Analysis of Pulse Modulation in LC Based Typical Indoor Environment

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Abstract² The 4th industrial revolution is affecting to medical and other industry. Recently, secure and reliable communication are required in medical or factory data transmission since ISM band is used and it occurs a lot of EMI Problems in existing RF communication. We use LC (Light Communication) to solve this problem in typical wireless environment. We use LED on the ceiling as the transmitter and PD in mobile device as the receiver for that. In this paper, we consider single carrier modulation for the connection between server and patients. We can also extend to Multi carrier Modulation such as DCO-OFDM for the high rate support. Based on the CIR model of the hospital or factory environment, the simulation is performed using OOK, 4-PAM, and 8-PAM to obtain link level performance. BER and the throughput are analyzed and compared in order to evaluate the potential use of VLC to the hospital ward or factory wirelss. It is shown that OOK can be applied to more secure cases and 8PAM can be better in considering the tradeoff between BER and throughput when the same transmitting power is used for that.

Index Terms² LC, single carrier, CIR, hospital ward, PAM, industry wireless

I. INTRODUCTION

The Fourth Industrial Revolution is appearing worldwide. The fourth industrial revolution is also affecting the medical and IoT industry. In the past, the focus was on treating patients, but now the focus is on prevention, management and rehabilitation. This trend is evolving along with Internet of Things (IoT) and communications technologies.

To take advantage of this IoT technology, communication technology is essential. In addition, wireless communication using Radio Frequency (RF) such as WiFi or Bluetooth was generaly used when communicating in a building such as a home and hospital.

However, in a medical environment such as a hospital, the use of RF can cause electromagnetic interference (EMI) problems and affect medical devices. In particular, EMI problems are fatal in places such as intensive care units where the use of medical devices is concentrated, or as clean rooms for leukemia patients, which cause fatal effects on patients' lives due to malfunction of medical devices. In a general room, if EMI problems occur in the vicinity of the patient using the life support device, the medical device may malfunction and affect the patient's life.

In addition. in the conventional industrial sector, when the machine was installed, it is possible to occur moving the machine. In an environment where these machines are fixed and connected by wire, it takes much cost to install a new wired network in changing the position of the machine. Thus, connecting two machines wirelessly can save the cost and allow the flexible position of machines.

When RF communication is used in industrial environment in which, severe interference occurs since many machines communicate in a narrow space

In order to reduce this interference, LC can solve this problem since external light can be blocked to enhance the security

The development of IoT technology has exploded wired and wireless network traffic. Although wide frequency bands are needed to deal with increased traffic, current mobile communication systems have limited frequency band allocation.

The demand for short-range wireless communication increases in indoor environment, it is expected that the available frequencies will almost run out and the radio spectrum will be depleted.

In this paper, we consider Light Fidelity (LiFi) technology [1] that combines high efficiency LED technology with unlimited internet sharing technology, WiFi technology. Li-Fi can use short-range wireless communication technology without limiting the use of frequency, which is effective as a short-range wireless communication technology in the situation where the frequency spectrum is saturated [2]. And since it does not cause EMI problems because it does not use RF, it can be effectively used in EMI sensitive environments such as hospitals.

LiFi communicates using visible light and Intensity Modulation/Direct Detection (IM/DD). IM is a modulation method that uses a LED light to change the light output to a modulated signal. DD uses a light detector to detect and demodulate a signal transmitted by the LED light.

There are two main ways to modulate LiFi. The first is Single Carrier Modulation and the second is Multi Carrier Modulation. In single carrier modulation, On-Off Keying (OOK), Pulse Amplitude Modulation (PAM) and Pulse Position Modulation (PPM) schemes are used.

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In multi carrier modulation, Direct Current-Biased Optical Orthogonal Frequency Division Multiplexing (DCO-OFDM) and Asymmetrically Clipped Optical Orthogonal Frequency Division Multiplexing (ACO-OFDM). And the modulation method based on LiFi using visible light is Color Shift Keying (CSK). [3]-[5] .

In order to support possible application, single carrier modulation format should be considered to support the use cases of low data rate. Hence, we need to investigate the pulse modulation other than OFDM in VLC based real environment.

