Design and Implementation of a Next-Generation Hybrid Internet of Vehicles Communication System for Driving Safety

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Abstract —In this paper, we design and implement a next-generation hybrid Internet of Vehicles (IoV) communication system, which integrates DC-based power line communication (PLC), visible light communication (VLC), and 3G/4G mobile communication techniques. As a result, the proposed system can achieve the goal of interconnection of in-vehicle (IV), vehicle-to-vehicle (V2V), and 3G/4G mobile networks, and therefore can provide flexible services and driving safety. The prototype system implemented has been tested to demonstrate the video transmission through PLC on a real vehicle and V2V data transfer by VLC.

Index Terms—DC power line communication (PLC), driving safety, Internet of Things (IoT), Internet of Vehicles (IoV), visible light communication (VLC)

I. Introduction

Nowadays, the Internet of Things (IoT) techniques have widely been applied in many fields such as smart homes, intelligent campuses, smart cities, and intelligent transportations. The concept of the IoT techniques is also employed in the automotive ecosystem and provides mechanisms to integrate connected components in automobiles, thus forms connected cars named as Internet of vehicles (IoV) [1].

Datta *et al.* [2] pointed out that the most important claim of the next-generation IoV development is to provide seamless interoperability among vehicular components, consumer smart mobile devices, and some external computational platforms (such as edge computing devices and cloud-based servers).

Recently, the telematics technology is no longer limited to the integration of electronic components and multimedia applications in a vehicle but is gradually in the way toward developing the next-generation IoV communication systems.

The advanced IoV communication could integrate in-vehicle (IV), vehicle-to-vehicle (V2V), low power wide area networks (WANs) [3], vehicle-to-infrastructures (V2I), and 3G/4G mobile networks to provide flexible services and driving safety.

The Telefonica marketing survey reveals that about 73% of people thought the most important functions of the next-generation IoV should be provided are safety related issues such as accident prevention and accident reduction [4], [5].

Therefore, the advanced active safety will be one of the most important applications of next-generation IoV. As a result, the key issue of next-generation IoV is to develop active driving safety application services such as collision avoidance, traffic-sign recognition, pedestrian anti-collision, cooperative lanes driving safety system, and dynamic & static path guidance [5].

However, the current IoV communication system is still insufficient to meet the need of the advanced active driving safety applications.

To face such need, we propose a next-generation hybrid IoV communication system, which integrates several main heterogeneous networks to accomplish interconnection of IV (DC-based PLC [6] and CAN bus with OBD-II [7]), V2V (VLC [8]), and 3G/4G networks to achieve the purpose of driving safety.

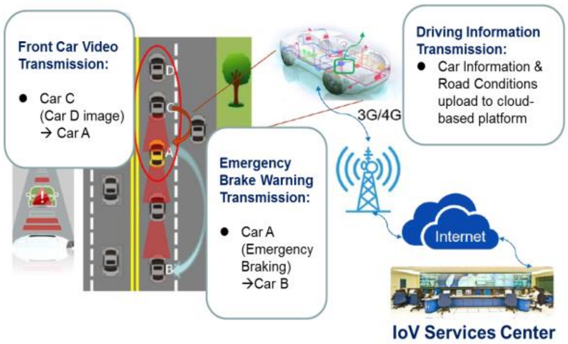

Fig. 1. A scenario of an advanced active driving safety application of our proposed system

Fig. 1 shows a scenario of an advanced active driving safety application that uses our proposed system. A camera and a displayer are equipped and linked by PLC in the front and rear of a car, respectively. The VLC receiver and transmitter are also equipped in the front and rear of a car.

For IV communication, the DC-based PLC can transmit the image of the front car (Car D) to the rear car

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(Car A) via rear display in Car C. Let Car A's view won't be blocked by Car C. The V2V communication is linked by VLC.

An emergency brake message and related vehicular information (i.e., right/left turn signal and speed) of the front car can be passed to the rear car via VLC for collision avoidance purpose.

