Connected OCC Signages for Small-Cell Networks

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***Abstract*—** This paper investigates an emerging technology called Optical Camera Communication (OCC) that targets visible light spectrum, realized by LED and camera for data transmission and reception. Herein we pay a particular interest in Digital Signage, which has multiple LEDs with texture effect, enabling the delivery of short messages to smartphone users within a small network called small-cell operating at a short distance (within 50m). The implemental performances of different modulation schemes are analyzed, and methodological discussions are shown.

Keywords—*Optical Camera Communication; OCC, optical spectrum; camera; Digital Signage; IEEE 802.15.7m; modulation performance.*

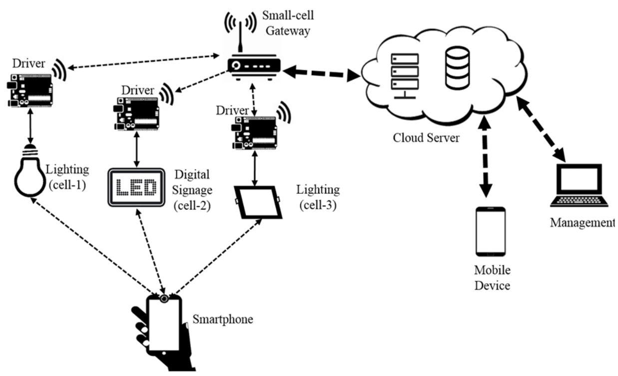

Fig-1. Overall architecture of OCC Small-Cell

I. INTRODUCTION

The exponential increasing demand on wireless connectivity has been reported. Conventional radio-frequency (RF) spectrum have reached or are close to achieving their peak capacity and efficiency. The shortage of spectra bandwidths because most frequencies have already been allocated. Undeniably, the optical spectrum becomes an emerging technology for wireless connectivity.

Located in the upper part of wavelength chart, optical wavelength brings us the great opportunity for wireless communication systems. As compared to RF, valuable advantages to optical wireless communication are introduced such as none-interference to the radio waves, light-of-sight experience, and an extremely large spectrum.

As a leading role, the first IEEE standard association was published in 2011 [1] brings us a promising future for optical wireless communication (OWC). Despite the rapid proliferation of OWC, in the absence of its killer app, the updates on OWC technology to adapt to a variation of lighting sources and photodetectors (including cameras) are needed. The on-going standardization of IEEE, namely IEEE 802.15.7m task group [2], has covered the co-existence of technologies and the support of a variety of devices very well. Subsequently, from January 2016 to the date, the submission of technological proposals has been successful and the fourth draft of the standard specification, D4 version is to be released by the end of October 2017. Hopefully, the standard can be published in the middle of 2018.

Overcoming multiple disadvantages of cameras in communication due to their primary function in capturing images [3], the research effort has recorded [4] that the supplementary communication is served well with cameras just the way photodiodes can do. Camera based OWC is also known as Optical Camera Communication (OCC). Multiple modulation schemes for OCC have been proposed, being suitable for various applications and services [4]. The content of this paper introduces the up-to-date OCC systems, particularly suggests a communication scheme as the use-case of digital signage for delivering data.

The remainders of this paper are organized as follow. In Section 2 we discuss the architecture and suitable modulation schemes for OCC small-cell. In Section 3 we present several experimental results of selected schemes. Finally, Section 4 discusses and concludes our work.

II. OCC SMALL CELLS

A. System Architecture and Scenario

Figure 1 illustrates an overall architecture of connected lightings for the small-cell network. Based upon the lighting systems and the choice of modulation schemes, the covering distance of small-cell network connectivity is from 10m to 50m.

Different classes of the light sources, such as ceiling lights and digital signage, are applicable for OCC. Among those, digital signage with perceptible texture effect delivered to human is of interest. However, a large number of LEDs blinking randomly is a challenge for OCC.

B. Selection of Modulation Schemes

Baseband modulation is commonly used for OCC to deal with the limitation that comes with a camera receiver. Common modulation techniques, such as On-Off-Keying (OOK),

Published by Visible Light Communications Associated at "2nd International Conference and Exhibition on Visible Light Communications 2018" on March 16, 2018 in Yokohama, Japan.

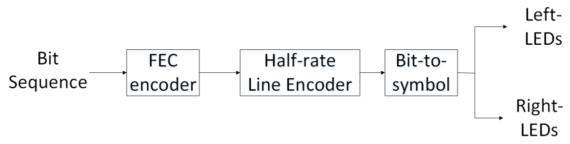

Fig-2. Reference architecture for S2-PSK transmitter

Variable Pulse Position Modulation (VPPM), Frequency Shift Keying (FSK), etc., are also implemented for OCC systems. Among different modulation candidates that have been introduced to TG7m [5], we contributed several communication systems as highlighted in table 1.

Table 1. Possible Modulation Schemes for OCC Small-cells

Modulation scheme	Tx type	Expected bit rate	Expected coverage
M-FSK/OOK	Indoor LED panel	150bps	3m
M-FSK	LED bulb	50bps	3m
S2-PSK	Texture Signage	10bps	20m
S2-PSK	Traffic light	200bps	30m

The choice of S2-PSK is made as the reasons follows. Firstly, the integration of communication with texture effect is mandatory. Secondly, either a global shutter camera or a rolling shutter camera (smartphone camera is of this type) is applicable for decoding modulated data. As the frame rate of the camera is limited to the image processing tasks, the optical clock rate is selected at 10Hz/20Hz. As a consequence, the bit rate (error-free) is 10bps/20bps respectively.