The link level simulation is presented for three pulse modulation (OOK, 4-PAM, 8-PAM). We also compare BER and throughput according to the increase of Eb/No in two typical indoor wireless environment, which are hospital ward and industry wireless.

In this paper, we describe the system model in Chapter 2 and proceed to simulate the single carrier modulation in Chapter 3. The results and analysis will be presented in section IV while a final conclusion will be given in section V.

II. System Model

A. Hospital Ward Environment

This paper is based on Zemax which is a commercially available optical and illumination design software to create realistic visible light communication channel. Zemax can calculate the detected power and path lengths from Tx to Rx for each ray. Zemax then bring this information to Matlab and CIR for hospital ward environment is obtained through proper normalizations.

The hospital ward simulation environment is constructed with Zemax as shown in Fig. 1. We consider a hospital emergency room with beds, reception desk and large diagnostic instruments such as MRI, CT scan surgical equipment.

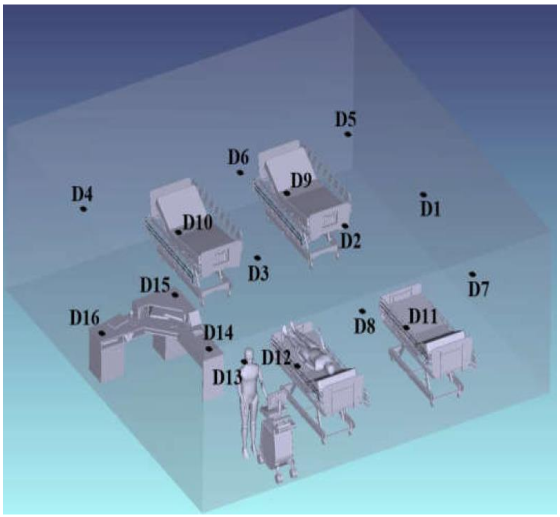

Fig. 1. Location of PD in hospital ward

The size of the conference room is 8m × 8m × 3m, the wall and ceiling are plaster, the bottom is pinewood, and there are 16 LEDs and 16 PDs inside. [6]

The transmitter is LED S1 ... S16 and the receiver is PD D1 ... D16 as shown in Fig. 2. In this paper, we use overall LEDs and PD D1. The FOV and the area of the detector are 85°and 1cm2. The user of the D1 is located on the right side of the room, where the light is hard to reach. But, there are few instruments around it, making it the most stable environment in the room.

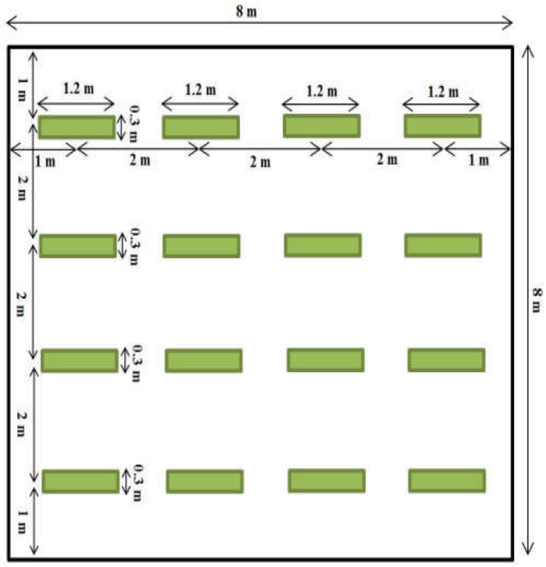

Fig. 2. Location of LED in hospital ward

The brightness of all LED lights is 19W. The illumination is set at a certain distance and the Half viewing angle of the illumination is 54 °.

