A Bi-directional Visible Light Communication System Based on DTMB-A

Yangtian Yan, Bangcheng Sun, Yun Zhao, Zhenhui Huang, Hui Yang, Jian Song, *Senior Member, IEEE*
Tsinghua National Laboratory for Information Science and Technology
Department of Electronic Engineering, Tsinghua University, Beijing 100084, P.R. China
CNR Tangshan Railway Vehicles Co.,Ltd R&D
E-mail:yyt12@mails.tsinghua.edu.cn

***Abstract*—In this paper, we propose a new method to realize bi-directional visible light communication (VLC). We implement the bi-directional VLC system based on digital television terrestrial multimedia broadcasting-advanced (DTMB-A) and apply time-domain synchronous OFDM (TDS-OFDM) in the physical layer. A new type of APSK constellation with Gray mapping is used to provide a considerable shaping gain in both the independent demapping and the iterative demapping. Our system realizes the goal of bi-directional transmission between the station and the train, by which we could download driving data conveniently instead of getting on the vehicle. We also measure the output spectrum of photodetector and present our analysis. Through the experiment testing, the download rate of this bi-directional VLC system can achieve 63.67 Mb/s and the physical layer rate can reach 180Mb/s when two computers are connected through our system within the distance of 0.1m. With transmission distance exceeding 0.1m, the signal using 256APSK constellation mapping and 1/2 code rate can still be normally demodulated.**

***Index Terms*—bi-directional visible light communication (VLC), light emitting diode(LED), digital television terrestrial multimedia broadcasting-advanced (DTMB-A).**

I. Introduction

Due to the advantage of low cost, long lifetime and high efficiency, light emitting diode (LED) has been widely used and is replacing the fluorescent lamp and incandescent lamp in the field of lighting, displaying and etc [1]. White LED also has the advantage of good modulation performance and high response sensitivity which makes it possible for the optical communication purpose: the flickering light emitted by white LED can be used to send messages. At present, the power of commercialization white LED has reached 5W. Meanwhile, the vision that white LED luminous efficiency exceeds 100 lm/W and achieves 200 lm/W (which can completely replace the existing lighting equipments) can be realized in the near future. Intensity modulation and direct detection technology (IM/DD) is widely used in VLC systems, which means that the intensity modulated signals can be directly recovered by the photoelectric detector at the receiver [2]. It only requires little modification to the existing infrastructure to achieve the purpose of illumination and communication simultaneously. VLC is a new emerging wireless optical communication technology with the rapid spread of the LED. VLC has the advantage of wide spectrum resource, extensive application scenario, high transmission power, no electromagnetic issue and no radiation problem harmful to people, which can be a great supplement to infrared and wireless communication. Therefore, VLC has great development prospects, has attracted wide attention and research. Now, it has been widely used in the field of indoor positioning system, smart transportation system and underwater communication [3] [4] [5].

Although VLC develops rapidly, there are still some technical bottlenecks. The biggest challenge is the limited modulation bandwidth of white LED, which limits the transmission rate of the system. Researchers have proposed many schemes of extending the modulation bandwidth and improving the spectrum efficiency, thereby improving the transmission rate of the system, such as adding a blue filter before signal detection, high order modulation, OFDM, equalization technique, and etc [6]. So far, the experimental rate of one-way transmission within 30 cm has reached 3.4Gb/s by using discrete multi-tone (DMT) modulation and avalanche photodiode (APD) at the receiver [7]. However, bi-directional transmission especially the uplink transmission is a technical challenge for VLC. Some researchers propose to realize the bi-directional transmission using retro-reflecting device, which is low in both transmission rate and modulation bandwidth because of its pure physical method. The scheme to implement the uplink transmission by radio frequency is inappropriate especially in the radio sensitive environment like airplane and hospital. The application of uplink transmission using infrared technology is restricted by short transmission distance, low transmission rate and high demands of power [8]. Y.F.Liu and others use time division duplex (TDD) to realize bi-directional transmission and apply On-Off Keying (OOK) modulation both in the uplink and downlink transmission. However, synchronization is a great challenge and it can only reach the rate of 2.5Mbit/s, which is too low [9] [10].

In this paper, we analyze the challenges existing in bi-directional VLC and propose a new method to realize bi-directional VLC for high-speed railway. We implement the bi-directional VLC system between the train and the station, in order to download the vehiclear driving data conveniently without getting on the vehicle when the train is pulling into a station or repaired at the garage. This bi-directional VLC system is cost-effective, easily implementable and conveniently upgrading, which can be applied to numerous scenarios.

