Analysis and Comparison of VLC based Pulse Modulation in LiFi Enterprise Standard Environment

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Abstract—In the 5G age, communication speed is getting faster, and as a result, IoT is getting more and more developed. In such a situation, the frequency band becomes insufficient and the higher frequency band is used. In this situation, LiFi technology is expected as an alternative to RF communication. This is because LiFi technology can be used effectively in enterprise conference rooms, which is the indoor environment using LEDs and many IoT devices. In this paper, the simulation is performed using OOK, 4-PAM, and 8-PAM in the enterprise conference room environment for the LiFi based network. The BER (Bit Error Rate) and the throughput of pulse modulation are calculated and compared according to the LiFi Standard to analyze the link performance and also evaluate the feasibility of employing LiFi technology in the conference room for providing the higher data support and more secure connection over conventional RF communication networks

Index Terms—LiFi, VLC, pulse modulation, OOK, 4-PAM, 8-PAM

I. Introduction

Wireless communication technology mainly uses Radio Frequency (RF) frequency. This RF wireless communication is often used in everyday life such as Cellular Network, WiFi, Bluetooth. However, RF frequency bands are now beginning to use increasingly higher frequency bands to use new frequencies in saturation. While using higher frequency bands, the data rate has increased, but the cell range has become smaller and smaller.

LiFi technology has been devised to solve this situation and it is a technology to transmit data by using high frequency of visible light band using Lighting-emitting Diode (LED) and Photo Diode (PD). LiFi technology uses a visible light band of 430 to 790 THz to ignore interference from RF signals and can be used without reporting to the license-exempt band. In addition, since the LED plays the role of the AP, it can communicate quickly with the high frequency high data rate [1].

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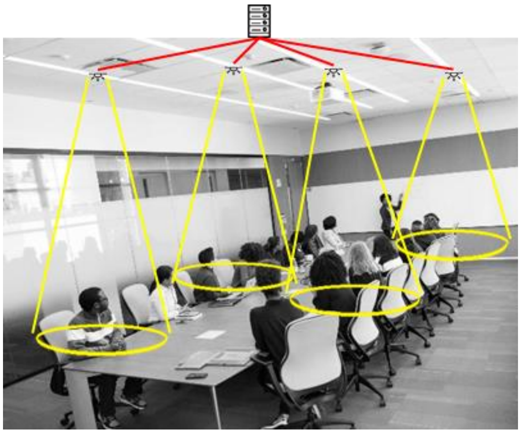


Fig. 1. LiFi use case in enterprise conference room

In this paper, we assume the corporate meeting room where LiFi can effectively exploit these advantages as shown in Fig. 1. The conference room is an indoor environment and it blocks the external lights for the meeting and turns on the lights using LED only. Therefore, a large number of LEDs are installed on the ceiling and operate as an AP. Security is very important because we discuss business issues in corporate meeting rooms. Existing RFs are vulnerable because they can communicate through windows or doors. However, since LiFi uses light to communicate, it can communicate only where light passes through it. Based on the reliability of this communication, users can use various types of IoT devices.

Although IoT devices are relatively unreliable depending on the type, there are cases where a high-speed communication is required and a communication requiring a more reliable even if the speed is low. Single carrier modulation and multi-carrier modulation should be considered to realize these various communication speeds and complexities. Because Compared with single carrier modulation, multi carrier modulation is more bandwidth-efficient but less energy-efficient. One and perhaps the most common realisation of multi carrier modulation in LiFi networks is OFDM. In single carrier modulation, On-Off Keying (OOK), Pulse Amplitude Modulation (PAM) and Pulse Position Modulation (PPM) schemes are used. OOK is one of the best modulation schemes to use in LiFi simply. It is easy to implement because of low system performance but low implementation complexity. PAM is a method of transmitting data by finely adjusting the on and off levels of the LED. Therefore, at low dimming levels, the stable communication range is reduced. PPM is a method of transmitting M message bits using a single pulse. Compared with OOK, the power efficiency is high but the spectral efficiency is low [2].