B. Industry Wireless Environment

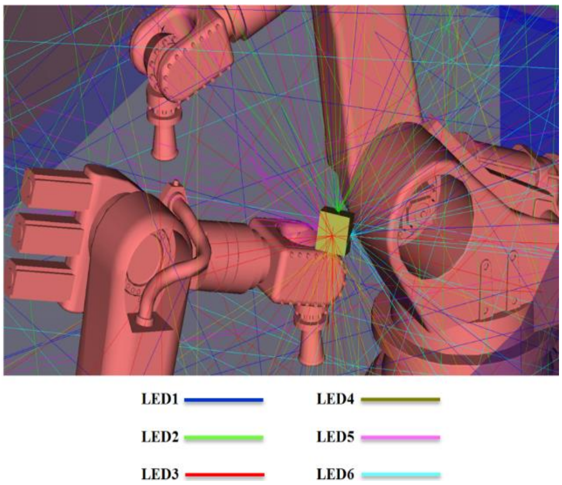

Fig. 3. Location of PD in industry wireless

We use the simulation environment provided by IEEE 802.11 TGbb to realize the Industrial Wireless environment using VLC [6]. Fig. 3 shows two robots in one cell in the Industrial Wireless environment. The wall and floor are made of Concrete and the ceiling is made of aluminum metal. The size of the room with the machine is 8.03m × 9.45m × 6.8m. The height of the robot is 2.7m and the height of Plexiglas boundary is 2.5m. Fig. 3 and Fig. 4 show the positions of transmitter and receiver, respectively. The transmitter is placed in the shape of a cube, with the LEDs on each side. Six LEDs are composed of S1 - S6. The half viewing angle and power per each luminaire are 60°and 1 cm². In this paper, we use 6 LEDs to communicate. The receiver is attached to a simple wall 2.5m high. The total number of receivers is 8, and each name is D1 - D8. In this paper, we use D7 receiver. The FOV and the area of the detector are 60° and 1 cm².

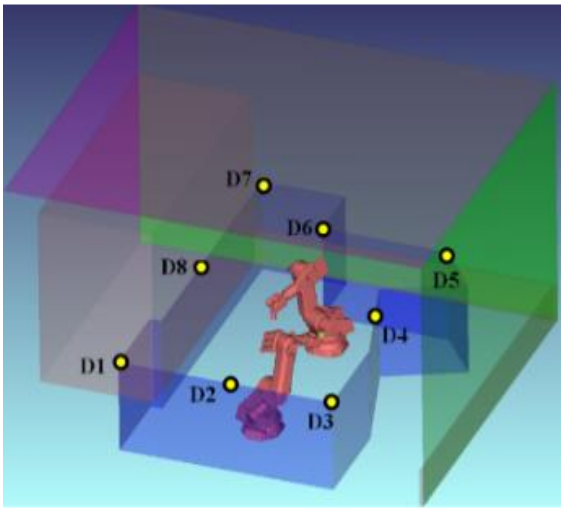

Fig. 4. Location of PD in Industry Wireless

III. PULSE MODULATION FOR LIGHT COMMUNICATION

In this paper, realistic VLC simulation using pulse modulation in two typical indoor environments was conducted through MATLAB.

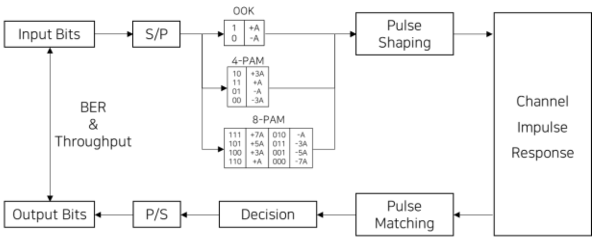

Fig. 5. Block diagram of single carrier modulation

The simulation of pulse modulation is shown as a block diagram in Fig. 5. First, a random bit sequence is generated, and mapping is performed using the OOK scheme, the 4-PAM scheme, and the 8-PAM scheme. OOK is mapped to 2, 4-PAM to 7, and 8-PAM to 15 to perform pulse shaping.

After passing through the pulse shaping, the signal passes through the CIR provided by TGbb according to the simulation environment. The CIR value between the LED and the PD, h(t) is denoted by

$$h(t)\quad \sum_{i=1}^{N_r} P_i\ (t\ \ G_i) \qquad W \quad (1)$$

ZKHUH 3L LV WKH RSWLFDO SRZHU RI WKH L WK UD\ 2L LV WKH SURSDJDWLRQ WLPH RI WKH L WK UD\ 7 W LV WKH GHOWD function and Nr is the number of rays received at the detector. [7]

The simulation of single carrier modulation is shown as a block diagram in Fig. 5.

