# A Hybrid Algorithm for Optimizing the Visible Light Communication

Boni Liu

*Abstract*—**This paper proposes a hybrid algorithm for enhancing the performance of visible light communication (VLC). VLC-based system utilizes light-emitting diodes (LEDs) to illuminate the surroundings and transmit the data simultaneously. The key motivation behind this study was to design a system that can reduce the bit error rate (BER). Consequently, it is important to evaluate different modulation strategies for VLC-based systems and compare their performances. This paper focuses on optimizing various parameters of VLC systems by proposing a novel hybrid scheme. The hybrid strategy combines the On-off keying (OOK) method with the Pulse Width Modulation (PWM) to optimize performance parameters. The study designs the circuit for both modulation techniques including the transmitter and receiver circuits. The key parameters to be studied are BER, bandwidth and flickering to determine which modulation technique is better and finds the best trade-offs among these modulation schemes. MATLAB based simulations compare the modified algorithms with the original algorithms and prove the effectiveness of the proposed method.**

*Index Terms*—**Visible Light Communication, On Off Keying, Pulse Width Modulation, Bit Error Rate**

## I. INTRODUCTION

Visible Light Communication (VLC) systems use light emitting diodes (LEDs) which pulse very fast without perceptible effect on the illumination and human eye. With state-of-the-art developments in the LED technology having switching times in nanosecond, there has been renewed interest in the studies of visible light communication [1]. Classic radio frequency (RF) spectrum under 6 GHz is quickly running out of bandwidth for higher data-rates.

As VLC has several advantages and more applications than the classic wireless communication systems, many researchers and academics have started to pay more attention to this field, as a result many interesting studies about VLC systems have emerged [2-3]. Though, these systems still have some drawbacks in practical applications like limited Data Rate, High Bit Error Rate (BER), Flickering and Dimming Support. For high data rate VLC systems, the transmitter and receiver must be compatible. However, higher data rates, beyond 2 Gb/s, are challenging due to the low Signal to Noise ratio (SNR), Inter Symbol Interference (ISI) and higher Bit Error Rate (BER).

Manuscript received January 20, 2021; revised March 24, 2021

The Science Research Fund of Xi’an Aeronautics University (Grant no. 2019KY0208) supported this paper.

Boni Liu is a lecturer in Xi'an Aeronautical College, Xi’an, China. (200607004@xaau.edu.cn)

To address the aforementioned issues, some modulation strategies such as On-Off Keying (OOK), Pulse Position Modulation (PPM), Pulse Width Modulation (PWM) have been proposed [4-6]. OOK modulation technique fails to provide higher data rates, dimming support, and flickering mitigation. However, it provided the ease of implementation.

Whereas PWM was proposed as an efficient way of achieving modulation, flickering mitigation and dimming support. Higher data rates are also achievable by using PWM but it was shown that dimming parameter restrain the attainable output because of high BER.

To improve the BER and data rate, a combination of PPM and Pulse Shape Modulation (PSM) was proposed [7]. According to the study, the data rate increased without increasing the power. Hence, increasing the complexity of the system. In a VLC system, non-negative pulses are being transmitted which makes DC biasing applicable. It maintains the minimum required brightness when no data is being transmitted and also mitigates flickering issue and BER.

This paper evaluates the VLC system performance in terms of BER, flickering, and transmitted data rate and provides a balance between BER and flickering. It also provides a comparison between different modulation techniques and shows how the performance in optimized when using the modified OOK technique.

The proposed VLC system consists of a transmitter and receiver. Both the sections consist of Arduino for processing the received input. Arduino is an Open Source Hardware equipped with sets of digital and analog input/output (I/O) pins. The data rate in bits per second (bps) Arduino offers for serial communication or digital communication can be300, 600, 1200, 2400, 4800, 9600, 14400, 19200, 28800, 38400, 57600, or 115200. However, 9600 is the standard baud rate usually used.

The main contributions of the study are: To design a hybrid algorithm by combing the OOK and PWM strategies; to design a VLC system that can reduce the bit error while also increasing the data rate; to design the transmitter and receiver circuits for both the old and the novel algorithm to compare their performances.