For V2I communication, car information can be uploaded to vehicular information cloud service platform via 3G/4G networks. Thus maintenance service center staff can monitor the current vehicle driving status and provide assistance immediately if needed [9].

This paper contributes to provide a communication links for IoV and V2V by using the PLC and VLC communications. And therefore we will more focus on the developing of PLC and VLC.

The remainder of this paper is organized as follows. The proposed system is introduced in Section II. A prototype and experiments of the proposed system are demonstrated in Section III. Finally, we make a conclusion in Section IV.

II. Proposed System

The proposed system consists of DC-based PLC modules, VLC TX/RX modules, a vehicular heterogeneous networks gateway, and a vehicular information cloud service platform. The system blocks of the proposed system are shown in Fig. 2 and will be expressed as follows.

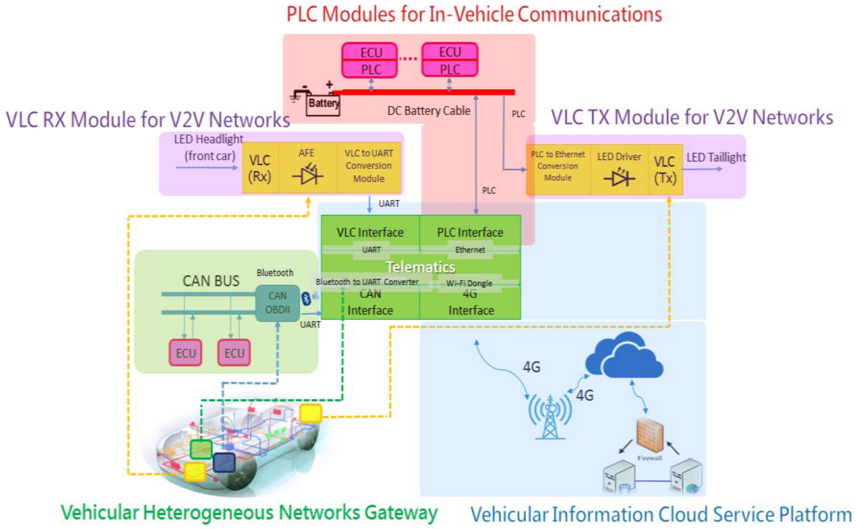

Fig. 2. The proposed system.

A. DC-based Power Line Communication Modules

Among the developed IV communication techniques, the DC-based PLC is the one not only can efficiently provide communication but also can reduce IV communication cables usage in a vehicle [10].

With the gradual upgrading development of the modern vehicle and even an electric vehicle, IV communication cables may lead a vast growth of the whole weight in a vehicle.

Hence, DC-based PLC is very suitable for the IV communication purpose. Several previous works about the DC-based IV PLC have been published in [11]-[13]. However, the developed DC-based PLC systems were not implemented in a real vehicle.

In this work, we employ the Qualcomm QCA6410 SoC chip, which is with the Ethernet interface and the HomePlug AV (HPAV) PLC Protocol Bridge to implement the DC-based PLC transceiver modules.

The DC-based PLC transceiver module is designed to achieve high speed transmission for sending a high quality full-HD video real time and therefore can meet the requirement of the next-generation IoV-based active driving safety applications. Figure 3 shows the architecture of the proposed DC-based PLC transceiver module.

The transmitting and receiving signal connected pins of the QCA6410 can't directly be connected to the 12V-DC power line cables. We design a coupling circuit for connecting signals to the 12-DC IV power line cables. Moreover, a protection circuit is also designed to prevent the transient high voltage pulse to damage Qualcomm QCA6410 SoC chip.

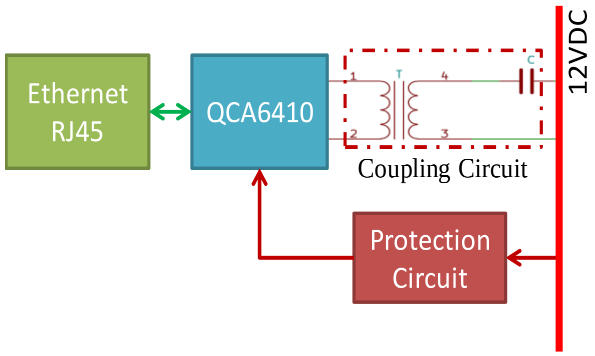

Fig. 3. The architecture of DC-based PLC transceiver module.