III. Experimental Results

A. S2-PSK modulation

A reference architecture to implement S2-PSK is as shown in Figure 2. The bit sequence is protected by Forward Error Correction (FEC) and then encoded by a half-rate line encoder. For a short packet protection, we have implemented several FEC as given in tale 2. The half-rate line encoding table as given in table 3 serves two purposes: (i) to support Rx decoding under the dismiss of one LED among a pair of LEDs seen by Rx (rarely happen but helpful), and (ii) to protect the signal from the error caused by the rotation of camera and the error caused by the time deviation between a pair of light sources on the rolling image (main purpose of this line coding).

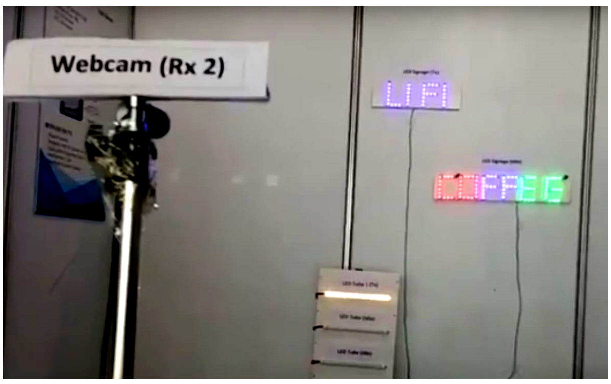

Fig-3. A demo of OCC using textured-LEDs and LED tube

The number of LEDs on the textured signage is divided into the left part and the right part (roughly equal division) so that all two waveforms output from the bit-to-symbol converter can be used to driver 2-dimensional LED signage.

Table 2: The choice of FEC

FEC option	Output packet length (bits)
RS(15,11)	60
RS(15,7)	60
BCH(7,4,1)	7
BCH(15,7,1)	15
BCH(15,5,3)	15
BCH(31,11,5)	31

Table 3: Half-rate line encoding

Duration	one bit time	one bit time
Data bit	0	1
RLL coding	0 0	0 1

As designed, the waveforms to all LEDs shall have square waveform so that the demodulation becomes simple. Two waveforms to drive a pair of LEDs have the same phase or inverse phases depending on a single bit output from the half-rate line encoder.

The optical clock rate (10Hz or 20Hz) is freely selected from the modulation rate. This selection is because the selection of modulation rate is to generate the light intensity change being imperceptible to human eyes (greater than 200Hz) while the selection of the optical clock rate is dependent on the camera frame rate being supported.

B. System Configuration

The capture of system demo is as illustrated in Figure 3.

The probability of bad-sampling (denoted as *prob*(*bs*)) that happens due to the long sampled-and-hold time of camera shutter is calculated as

$$\text{prob}(bs) \approx \frac{t_e}{T_{mod}}$$

where T_{mod} is the chosen pulse interval for modulation and t_e is the sampled-and-hold time of the camera shutter (also known as the integration time).

Camera devices that we are using, such as Google Nexus smartphone camera and PointGrey camera, support the integration time as small as ten us. As a consequence, the modulation rate is freely chosen in between 600 Hz and 10 kHz to achieve a reasonable sampling error rate. From our experiment, the modulation frequency greater than 600 Hz is recommended for the indoor non-flickering characteristic while half-rate line encoder is applied in conjunction with S2-PSK bit-to-symbol mapping.

(a)

(b)

(c)

(d)

Fig-4. The processing procedure of textured-LED at a receiver (a) An image of textured-LED captured at 7m distance, (b) The detection of light sources, (c) Grouping LEDs and RoIs defining, (d) Data reception from the signaling RoIs

C. *Experimental Demonstration*

Like the other communication systems, the OCC receiver side is more complex in compared to the transmitter side. In the S2-PSK system, the difficulty comes from the detection of multiple LEDs and grouping those into a Region-of-Interest (RoI) for the latter waveform extraction process. Figure 4 demonstrates the procedure of processing at the receiver side.

Similarly, the demodulation of signals from LED bulbs has its own challenge. In both cases, the detection and tracking of LEDs is essential to the extraction of their waveforms. The detection of signaling-RoI (i.e. light source area) for textured signage is more complex than that for typical LED bulb. Once the waveforms are extracted, the exclusive-OR (XOR) operators are operated to decode the single bit transmitted.

Figure 5 shows an illustrative process for the demodulation of LED bulbs. From our experiment, the distance at which the size of LED on the captured image is greater than three pixels (in height) can provide an acceptable performance for the XOR decoder. Consequently, 20m distance can be achieved.

(a)

(b)

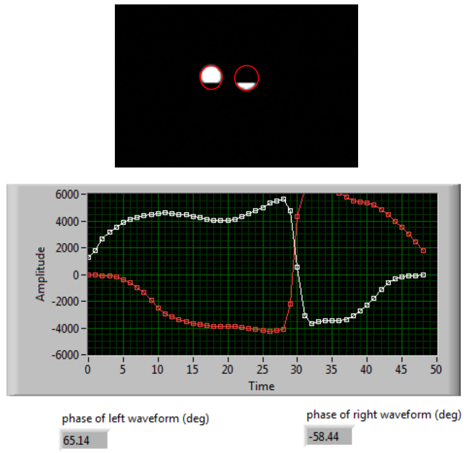

Fig-5. The waveforms extracted from a pair of LEDs
(a) LED bulbs, (b) Waveforms extracted from LEDs.

IV. Conclusion and Discussion

The communication system using multiple light sources was provided. Textured signage effect was considered. The further distance was achieved with the S2-PSK scheme that demodulated data bit based on the XOR comparator from pixels intensity.

Acknowledgment

This work was supported by the ICT R&D program of MSIP/IITP. [B0101-16-0429, Development of Open Screen Service Platform with Cooperative and Distributed Multiple Irregular Screens]

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