The rest of the paper is organized as follows. In section II a description of our bi-directional VLC system is given.

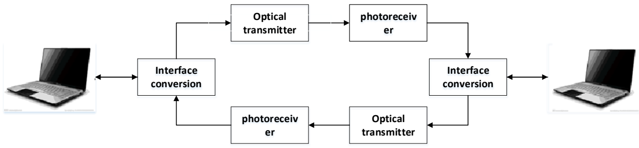

Fig. 1. bi-directional VLC system block diagram between the train and the station.

Fig. 2. bi-directional VLC system entities between the train and the station.

Section III investigates a demonstration and gives performance evaluation. Finally, the conclusions are drawn in section IV.

II. System Description

The block diagram of bi-directional VLC system between the train and the station is shown in fig.1. The entities of bi-directional VLC system between the train and the station is shown in fig.2. As is shown, the computer output two-way IP data turn into two one-way transport stream (TS) data after interface converting and are transmitted by two sets of one-way VLC systems. This system is based on DTMB-A standard, and applies TDS-OFDM at the physical layer to realize the comprehensive processing of signals in both time domain and frequency domain. Double PN sequences are inserted into the guard interval. PN-MC sequences are the Inverse Discrete Fourier Transform(IDFT) of frequency domain binary sequence (we use double PN-MC256 in our system), which can be used for synchronization and channel estimation. Thus it does not need additional pilot overhead and possesses high spectrum efficiency. The system parameters are listed in table 1.

The digital part of interface converting, optical transmitter and optical receiver are integrated into one piece of FPGA in order to simplify the design and improve the reliability. The block diagram of the optical transmitter-receiver is shown in fig.3. Fig.4 shows the entities of the optical transmitter-receiver. The functional block diagram of digital signal processing in FPGA is illustrated in fig.5.

At the transmitter, The IP data turn into one way TS data after interface converting. To ensure the randomness of the transmitted data, the data stream input from interference need scrambling. Scramble is a pseudo-random binary sequence (P RBS) with maximum length of 32767, which is generated from the linear feedback shift register (LFSR) shown in

TABLE I
SYSTEM PARAMETERS

working band	2-26MHz
effective bandwidth	22.68MHz
Guard interval	double PN-MC256
FFT	4096
Constellation mapping	256APSK
FEC code rate	1/2
FEC code length	15360
net load	80.07Mb/s
IP data transmission rate	> 50Mb/s
physical layer rate	180Mb/s

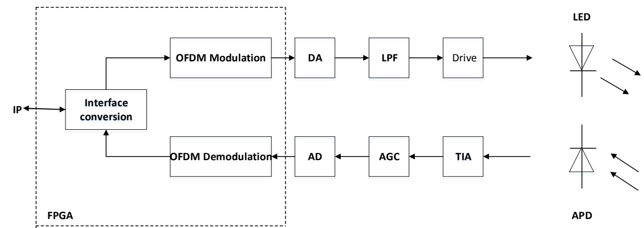

Fig. 3. block diagram of the optical transmitter-receiver.

fig.6. Its initial phase is 100101010000000, and its generator polynomial is [11] [12]:

$$G(x) = 1 + x^{14} + x^{15} \quad (1)$$

Scrambling data are produced by the input bit stream and the PN sequence under the rules of mode two operation. The bit stream after scrambling is dealt with forward error control coding (FEC) using low density parity check code (LDPC). The parameters of the LDPC code are shown in Table 2 (In this system, the code rate is 1/2 and the code length is 15360 bits). Then we make constellation mapping and add the double PN frame head to form data frames. The control frame and the data frame synthesize into one multiframe signal. For base band processing, we use square root raised cosine (SRRC) filter with roll-off factor $\alpha = 0.05$ for baseband pulse shaping to obtain the base band transmission signals. This signals form radio-frequency (RF) signals after quadrature up-conversion. The RF signals after digital-to-analog conversion (DA), low pass filter (LPF) are modulated to the light intensity to drive LED. It is worth mentioning that a novel APSK constellation with Gray mapping is used in DTMB-A system [13] [14]. We use 256 APSK constellation mapping in our system as is shown in fig.7.