B. Visible Light Communication (VLC) TX/RX Modules

The block diagram of the proposed VLC transceiver is shown in Fig. 4. In the transmitter (TX) module, the 28-bit vehicle information obtaining from vehicular heterogeneous networks gateway is encoded by Manchester code (as shown in Fig. 5), where a bit 0 is given by a low-to-high transition and a bit 1 is represented as high-to-low transition.

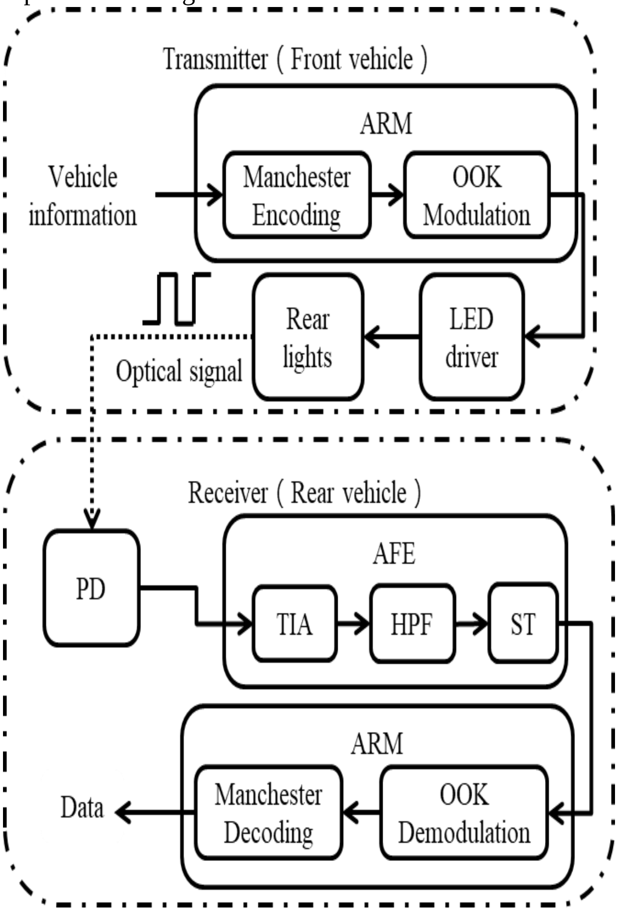

Fig. 4. The block diagram of VLC transceiver.

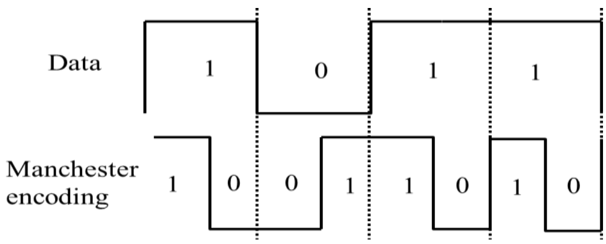

Fig. 5. Manchester encoding.

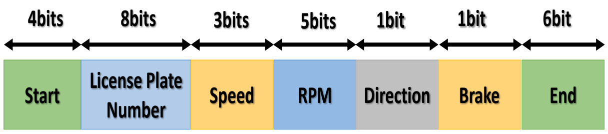

Fig. 6. The frame format of vehicle information for VLC system.

The frame format of the 28-bit vehicle information is given in Fig. 6, where the fame begins with four-bit start field and stops with six-bit end field. To achieve driving safety application, the eighteen bits vehicle information including the vehicle speed, engine revolution per minute (rpm), turn signal, and brake signal are also considered within a frame.