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). DCO-OFDM adds a DC bias to make the signal positive. OFDM signals have high negative peaks because they have a very high peak-to-average power ratio. Therefore, to eliminate all negative peaks, the DCO-OFDM signal requires very high DC bias. In ACO-OFDM, data is transmitted only on odd subcarriers. Bipolar signals that occur at the output of the IFFT are clipped to 0 to give a non-negative signal. Thus, clipping noise only affects unused even subcarriers. However, data carrying odd subcarriers has no clipping noise. Color Shift Keying (CSK) encodes signals in color intensity emitted from RGB (Red, Green, and Blue) LEDs. In CSK, the incoming bits are mapped to the instantaneous chromaticity of the color LEDs while maintaining a constant average color [3]-[5]. However, OFDM requires that transmitters, including LEDs and drive circuits, have a wide range and fairly good linearity characteristics. To solve this characteristic of LED Tx, OFDM using discrete power level stepping technique has been proposed in [6]. This technique is a digital-to-analog conversion implemented in the optical domain. However, this modulation format relies on Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT). This adds complexity to the transmitter and receiver. Therefore, in this paper, the simulation using OOK and PAM is performed during Single Carrier Modulation [7].

In this paper, the simulation is performed using the Channel Impulse Response (CIR) value in the real Enterprise Conference Room environment provided by the IEEE 802.11 TGbb standard. It implements more realistic simulation using the frontend model filter. The frontend model filter implements a driver that attaches to LEDs and PDs that serve as Tx and Rx, respectively. The Tx front end consists of a driver and LEDs. The DSP and driver are connected by impedance. The driver performs impedance matching from 50Ω to several Ω on the LEDs. Sophisticated circuit design can also increase bandwidth; a large area of active area for high-power LEDs limits bandwidth. The driver is custom designed for each LED. The driver can change the modulation and bias currents. Only a fraction of the total optical output power of the LED is actually modulated. The modulation part of the LED current affects the coverage of the LC link. The RX front end consists of a photodiode and bootstrap transimpedance amplification (TIA). In low light situations, the impedance of MΩ commonly seen in PDs is matched to the DSP's standard 50Ω interface using a bootstrap TIA. Large areas of the PD limit bandwidth. Bootstrap TIAs can significantly increase bandwidth by compensating and precisely designing the PD's high capacitance with less noise [8].

We use OOK, 4-PAM, and 8-PAM as the modulation method and compare BER and throughput according to the increase of Eb/No.

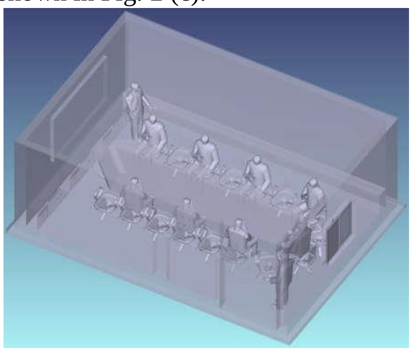
In this paper, we describe the system model in Chapter 2 and proceed to simulate the Pulse Modulation in Chapter 3. The results and analysis will be presented in section IV while a final conclusion will be given in section V.

II. System Model

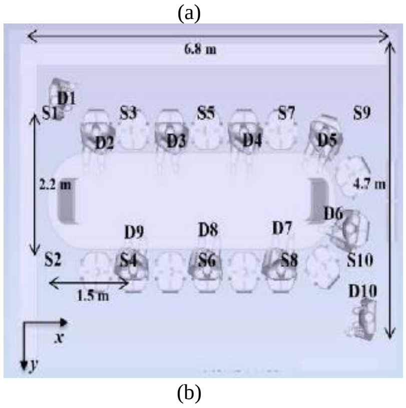
In this paper, we use simulation environment provided by IEEE TGbb to implement realistic simulation using VLC in Enterprise Conference Room environment.

We consider a conference room where ten users sit around a table, as shown in Fig. 2 (a). In order to construct a realistic meeting room environment, windows, monitors, chairs, tables, and mobile phones were placed as shown in Fig.2 (b). The size of the conference room is 6.8m × 4.7m × 3m, the wall and ceiling are plaster, the bottom is pinewood, and there are 10 LEDs and 10 PDs inside.

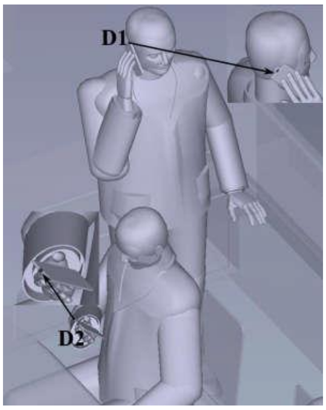
The transmitter is LED S1 ... S10 and the receiver is PD D1 ... D10. In this paper, we use LEDs S1 and S3 and PD D1 and D2. The FOV and the area of the detector are 85 ° and 1cm^2. The user of the D1 is a standing person with a height of 1.8m. The user of the D2 is seated and the PD is above the height of 1.1 m. The PD is mounted on the top of the cell phone and is at a 45 ° angle to the ceiling, as shown in Fig. 2 (c).



