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Real Time Vital Sign Transmission Using IEEE 802.15.7 VLC PHY-I Transceiver

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***Abstract*—Visible Light Communication (VLC) Technology is the short range optical wireless communication technology using the light source such as LEDs for data transmission. The major advantage of VLC is that it causes no interference to RF-based devices and no bad effect to human body. Thus, this makes it possible to be used in intrinsically safe environment such as in a hospital. Moreover, it doesn't have the restriction likes a radio wave, VLC using a license free frequency bands. IEEE 802.15.7 VLC standard is one of the VLC standard. This standard consists of PHY I, II and III operating modes. In this paper, we first focus on analyzing PHY I with OOK modulation, which is targeted towards applications requiring data rate range from 11.67 kb/s to 100 kb/s with 200 kHz optical clock rate. Moreover, we propose the improvement of the real time vital sign transmission based on IEEE 802.15.7 VLC standard using PHY I operating modes for sending the vital signs data, which are temperature and heart rate. Compared with our previous system, there are improvements in many directions. The obvious improvement is the communication speed. Moreover, the transmission range is able to be increased by adding the VLC repeater.**

Keywords*—*IEEE 802.15.7 PHY-I; LED; optical wireless communicatoion; Visible Light Communication (VLC)

I. INTRODUCTION

In recent years, a visible light communication (VLC) is becoming a popular technology in wireless communication field. The existing old electric light-bulbs are going to be replaced by the LEDs. Even though the initial price of LEDs is typically higher than the old electric light-bulbs, LEDs cost less to operate. Therefore, LEDs are expected to become widely used soon [1]. This expected wide-scale availability of LEDs opens the door for VLC.

VLC uses wavelength range of 375 nm - 780 nm as a carrier. This range of wavelengths, which can be perceived by the human eye, is called as visible light [3]. In VLC, LEDs are concurrently used for illumination and communication. For a white LED, it can be turned on and off rapidly at a frequency of megahertz. This qualification makes it possible to be used for the high-speed transmission of data, which human eyes cannot perceive the light changes [4].

In comparison with the ordinary wireless communication technology that uses radio frequency (RF) as a carrier, VLC provides various remarkable advantages. It has no electromagnetic interference (EMI) and RF radiation. VLC is a line-of-sight communication which provides high security in communication. Moreover, it uses the license free frequency bands which have 10,000 times of spectrum more than the RF spectrum [5].

There are several standards defined for VLC in these days, including JEITA CP-1221, IEEE 802.15.7 and 802.11 IP PHY [6]. For IEEE 802.15.7 standard, physical (PHY) and MAC layers are defined. This standard supports a high data rate which able to be used for audio and video multimedia transmission. Mobility of nodes inside the system, application with the illumination infrastructures and error correction of data due to interference and noise from environment are also considered [7].

The standard provides three types of PHY operating modes for VLC, including PHY I, II and III. Each type operates in different data rate range, 11.67 kb/s - 266.6 kb/s, 1.25 Mb/s - 96 Mb/s and 12 Mb/s - 96 Mb/s, respectively. PHY I and PHY II support two types of modulation schemes, on-off keying (OOK) and variable pulse-position modulation (VPPM). These two types of operating modes uses only one light source. For PHY III, it uses different colors of multiple light sources based on color shift keying modulation scheme (CSK).

In this paper, we will firstly focus on the OOK modulation of PHY I. Even though the data rate is low, it is able to be used with various applications such as a localization using VLC, a commercialization using VLC and a simple wireless communication using VLC in the hospital. After merging the standard with our previous work, a real time vital sign transmission using VLC [8], the data rate is improved by 1000 times. Furthermore, to extend the distance between the transmitter and the receiver, the VLC repeater which was implemented in our previous work [9] is able to be used here for increasing the transmission distance and for avoiding obstacles.

There are six sections included in this research paper. Section I, an introduction. Section II briefly introduces the PHY I operating modes of the standard and discusses on physical-layer data unit (PPDU) and the encoding and decoding. The design and the circuit implementation, as well as the experiment results are provided in Section III. Section IV clarifies the improvement of the real time vital sign transmission based on the PHY I of the standard. Section V

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shows the experiment of vital sign transmission with a four-direction repeater. Finally, this paper is concluded in the last section, section VI.