The output signal y(t) can be shown as

$$y(t)\quad h(t)\ ..x(t)\quad n(t) \qquad (2)$$

where x(t) is the original signal and n(t) is the sum of AWGN and Noise Floor.

Equation (2) means that the output signal can be generated by convolving the original signal with CIR values.

The signal passed through the CIR recovers the signal through the Rx frontend model filter. The recovered signal is demapped to determine the bit. The decoded signal is converted into a serial signal and compared with the original bit to calculate the BER value and throughput.

The throughput T is shown as

$$T \quad D\frac{b_c}{b_t} \qquad (3)$$

where bt is the number of total bit, bc is the number of UHFHLYHG ELWV ZLWKRXW HUURU DQ The . RI 22. PRGXODWLRQ -PAM DQG PRGXODWLRQ VHQGV ELW-PAM DW D W modulation is 2. Similarly, 8-PAM modulation sends 3 ELWV DW D WLPH -PAM modulation is 3.R I Throughput is calculated by dividing the bits received successfully by all bits and then multiplying by the weight.

IV. SIMULATION RESULT

TABLE I: SIMULATION PARAMETER FOR HOSPITAL WARD

Parameter	Value
Number of bits	1,000,000
Number of repeated counts	100
Bit Time Duration	100ns
Bandwidth	10MHz
Noise Floor	-70dBm
Scenario Name	Hospital Ward
Point of Tx	S1-S16(Overall)
Point of Rx	D1(2500,0,1700)
Optical CIRs	D1(Overall)
Topology	B-Dense small BSSs e.g. ~8m ×8m ×3m size, ~3m inter AP distance, 4 STAs/lights, P2P pairs
Management	Managed
Channel Model	Indoor Office
Traffic Profile	Enterprise

In this paper, we have performed in two typical indoor environments. The locations of Tx and Rx are fixed and the main simulation parameters are summarized in Table I and Table II. When we run the simulation, we generate 1,000,000 bits at a time and repeat the simulation 100 times, and made a final value by averaging all the repeated output values. The bit period is set to 100 ns to set the minimum throughput value and the bandwidth is set to 10 MHz. Noise floor was set to -70dBm according to [8].

TABLE II: SIMULATION PARAMETER FOR INDUSTRY WIRELESS

Parameter	Value
Number of bits	1,000,000
Number of repeated counts	100
Bit Time Duration	100ns
Bandwidth	10MHz
Noise Floor	-70dBm
Scenario Name	Industry Wireless
Point of Tx	S1-S6(Overall)
Point of Rx	D7
Optical CIRs	D7(Overall)
Topology	Industrial Robotic work cell e.g. ~8 m ×10 m ×7 m size, ~2 STAs/AP, P2P pairs
Management	Managed
Channel Model	Indoor Manufacturing Cell
Traffic Profile	Industrial