(a)



(b)



(c)

Fig. 2. Location of LED and PD in enterprise conference room

The brightness of LED lights S1 and S3 is 46W. The illumination is set at a certain distance and the Half viewing angle of the illumination is 80 °.

III. Pulse Modulation for LiFi

In this paper, realistic VLC simulation using pulse modulation in Enterprise Conference Room environment was conducted through MATLAB. The simulation of pulse modulation is shown as a block diagram in Fig. 3. 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. It then passes through the Tx Frontend Model Filter. The optical frontend for LC imposes impairments, which have a non-negligible impact on the performance, on the signal. Hence, these effects must be modeled in addition to the propagation channel. The optical frontend model uses a highpass filter and a lowpass filter to create a filter model with Matlab. The TX frontend comprises driver electronics and a LED or laser diode. And the RX frontend comprises a photo diode and a bootstrap transimpedance amplified (TIA) [8].

After passing through the Tx Frontend model filter, 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.

$$\mathrm{h(t)} = \sum_{i=1}^{N_r} P_i \delta(t-\tau_i) \tag{1}$$

where P_i is the optical power of the i th ray, τ_i is the propagation time of the i th ray, $\delta(t)$ the Dirac delta function and N_r is the number of rays received at the detector [9].

The output signal y(t) can be shown as

$$\mathrm{y(t)} = \mathrm{h(t)} \otimes \mathrm{x(t)} + \mathrm{n(t)} \tag{2}$$

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

$$T = \alpha \frac{b_c}{b_t} \tag{3}$$

where b_t is the number of total bit, b_c is the number of received bits without error and α represents the weight. The α of OOK modulation is 1 and the 4-PAM modulation sends 2 bits at a time, so the α of 4-PAM modulation is 2. Similarly, 8-PAM modulation sends 3 bits at a time, so the α of 8-PAM modulation is 3. Throughput is calculated by dividing the bits received successfully by all bits and then multiplying by the weight.

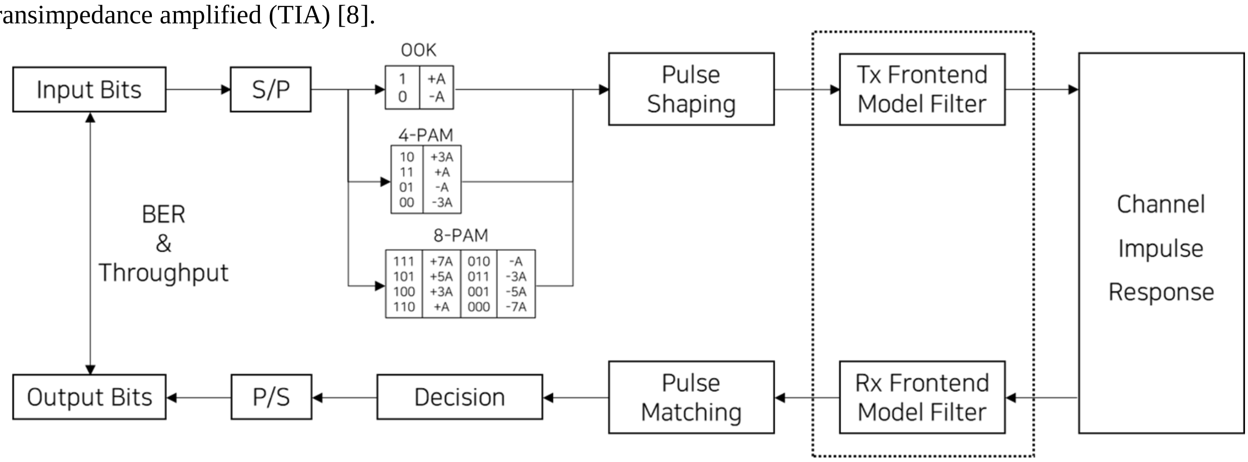


Fig. 3. Block diagram of pulse modulation

IV. Simulation Results

In this paper, we have performed in the Enterprise Conference Room environment. The locations of Tx and Rx are fixed and the main simulation parameters are summarized in Table I. 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 [10]. The distances of S1-D1, S1-D2, S3-D1 and S3-D2 are measured to confirm the change of Eb/No with distance.