As is shown in fig.7, 256 APSK consists of 8 rings and there are 32 constellation points on each of the rings. The most prominent characteristics of APSK are: the number of constellation points on each ring is the same; The constellation points on one ring have identical initial phase. Thus, the constellation points on each ring constitute phase shift keying (Gray-PSK) and the constellation points with the same phase form pulse amplitude modulation (Gray-PAM). In accordance with information theory, the channel input has to follow Gaus-

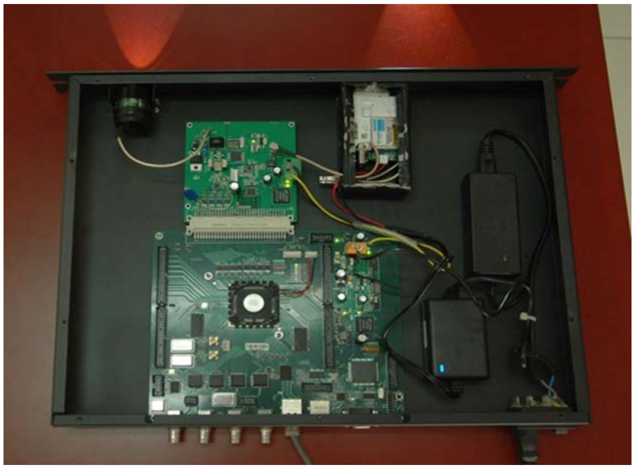

Fig. 4. The entities of the optical transmitter-receiver.

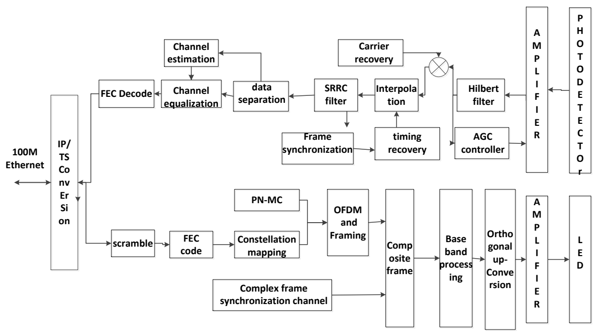

Fig. 5. functional block diagram of FPGA inner digital signaling processing.

sian distribution so that the system can achieve the channel capacity [15] [16]. However, in real systems, channel input can not follow Gaussian distribution due to the loss called shaping. APSK constellation diagram can effectively reduce the shape loss compared with QAM constellation diagram because the constellation diagram approximates better to Gaussian distribution. But normal APSK has no Gray mapping, so it has to explore its potential gain through iterative demapping. While APSK, which is used in DTMB-A, has Gray mapping and provide considerable shaping gain in the case of independent demapping and iterative demapping [17] [18].

At the receiver, APD photodetector generates light current after receiving the signals from LED lights. The light current is sent to OFDM demodulation module after transimpedance amplification, automatic gain control (AGC) and analog-to-digital conversion (AD). After demodulation, the TS stream reverts to IP data at the interface transfer module.

III. Demonstration and Performance Evaluation

We implement the experimental platform, whose block diagram is shown in fig.8: We use a computer to simulate

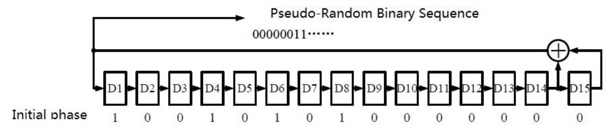

Fig. 6. block diagram of the scramble.

TABLE II
LDPC code parameters

code rate	code length(bit)	Information bits	code length(bit)	Information bits
1/2	61440	30720	15360	7680
2/3	61440	40960	15360	10240
5/6	61440	51200	15360	12800

the trip computer on the train. We set up a FTP server, whose output IP data are connected to an optical transmitter-receiver through network cable. The IP data are transmitted through bi-directional VLC. The output IP data of another optical transmitter-receiver are connected to an Ethernet switch through network cable. We download the required files using other computers to log in the server in another room. Fig.9 shows the output spectrum of the APD detector. As is shown in fig.9, the spectrum is tilted because of the tilted LED frequency response. The signal to noise ratio (SNR) is quite good, and the signal using 256APSK constellation mapping and 1/2 code rate can still be normally demodulated when the transmission distance excesses 0.1m.

After testing, we need 1 minute and 29 seconds to download a file of 708.38MB. The average downloading rate is 63.67Mb/s. Fig.10 is the screenshot of downloading files. This platform can simulate the driving data downloading process when the train is pulling into a station or repaired at the garage.