The paper is structured as follows: Section 2 presents the state of the art research in the visible light communication. Section 3 describes the model of the proposed system. Section 4 presents the analysis of the proposed strategy. Section 5 presents the flowchart while section 6 discusses the simulations. Lastly, section 7 presents the conclusion.

## II. State of Art

This section discusses the latest technologies and research in the visible light communication (VLC) systems. Reference [8] discusses the scope of VLC for 5G networks. Since VLC has som much untapped potential, using it for 5G networks can be game-changer and help reach it to a much wider audience around the world. Another research [9] focuses on the low penetration of the light through opaque material. This research proposes the spectrum for the VLC so that it can work in close to infrared region.

## III. The Model Of Proposed System

In communication technology, the space between the transmitter and the receiver is known as the channel and is used to transmit the carrier signal [10]. Many factors including interference, noise, and attenuation affect the channel. However, for VLC-based systems, the channel is defined as the space between the photo-detector (PD) and the LED. Its transfer function $H_j$ can be written mathematically as,

$$r_j = H_j s_j + \omega_j \tag{1}$$

Whereas the transmission and receiving symbols are $r_j$ and $s_j$. While the channel response and the channel noise are $H_j$ and $\omega_j$, respectively. Since the proposed VLC system uses a Line of Sight (LOS) channel, it will be modelled along with the optical power and path loss parameters.

### A. Flickering

Flickering is the disruption and fluctuation in the illumination of the light source that can be perceived by a human eye. So, an effective modulation technique should avoid flickering. Constant flickering can have an adverse impact on the health of our eyes as well. Therefore, changes in the light intensity must be faster than the eye can observe. According to IEEE standard e. IEEE 802.15.7, the flickering must be greater than two hundred Hz to avoid any adverse effects on human eyes. Hence, all modulation techniques must reduce flickering while at the same time producing higher date rate.

Flickering % can be calculated by using following equation;

$$Flickering\ \% = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}\ x\ 100 \tag{2}$$

### B. Bandwidth Efficiency

Bandwidth is defined as the inverse of minimum bit slot $(T_{min})$

$$B_{req} = \frac{1}{T_{min}} \tag{3}$$

The input pulse $x(t)$ is passing through the additive white Gaussian noise (AWGN) $\sigma(t)$:

$$y(t) = Rh(t) * x(t) + \sigma(t) \tag{4}$$

The PD current and the responsivity are given as $y(t)$ and $R$, respectively. The time average transmitted optical power is given by:

$$P_t = lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} x(t)dt \tag{5}$$

The average received optical power is given as:

$$P_r = H_{j_{LOS}}(0) P_{t(LOS)} + \sum H_{j_{ref}}(0) P_{t(ref)} \tag{6}$$

Whereas $H_j(0) = \int_{-\infty}^{\infty} h_j(t)dt$ is the gain of the DC channel

$$H_j(0)_{LOS} = \begin{cases} \frac{(l+1)A_{PD}\gamma cos^l(\varphi) g(\psi) T(\psi)_{cof} cos\,(\psi)}{2\pi d^2} \\ 0,\ else\ where \end{cases} \tag{7}$$

The LOS links and non-LOS paths are considered. On the first reflection, $H_j(0)_{ref}$ is the DC channel gain

$$H_j(0)_{ref} = \begin{cases} \frac{(l+1)A_{PD} * va}{2\pi D_1^2 D_2^2} dA\ cos(\alpha) cos\,(\beta) \\ 0,\ else\ where \\ va = \gamma cos^l(\varphi) g(\psi) T(\psi)_{cof}\ cos(\psi) \\ 0 \le \psi \le \psi_c \end{cases} \tag{8}$$

Whereas the transmitter and receiver are separated by the distance $d$, the space between the reflective point and the transmitter is given as $D_1$ while the space between the reflective point and receiver is given as $D_2$, the irradiance angle and the incidence angle to the receiver are α and $\beta$, respectively. The reflectance factor is represented as $\gamma$, reflective area of small region is $dA$, the order of lambertian emission is given as $l$, the receiving area of PD is given as $A_{PD}$, the angle of incidence and the angle of irradiance are $\psi$ and $\varphi$, the optical filter signal transmission coefficient is $T(\psi)_{cof}$ and $\psi_c$ is the field of view (FOV), the gain of the optical concentrator and the refractive index are given as $g(\psi)$ and $p$.