TABLE I: SIMULATION PARAMETER

Parameter	Value	
Number of bits	1,000,000	
Number of repeated counts	100	
Bit Time Duration	100ns	
Bandwidth	10MHz	
Noise Floor	-70dBm	
Environment	Enterprise Conference Room	
Point of Tx	S1(-1050, -3100, 3000) S3(-1050, -1600, 3000)	
Point of Rx	D1(-1398, -2880, 273) D2(-688, -2025, -307)	
Optical CIRs	S1-D1, S1-D2 S3-D1, S3-D2	
Distance	S1-D1	2.758m
	S1-D2	3.496m
	S3-D1	3.032m
	S3-D2	3.354m

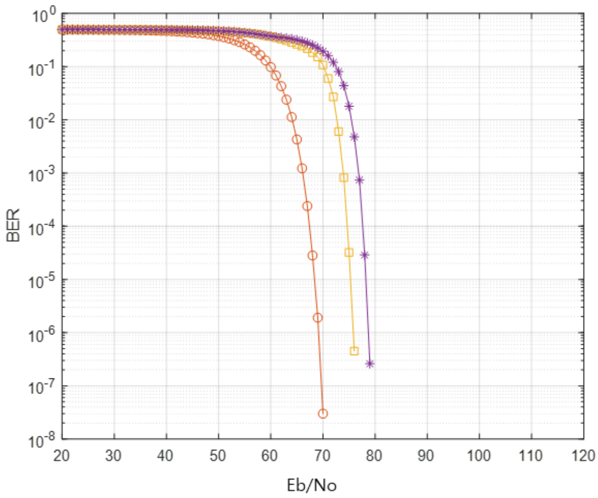


Fig. 4. S1-D1 BER values in enterprise conference room

Fig. 4 and Fig. 5 show that the BER values of OOK, 4-PAM and 8-PAM according to the increase of Eb/No in case of S1-D1 and S1-D2 of Enterprise Conference Room environment. The shortest distance between S1 and D1 is 2.758m and the shortest distance between S1 and D2 is 3.496m. The Eb/No to attain the BER value of 10^{-5}, which is reliable data transmission, was compared for three pulse modulation. In OOK modulation, S1-D1 requires 68.4dB and S1-D2 requires 80.2dB to achieve BER value of 10^{-5}. In the 4-PAM modulation, S1-D1 requires 75.3dB and S1-D2 requires 86.6dB for that. Finally, for 8-PAM modulation, S1-D1 requires 78.3dB and S1-D2 requires 89.8dB for that. It is observed that nearly 10dB SNR is required to support the distance 0.74m in the conference room for three kinds of pulse modulation.