II. PHY I Operation Modes

There are nine different data rates defined in the PHY I operating modes, five of them use the OOK modulation scheme with a maximum data rate of 100 kb/s and the other four use VPPM modulation scheme with a maximum data rate of 266.6 kb/s. The specification of PHY I operating modes is shown in Fig. 1.

TABLE I
PHY I OPERATING MODES

Modulation	RLL code	Optical clock rate	FEC Outer code (RS)	FEC Inner code (CC)	Data rate
OOK	Man-chester	200 kHz	(15,7)	1/4	11.67 kb/s
			(15,11)	1/3	24.44 kb/s
			(15,11)	2/3	48.89 kb/s
			(15,11)	None	73.3 kb/s
			none	None	100 kb/s
VPPM	4B6B	400 kHz	(15,2)	None	35.56 kb/s
			(15,4)	None	71.11 kb/s
			(15,7)	None	124.4 kb/s
			none	None	266.6 kb/s

Fig. 1. Format of the PHY I operating modes.

A. Physical-layer Data Unit (PPDU)

Following to the physical-layer of the standard, before each data transmission, data must get packed into a PPDU. The PPDU comprises of three main field, a physical-layer header (PHR), a synchronization header (SHR) and a PHY payload. The PPDU format is shown in Fig. 2.

Preamble (see 8.6.1)	PHY header (see 8.6.2)	HCS (see 8.6.3)	Optional fields (see 8.6.4)	PSDU (see 8.6.5)
SHR	PHR			PHY payload

Fig. 2. Format of the PPDU.

For SHR, it is the preamble field which is used for synchronization. It contains the fast locking pattern (FLP) and four of the topology dependent patterns (TDPs). The FLP is a pattern of “10” followed by “10”. The shortest FLP contains 64 bits of ‘1’ and ‘0’, where the longest FLP contains 16,384 bits. The TDP depends on the topology, whether it is a peer-to-peer, star or broadcast. However, TDP is able to be assigned as a topology independent.

The standard provides two modes of transmission, single data mode and burst mode. Fig. 3 shows preamble field of the single data mode. For the burst mode, FLP only includes inside the preamble field of the first frame.

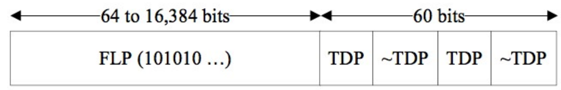

Fig. 3. Format of the preamble field.

The PHR consists of a PHY header, a header checks sequence (HCS) and the optional fields.

The PHY header contains many important information for PHY payload, such as the length of PSDU field. Data rate which is used for PHY header transmission must be the lowest one depends on the selected optical clock rate. Therefore, in this paper, the data rate used for PHY header transmission is 11.67 kb/s.

The HCS is a 2 octet CRC-16 of the PHY header. A cyclic redundancy check (CRC) is calculated by the following equation (1). The registers shall be initialized to all ones.

$$G_{16}\, x = x^{16} + x^{12} + x^{5} + 1 \tag{1}$$

The optional field is specified as six bits of zeroes for the 200 kHz optical clock rate in PHY I.

For PSDU, it contains PHY payload, which is the PHY frame data. Six bits of zeros are concatenated at the end of the field.

B. Encoding and Decoding

The PHR and the PSDU field have to be encoded at the transmitter and decoded at the receiver. For PHY I encoding and decoding scheme, a forward error correction (FEC) is the combination of a reed-solomon code (RS) and a convolutional code (CC). Zero padding method and zero puncturing method are also included in both encoding and decoding scheme. Fig 4 shows a diagram of the encoding scheme, the encoded symbols resulted from passing though the last step of the scheme, the run length limit (RLL) encoding method.

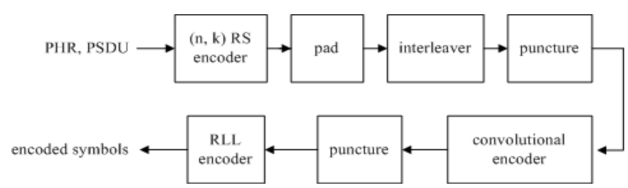

Fig. 4. Diagram of the PHY I encoding scheme.