$$g(\psi) = \begin{cases} \frac{p^2}{sin^2 \psi_c}, & 0 \le \psi \le \psi_c \\ 0, & 0 \ge \psi_c \end{cases} \tag{9}$$

A transmitter, a channel, and a receiver are three main aspects of the VLC-based system. The block diagram of the proposed VLC transmitting and receiving systems is shown in Figure 1. Figure 1(a) presents the transmitter. The transmitting system is composed of a microcontroller i.e. Arduino Uno for processing and modulating the user input (given by using Arduino IDE). This signal is transmitted using LED (LOS channel). A LED driving circuit is used to provide sufficient amount of current and voltage in order to drive the LED. The transmitted signal is then received by the receiving system presented in figure 1(b). It is composed of a PD (solar cell), it detects the signal (in the form of light energy) and converts it into electrical energy (current) which is then demodulated by using Arduino Uno.

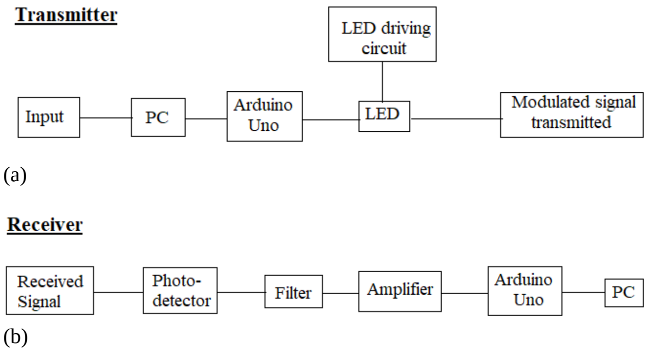

Figure 1: The Proposed VLC Model

## IV. Analysis of The Proposed Algorithm

### A. Adaptive Modulations Schemes

Visible Light Communication uses direct detection (DD) and intensity modulation (IM). A photo-detector (PD) in a DD receiver generates a current which is proportionate to its optical power. Whereas IM is technique in which modulation is achieved by changing the biasing current of LEDs. The modulation schemes used in VLC uses power to transmit information. Let the transmitted and the received optical signals be represented by $x(t)$ and $y(t)$, respectively. Considering the impulse response as $h_j(t)$, the received signal is

$$y(t) = \int_{-\infty}^{\infty} x(\tau)h_j(t-\tau)d\tau + n(t) \tag{10}$$

Whereas *n(t)* represents the AWGN. Here we assume $h_j(\tau) = \delta(t)$. In the case of VLC systems, $x(t)$ denotes the optical power from LED illumination, and not amplitude, and therefore it must fulfill the following conditions,

$$\begin{cases} x(t) > 0 \\ \lim_{T\to\infty} \frac{1}{T}\int_0^T x(t)d(t) \leq \gamma P \end{cases} \tag{11}$$

Whereas the average power is given as *P* and the range of the dimming factor is $0 \leq \gamma \leq 1$.

### B. On-Off Keying (OOK)

One of the easiest method to relay data is the OOK. To relay the logic value zero, a LOW pulse is transmitted. For the logic value of one, a HIGH pulse is transmitted. For practical applications, the LED is switched off for relaying a logic value of zero and switched ON for a logic value of one. The width of the pulse is varied according to the data rate. Figure 3 shows the timing diagram of the OOK process.

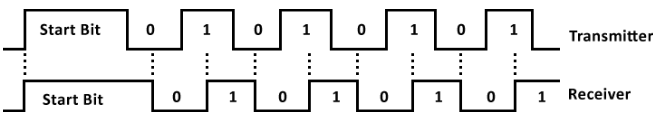

Figure 2: Timing diagram for the OOK

An on–off keying (OOK) transmitter emits a rectangular pulse of duration T intensity to signify a one bit and no pulse to signify a zero bit. The OOK signal is

$$x(t) = 2Pb\, rect\left(\frac{t}{T}\right) \tag{12}$$

Where b∈ information bit and rect is defined for $0 \leq x \leq 1$ and otherwise zero, and

$$BER = \frac{1}{2}erfc\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right) \tag{13}$$

### C. Modified OOK

In this modulation scheme, the digital input 1 is modulated by a high pulse and input 0 is sub-divided into high and low pulse. In order to improve flickering, we have divided the input 0 into both high and low pulses in such a way that high pulse duty cycle is 70% of that of the input 1. This modulation scheme improves the flickering of our VLC system but also the Bit error rate (BER) increases. Figure 3 presents the timing diagram of the modified OOK.

