needs, eliminating unnecessary information, while providing RF interference and jam-free secure communications.

III. SYSTEM DESCRIPTION

In this paper, we demonstrate a V2I scheme, that enables information exchange with LED lights and optical sensors of the vehicle and infrastructure. The vehicle transmits deceleration, acceleration, speed and brake status information and receives LIDAR point cloud map and video from the infrastructure with VLC. On the other hand, optical detectors deployed in the parking garage receive vehicle data to aggregate the information into the LIDAR point cloud map. The constantly updated aggregated map is disseminated by infrastructure LED lights to the vehicle.

The system setup is depicted in Fig.[2] At the vehicle side VLC-OBU is responsible to convert vehicle CAN Bus information into DCO-OFDM frames and drive vehicle LEDs with baseband DCO-OFDM signals and required DC bias. Moreover, it incorporates an optical receiver to capture information from infrastructure LEDs. VLC-OBU is controlled with LabView software and equipped with a Software-Defined Radio (SDR)(NI-2920 with LFTX/RX Daughter board), LED driver circuit, and an optical photodetector (Thorlabs PDA100A).

At the infrastructure, VLC-RSU converts LIDAR point cloud data into DCO-OFDM frames, drives the infrastructure LEDs with base-band DCO-OFDM signals and required DC bias. VLC-RSU incorporates the same hardware with VLC-OBU, where it is optimized to continuously stream map information instead of periodic vehicle on board information.

Figure 2: VLC based V2I communications system architecture.

Table I: System Setup Specifications

| Parameter  | Value          |
|------------|----------------|
| IQ Rate    | 200 kHz        |
| Modulation | 4-QAM DCO-OFDM |
| $N_{FFT}$  | 64             |
| $N_{PILOT}$| 4              |
| Data Rate  | 375 kbps       |

IV. EVALUATION

To determine the reliability of the considered VLC based V2I scheme, we evaluate the BER performance of V2I VLC links with respect to varying transmitter-receiver distance and receiver angles to incorporate LoS and directed-line-of-sight (DLoS) scenarios. System setup specifications are listed in Table[1]. For LoS VLC link of 39 m, $2.4 \times 10^{-5}$ BER is achieved with 4.83 dB signal to noise ratio (SNR), whereas $4 \times 10^{-5}$ BER is obtained for DLoS configuration with 20.98 dB SNR. For DLoS the receiver is inclined towards the parking structure wall, where it captures distorted signal through reflection and scattering along with partial LoS signals. Moreover, error free transmissions up to 33 m VLC link distance without any error correction coding is observed with a minimum SNR value of 23.42 dB. Therefore, VLC can be considered as a viable candidate to increase the redundancy of V2I indoor parking garage links of AVP applications.

V. SUMMARY

The VLC based online-map update and vehicle data dissemination is presented as a candidate technology to increase the reliability of indoor parking garage applications including AVP. Since, VLC based V2I schemes depend on spatial isolation, they are favorable for location based, low complexity, interference and congestion free V2I communications. The proposed architecture is evaluated with real world implementations, where indoor parking garage is experienced to provide stable VLC links including dynamic scenarios, as they provide ambient noise free channel for VLC. Moreover, due to multi-path fading resiliency of VLC, reflections from ground surface, walls, and nearby objects are observed to have limited adverse effects on the system performance.

REFERENCES

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