IV. Conclusion

We propose a new method to realize bi-directional VLC, applying a flexible multiframe structure, the TDS-OFDM technology at the physical layer and a new coding modulation based on Gray-APSK. Bi-directional transmission especially the uplink transmission is a technical challenge for VLC. . We implement an bi-directional VLC system, which realizes the goal of downloading driving data conveniently and efficiently without getting on the vehicle. After testing, the download speed can reach 63.67Mb/s with a transmission distance of 0.1m and the physical layer rate reaches 180Mb/s. The signal using 256APSK constellation mapping and 1/2 code rate can be normally demodulated, with transmission distance exceeding 0.1m.

Acknowledgment

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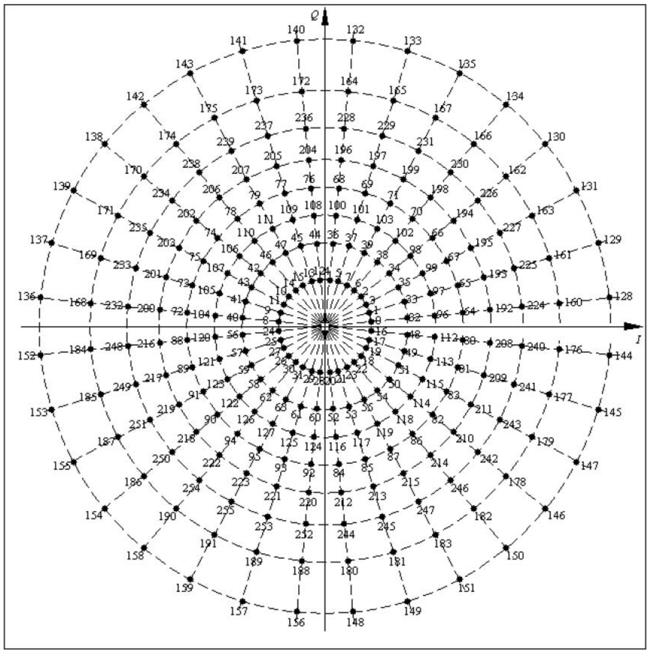

Fig. 7. 256 APSK constellation mapping.

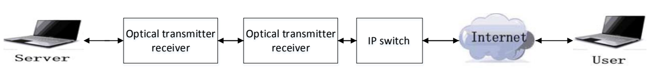

Fig. 8. the experimental platform of downloading driving data.

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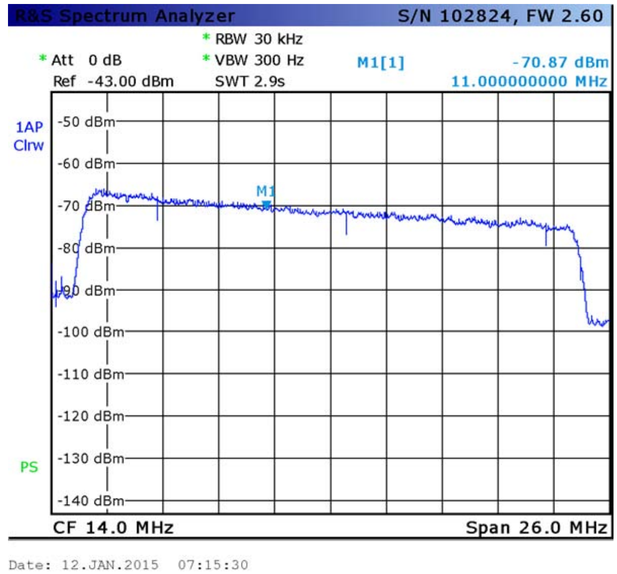

Fig. 9. the output spectrum of optical detector.

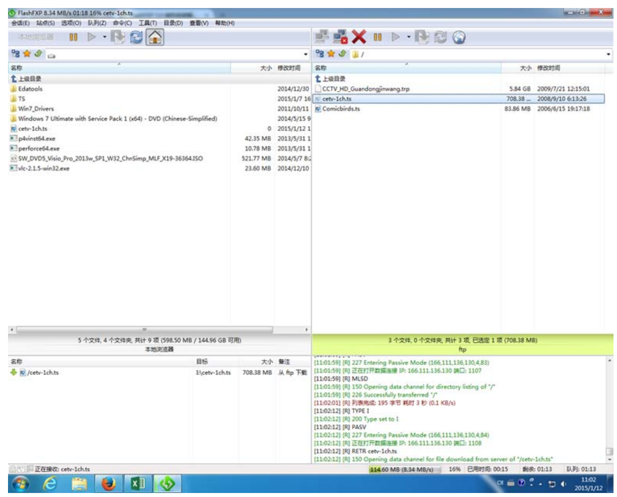

Fig. 10. the screenshot of downloading files.

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