III. Experiment and Result

According to the reviewed papers, e.g. [6], many comparisons of each rule in the standard are described. Here is one new comparison, which is the comparison of the distance between the transmitter and the receiver of each rule in PHY-I 200 kHz optical rate.

Fig. 5 shows the transmitter circuit which is the same as the transmitter circuit using in our previous work [9].

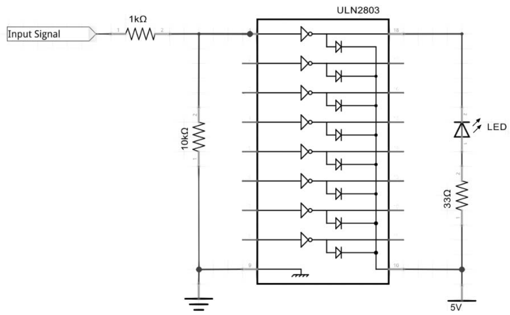

Fig. 5. Schematic of the Transmitter Circuit.

Fig. 6 shows the receiver circuit. This circuit is different from our previous work [9]. SFH203P is using here as the photodiode instead of TSL12S-LF to receive the light more perfectly in straight direction. Nevertheless, using of SFH203P makes the distance between the transmitter and the receiver decreases. To achieve 200 kHz clock rate corresponding to the standard, the dual op-amp is changed from MCP6402 to TSV992AIDT due to the low slew rate of the old one.

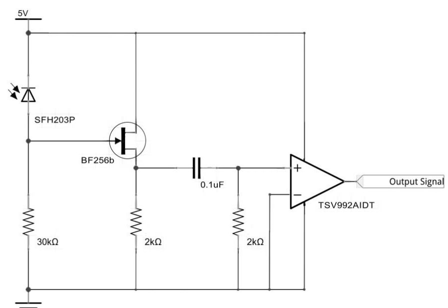

Fig. 6. Schematic of the Receiver Circuit.

The experimental result of the comparison between the maximum distances of each data transmission using different FEC specification of the five data rates is shown in Fig. 7. The distance displayed in the graph is the maximum distance between the transmitter and the receiver which makes the system able to transmit and receive data correctly at 100 kb/s without any average error in 5 sets of data, with 500 random data in each set. The x-axis is the five data rates, while the y-axis is the distance in centimeter.

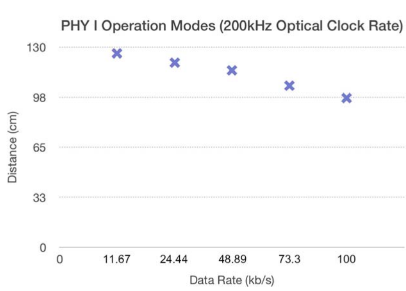

Fig. 7. Comparison between the maximum distance of each data rate.

IV. Real Time Vital Sign Trasmission

Here, we use the PHY I of the standard with the previous real time vital sign transmission system [8] to enhance the data rate, up to 100 kb/s, from 1 kb/s.

At the transmitter side, the temperature sensor and the heart rate sensor are using here to gather user information. This data will pass through the encoding and modulation schemes for transmitting as a light signal. At the receiver side, the receiver circuit will help to convert the light signal received from the photodiode into data. Next, this data will pass through decoding and demodulation schemes and will display in the receiver side program.

Fig. 8 shows the experiment of the real time vital sign transmission, working perfectly with the data rate of 100 kb/s.

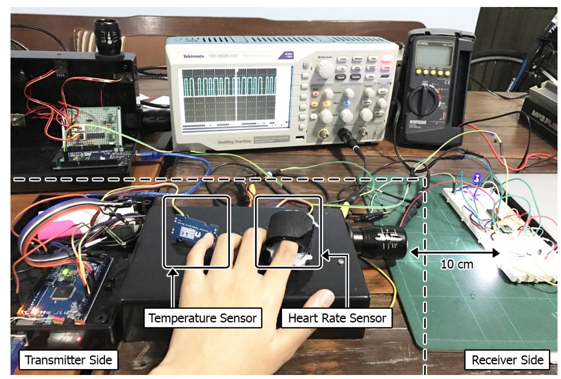

Fig. 8. Experiment of the real time vital sign transmission.