Particularly, we consider a commercial vehicle tail (rear) LED light as the transmitter, where the corresponding driver circuit is designed to receive the on-off keying (OOK) modulated signal. The OOK modulation used in this paper is to blink the commercial LED.

In the receiver (RX) module, the photodiode (PD) firstly converts the received optical signal into an electrical signal and the obtained electrical signals are fed into the transimpedance amplifier (TIA). However, the converted signal is usually weak and plagued by low-frequency noises from ambient light or indoor fluorescent light.

Therefore, a high pass filter (HPF) is implemented subsequently to remove any remaining low-frequency noise. The filtered signals input to the Schmitt trigger (ST), which is a comparator converting an analog input signal to a digital output signal.

Finally, a Manchester decoding algorithm is introduced to recovery the digital binary data. The detailed schematics of the receiver have been demonstrated in [8].

C. Vehicular Heterogeneous Networks Gateway

An in-vehicle infotainment (IVI) telematics platform is used to serve as a vehicular heterogeneous networks gateway. And firmware programs are written to handle the interface processes among several network protocols, namely PLC, VLC, CAN bus/OBD-II, and 3G/4G mobile networks. The goal of this gateway is to accomplish information exchange among these heterogeneous network protocols.

D. Vehicular Information Cloud Service Platform

Information cloud service platform is implemented by a server. Vehicle & driver information and traffic event can be automatically uploaded to the platform through the IVI telematics platform. An example of execution screen is demonstrated in Fig. 7.

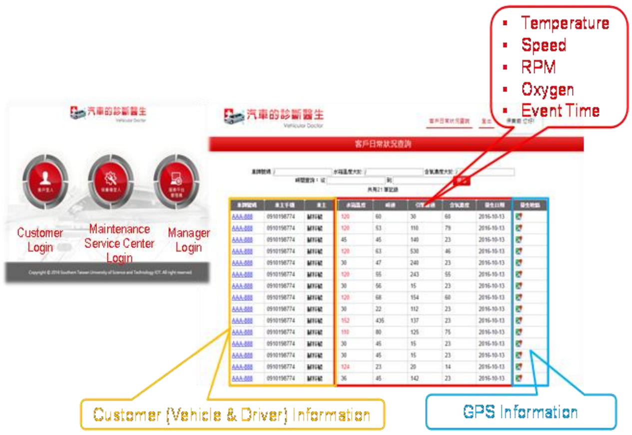

Fig. 7. An execution screen of vehicular information cloud service platform.

III. Experimental Results

The prototype of the proposed next-generation hybrid IoV communication system is presented in Fig. 8. And the functions described in Section II are tested.

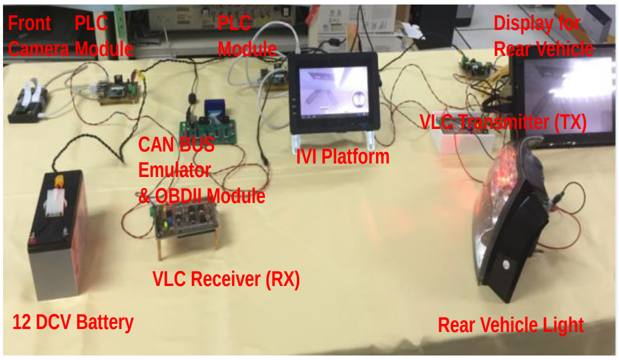

Fig. 8. The prototype of the proposed system.

As mentioned earlier, this paper will more focus on developing the PLC and VLC communications. The implemented DC-based PLC transceiver module is shown in Fig. 9.

Fig. 9. The implemented DC-based PLC transceiver module.