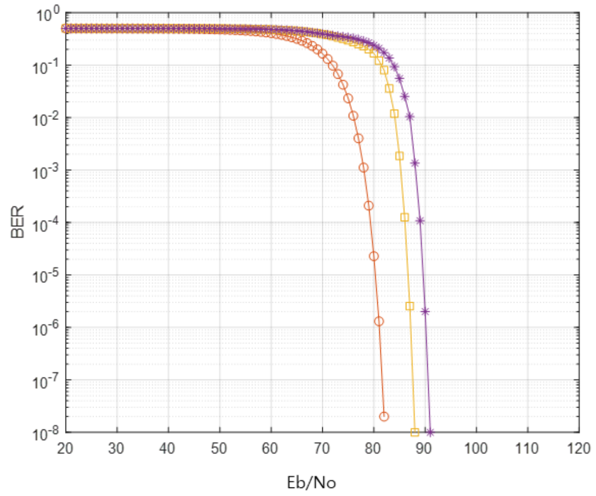


Fig. 5. S1-D2 BER values in enterprise conference room

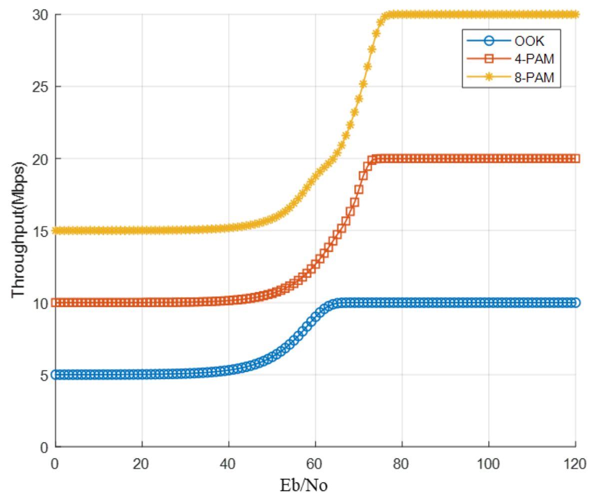


Fig. 6. S1-D1 throughput in enterprise conference room

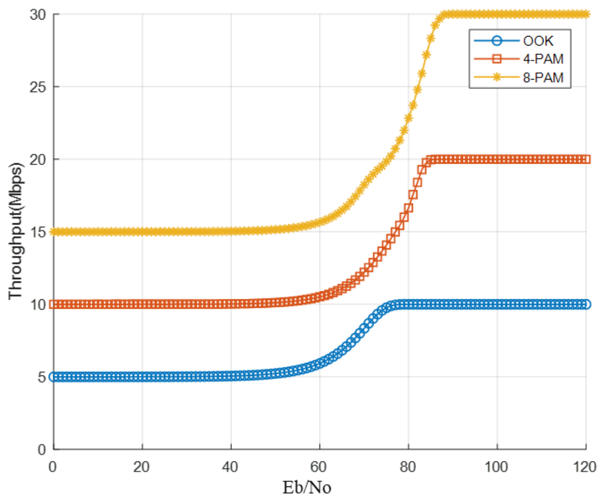


Fig. 7. S1-D1 throughput in enterprise conference room

In the PAR of IEEE TGbb, minimum throughput of 10Mbps is required when we develop a single link for LiFi communication [11] and 8-PAM in case of S1-D1 and S1-D2 according to the variation of Eb/No. In Fig. 6, at least 68dB is required to attain 10Mbps in case of OOK modulation. In Fig. 7, at least 80dB is required to attain 10Mbps in case of OOK modulation. Other 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 twice as much throughput as OOK, but requires more 7dB 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.

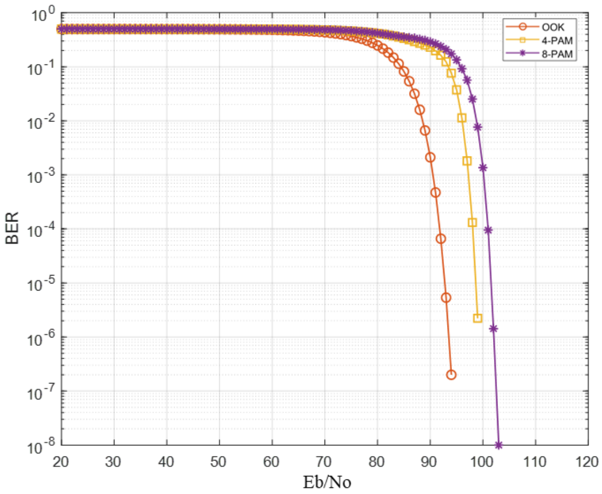


Fig. 8. S3-D1 BER values in enterprise conference room

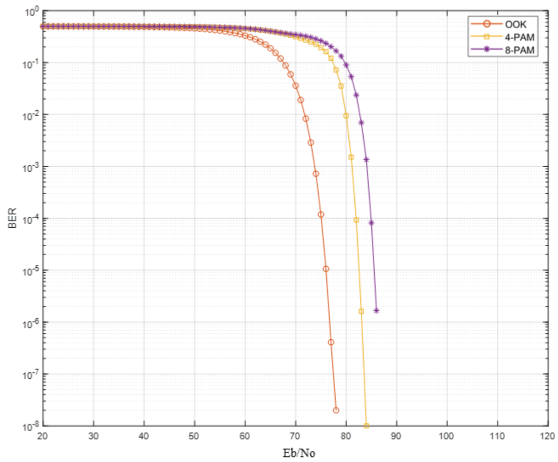


Fig. 9. S3-D2 BER values in enterprise conference room

Fig. 8 and Fig. 9 show the BER values of OOK, 4-PAM and 8-PAM according to the increase of Eb/No in case of S3-D1 and S3-D2 of enterprise conference room environment. The Eb/No values achieving a BER value of 10^{-5} is 92.7 dB for S3-D1 and 76 dB for S3-D2 in case of OOK modulation scheme, respectively. The distance between S3-D2 is 3.354m and that between S3-D1 is 3.032m respectively. It is observed that S3-D1 results in the worse BER performance even though S3-D1 has the shorter distance that S3-D2. This is due to the fact that angle between the transmitter and receiver. The LED of the transmitter S3 has a half viewing angle of 40 degrees, hence it results in spreading under the receiver.