The VLC transceiver program is using in both sides of the system, transmitter side and receiver side. To use this program, the user must first select the COM port, the data type and the data rate. There are two types of data, primary data and secondary data. Choosing of primary data, program will get the real time vital sign data from the sensors. Otherwise, choosing of secondary data, program will get the previously stored data directly from the textbox displayed in the program.

Fig. 9 shows the example of using the program at the transmitter side. The primary data sending here are temperature and heart rate, 37.01 °C and 87 bpm respectively.

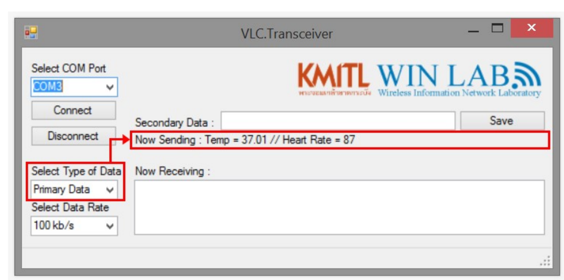

Fig. 9. Program at the transmitter side.

Fig. 10 shows the example of using the program at the receiver side, receiving the data and displaying line by line.

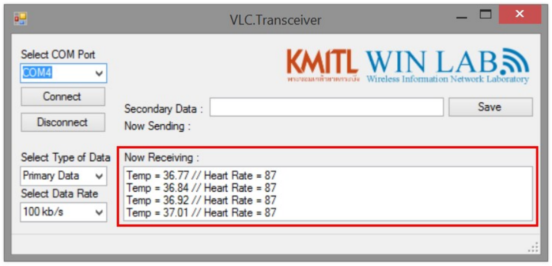

Fig. 10. Program at the receiver side.

V. VITAL SIGN TRANSMISSION WITH A REPEATER

Not only to study on the standard and to increase the data rate of the real time vital sign transmission system, we also try to add the implemented VLC repeater [9] in this improved system to increase the distance between the transmitter and the receiver and to avoid the obstacle in communication. The result of the experiment shows that the addition of the VLC repeater is able to extend the distance perfectly. One of VLC repeater can help increasing the distance of 590 cm.

Fig. 11 shows the example of the experiment using a 4-directional VLC repeater as the repeater in the system.

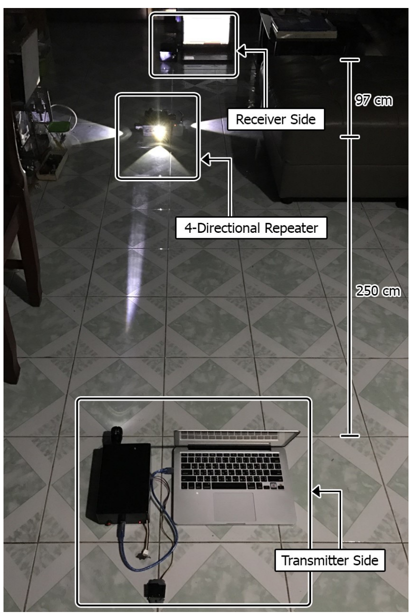

Fig. 11. Experiment of vital sign transmission with a 4-direction repeater.

The temperature and heart rate data is transmitted and received in 100 kb/s using secondary data saved at the transmitter side. With the limit space of the experiment room, the repeater here helps extending the distance of 250 cm instead of maximum length of 590 cm.

VI. CONCLUSION

In this work, real time vital sign transmission using IEEE 802.15.7 VLC PHY-I transceiver is implemented to study the physical layer of the standard and to increase the data rate from 1 kb/s of our previous system. Changed of the receiver circuit and the software, the system is able to transmit and receive the real time temperature and heart rate smoothly in 100 kb/s. The comparison between each rule of PHY-I 200 kHz clock rate in term of the distance between the transmitter and receiver shows that the different of distance of each rule is not much, by changing the distance of 1 cm can make big damage to the received data.

In addition, we also added the implemented VLC repeater in this improved real time vital sign transmission system. The result of the experiment shows that the addition of one VLC repeater is able to extend the distance perfectly, maximum of 590 cm.

For the future work, we plan to study more on the standard. The next and next layer will be included in the system, the MAC sublayer and the MAC layer.

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