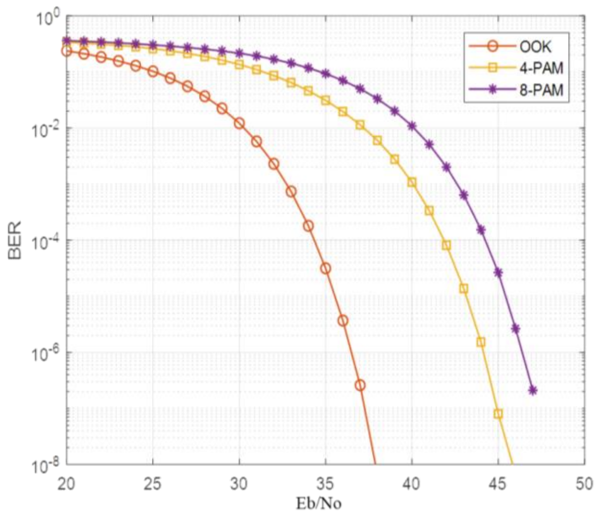

Fig. 4. BER of three schemes in hospital ward environment

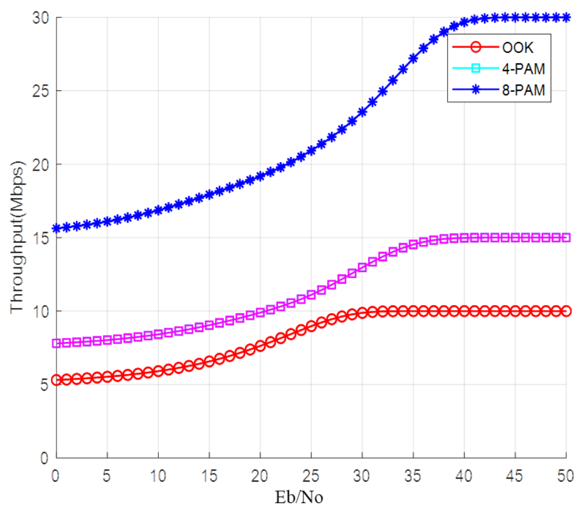

Fig. 5. Throughput of three schemes in hospital ward environment

Fig. 4 shows that the BER values of OOK, 4-PAM and 8-PAM according to the increase of Eb/No in case of overall LED-D1 of Hospital ward environment. The

Eb/No to attain the BER value of 10^{-5}, which is reliable data transmission, is compared for three pulse modulation. In OOK modulation, overall LED-D1 requires 35.5dB to achieve BER value of 10^{-5}. In the 4-PAM modulation, overall LED-D1 requires 43dB for that. Finally, for 8-PAM modulation, overall LED-D1 requires 45.5dB for that. It is observed that OOK and 4-PAM differ by 7.5dB in the same BER and 4-PAM and 8-PAM differ by 2.5dB.

Minimum throughput of 10Mbps is required when we develop a single link to apply LiFi communication in case of various IoT based use cases. In Fig. 5, at least 30dB is required to attain 10Mbps in case of OOK modulation. 4-PAM modulation requires 22dB to achieve 10Mbps. And 8-PAM modulation schemes can basically achieve the minimum 10 Mbps over all ranges of Eb/No.

However, in view of stable throughput behavior, the BER value at the low Eb/No value is not recommended for real environment. 4-PAM has 1.5 times as much throughput as OOK, but requires more 7.5dB of Eb/No over OOK modulation for stable data throughput. 8-PAM provides 3 times as much throughput as OOK, but 8-PAM requires 10 dB of Eb/No over OOK, hence it seems that 8-PAM is more efficient than 4-PAM in view of the trade-off between data throughput and required Eb/No to achieve minimum BER performance for stable LiFi communication.

Fig. 6 shows the results of the simulation in the industrial wireless environment, in which data is transmitted using all six LEDs and received at D7. In the simulation, all the 6 LEDs use 1W of transmitting power per each. It is shown that the Eb/No to attain BER value of 10^{-5} was 91.1 dB for OOK, 99.3 dB for 4-PAM, and 102.3 dB for 8-PAM, respectively

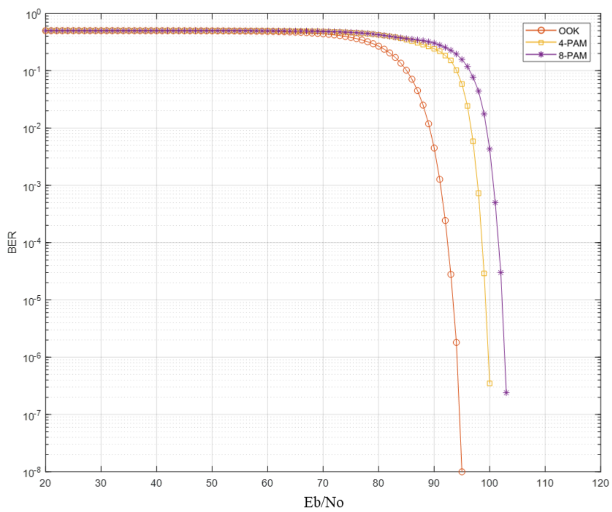

Fig. 6. BER of three schemes in industry wireless environment

Similar results was observed in the case of hospital ward except Eb/No value is increased to achieve BER of 10^{-5}.