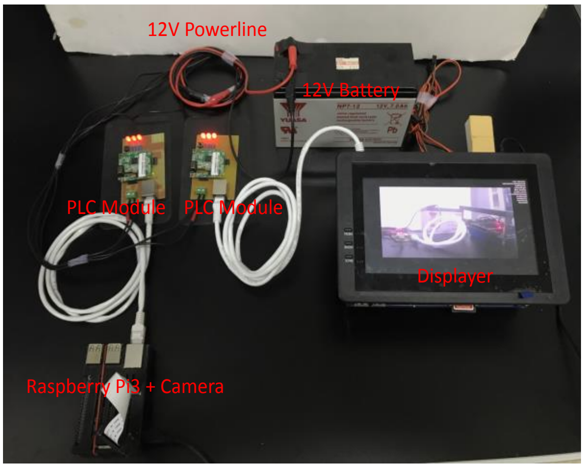

Fig. 10. The prototype of DC-based PLC [6].

Fig. 10 shows the prototype of our DC-based PLC system [6] for IV transmission purpose. A 12V vehicular battery is used as power source.

A camera mounted on a Raspberry Pi 3 records the video and the full HD video is then transmitted to displayer though the PLC transceiver. This PLC system has also been tested on a real vehicle as shown in Fig. 11.

The PLC transmitter with a camera placed in the frontend of a vehicle for recording video in front of the vehicle. The PLC receiver with a display shows the video for the driver of the rear car. This application function will be useful for the driving safety.

Fig. 11. The DC-based PLC transceiver tested on a real vehicle.

Table I shows the experimental results of the DC-based PLC transceiver modules. In prototype test environment (as in Fig. 10), the speed of upload and download achieves 95.8 Mbps and 96.0 Mbps, respectively.

In real vehicle test environment (as in Fig. 11), the speed of upload and download achieves 78.4 Mbps and 65.4 Mbps, respectively. The data rates in real vehicle test environment are less than those in the laboratory, which is expected because the engine noise and the multipath effect exist in real vehicle.

TABLE I: EXPERIMENTAL RESULT OF DC-BASED PLC TRANSCEIVER MODULES

Test Environment	**Speed (Mbps)**	
	Upload	**Download**
Prototype	95.8	96.0
In Real Vehicle	78.4	65.4

Packet Size: 8 KBytes Data Transmission: 90 MBytes

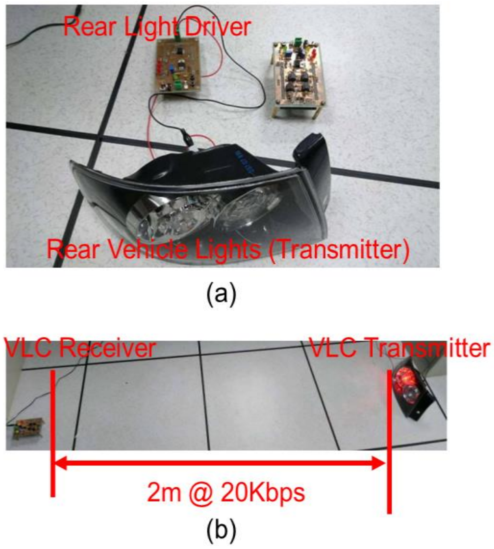

Fig. 12. The photograph of the prototype of VLC TX/RX modules.

Fig. 12 shows the prototype of our proposed VLC TX/RX modules, which is integrated with rear vehicle lights. Currently, the distance of transmission is 2 meters and up to 20 Kbps, as demonstrated in Fig. 12 (b).

IV. Conclusions

In this paper, we have proposed and implemented a next-generation hybrid IoV communication system, which was composed of DC-based IV PLC modules, VLC TX/RX modules, a vehicular heterogeneous networks gateway, and a vehicular information cloud service platform. We also built up the interface of vehicular heterogeneous networks.

We have successfully installed and tested PLC modules of the proposed system in a real vehicle. For further work, VLC modules of the proposed system will also be installed and tested in real vehicle for verifying V2V communication in real vehicle environment.

The proposed VLC module will be continuously improved for increasing transmission distance. The driving safety aided mechanism [15] will be integrated into our display by the on-screen display (OSD) technology for alerting rear vehicles. Also, we will try to integrate some other communication protocols such as DSRC (Dedicated Short Range Communications), RoLa-based LPWAN (Low-Power Wide-Area Network), and SigFox for V2I communication applications.

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