However, the user of D1 is standing and the user of D2 is sitting, and the angle of each receiver is 45 degrees. Therefore, a D1 user who is standing is close to the LED signal of S3 on the ceiling but the CIR is not strong because the angle of the receiver is not aligned to get the light signal very well. However, the D2 user can receive the light of S3 directly and it provides the higher CIR value between S3 and D2. Similarly, it also be illustrated for 4-PAM, S3-D1 requires 98.7dB and S3-D2 requires 82.5dB to attain BER values of 10^{-5}, and for 8-PAM, S3-D1 requires 101.5dB and S3-D2 requires 85.5dB to achieve same BER values, respectively.

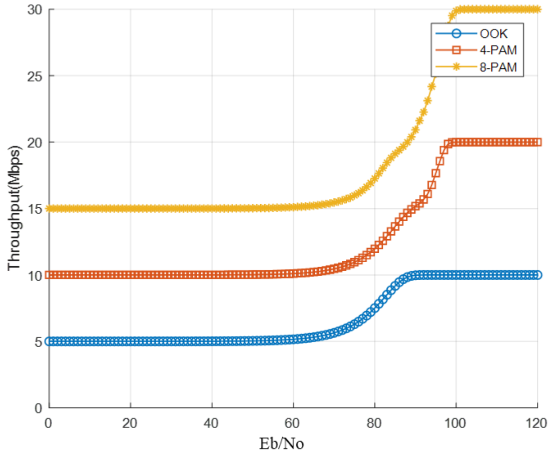


Fig. 10. S3-D1 throughput in enterprise conference room

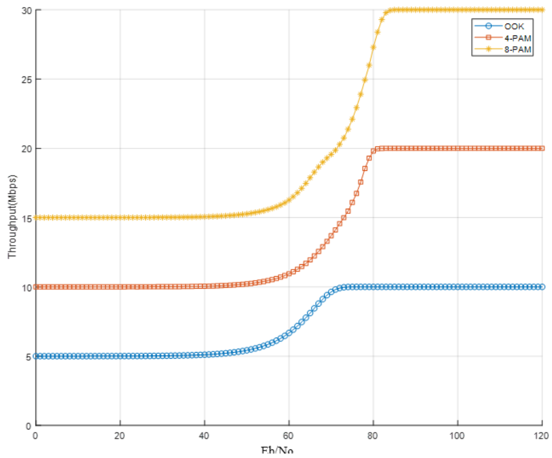


Fig. 10. S3-D2 throughput in enterprise conference room

Fig. 10 and Fig. 11 show throughput for OOK, 4-PAM and 8-PAM in case of S3-D1 and S3-D2 according to the variation of Eb/No. Simulation results show that the required Eb/No is 93dB for S3-D1 and 76dB for S3-D2 to attain minimum 10Mbps in the OOK modulation, respectively. The throughput of 4-PAM and 8-PAM are double and triple values than OOK, respectively, but they require the higher Eb/No values than OOK as we already observed in Fig. 6 and Fig. 7.

Simulation results show that required Eb/No to attain, 10^{-5} BER value is the lowest in OOK method and highest in 8-PAM modulation. That's why in the indoor LiFi 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 required 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 higher throughput such as enterprise conference meeting.

V. Simulation Results

In this paper, the analysis and comparison of pulse modulation were made using OOK, 4-PAM and 8-PAM in a realistic indoor LiFi enterprise standard 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. And the underwater environment is an extreme environment where the signal is strongly absorbed in the water. Therefore, 8-PAM or other communication methods do not provide reliability. Therefore, OOK communication that shows low BER at low Eb/No is effective [12].

In the case of 8-PAM, throughput is highest than OOK and 4-PAM, hence it can be effectively used in corporate meeting rooms that require high data rates. Since indoor navigation requires a high data rate to process the map and location data, 8-PAM modulation can be used effectively for that. And home and office environments use LiFi to create LiFi APs using all the lights in the room, making it the best environment to use LiFi. The environment requires high data rates because it uses computers, printers, mobile phones and other mobile devices that are in high demand for the Internet. In addition, since it is a stable environment indoors, 8-PAM that provides high throughput can be efficiently used [13].

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; Jeong Gon Kim wrote the paper; all authors had approved the final version.

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