7 K D W ¶ V Z K\ the number is transmitter is less than that of hospital ward and the CIR value is smaller since the some angle between transmitter and receiver is not the line of sight.

In Fig. 7, at least 93dB of Eb/No is required to attain 10Mbps in case of OOK modulation. 4-PAM requires 97dB of Eb/No to achieve 20Mbps of throughput, which is double to OOK modulation and 8-PAM modulation requires 98dB to achieve 30Mbps of throughput, which is triple to OOK modulation.

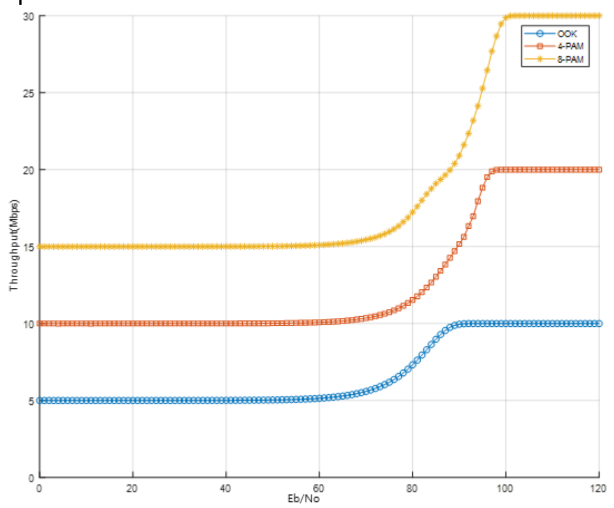

Fig. 7. Throughput of three schemes in industry wireless environment

Simulation results show that required Eb/No to attain 10^{-5} BER value is the lowest in OOK method and highest in 8-PAM mR G X O D W L R Q   7 K D W ¶ V Z K\ L Q W K H L Q G R R U / L) L communication simulation environment where the CIR value is low, the OOK method has relatively low probability of occurrence error since the power level of signal is divided into two level hence the interval between two levels is wider than multiple level based pulse modulation.

Simulation results show that the throughput of 8-PAM is higher than 4-PAM, but it requires higher Eb/No value. Therefore, if we consider the trade-off between Eb/No and throughput, OOK can be preferred to apply the use case with low Eb/No and low data rate and 8-PAM is the best choice if we apply the cases of higher throughput such as medical image transmission.

V. Conclusion

In this paper, it is observed that simulation for single carrier modulation is investigated in typical indoor wireless environment.

It is considerable that other modulation including single carrier rather than OFDM need to considered for providing the various data rate and real application.

8-PAM seems to be effective regarding the tradeoff between BER and throughput for applying hospital ward environment. Simulation results show that the required Eb/No to attain BER value of 10^{-5} is influenced by the distance, angle and modulation method between LED transmitter and PD receiver. Depending on the modulation scheme, Eb/No required by OOK is the lowest, and it is expected to be effectively used in environments requiring reliable communication. The OOK modulation can be applied to hospital environments where the use of WiFi is limited due to the large number of medical devices and it requires reliable communication in transmitting secure data such as patient records. In the case of 8-PAM, throughput is highest than OOK and 4-PAM, hence it can be effectively used in medical data transmission to require high data rates. Since indoor navigation requires a high data rate to process the map and location data, 8-PAM modulation can be effectively used for that. [2]

In the future, research will be conducted to compare DCO-OFDM, which is a multi-carrier modulation scheme, with pulse modulation. We also observed that not only the distance but also the angle between LED and PD affect the link performance, hence it must be considered when we design LiFi network to provide high throughput and reliable service to LiFi support between AP and VLC based user and devices

Conflict of Interest

The authors declare no conflict of interest

Author Contributions

Jeong Gon Kim and Ho Kyung Yu conducted the research; Jeong Gon Kim and Ho Kyung Yu analyzed the data; Ho Kyung Yu wrote the paper; all authors had approved the final version.

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