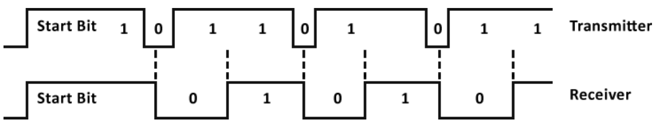

Figure 3: Timing diagram for the modified OOK

## V. Flow Chart

### A. Transmitter

Figure 4 presents the flowchart of the whole process. In the transmitter section, first the data is sent to the Arduino microcontroller by the PC. The Arduino receives and converts this data into bits (1 and 0) and furthermore modulates the bits according to the desired modulation scheme. The Arduino then sends the modulated data to the LED by which for every 1, a pulse is generated and transmitted to the led and for every 0, no pulse is transmitted. The data is encoded in the led in the form of 1 and 0. The LED then receives the data and transmits a digital 1 if it is on and 0 if it's off.

### B. Receiver

In the receiver section, the optical pulses are interpreted by a PD into an electrical signal which is then amplified by an amplifier. In our case the maximum voltage of 1watt solar panel is 5 volts. The maximum threshold value for maximum voltage is 700, by using this information, the threshold value of the solar cell is set to 500 by using the Arduino IDE, such that when light hits the solar cell and its threshold value reaches to a point greater than 500, the microcontroller reads it as binary 1 and when its threshold value is less than 500 the microcontroller reads it as binary 0. The Arduino receives the data and demodulate it according to the demodulating algorithm and then finally sent it to PC.

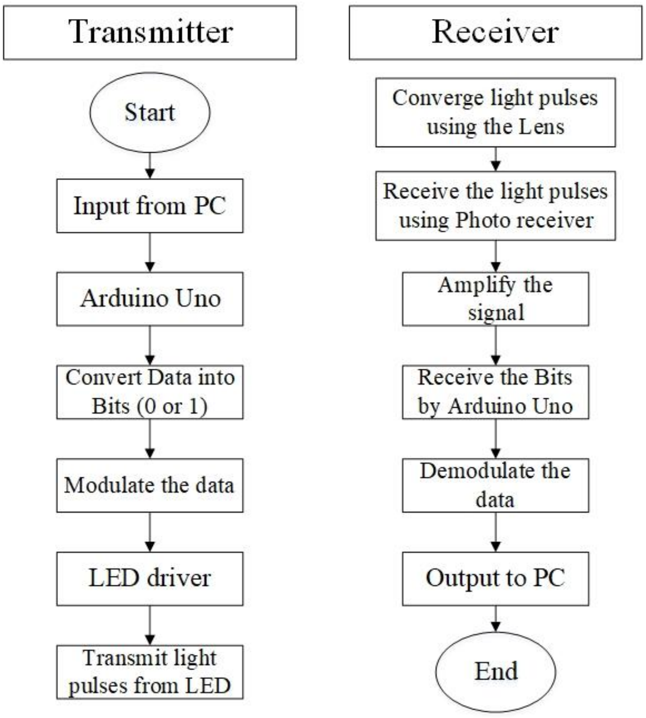


Figure 4: Flow Chart

## VI. Simulations and Discussion

Figure 5 shows the relationship between data rate and BER, by comparing OOK modulation and Modified OOK with and without lens. The results show that OOK modulation has better BER as compare to Modified OOK, and when we apply lens on both modulation schemes BER will reduce further.

Figure 6 shows the relation between BER and flickering when two different modulation techniques are used with and without lens. So note that in OOK modulation flickering is very much observable (high) and the BER is moderate where as in Modified OOK flickering is less observable so BER is much higher. In this case we have used lens to reduce BER.

Figure 7 provides the relationship between the BER and bandwidth. It shows that OOK modulation utilizes less bandwidth than Modified OOK and has less BER when used with converging lens as compare to Modified OOK modulation (with or without lens).

## VII. Conclusion

This paper proposed a hybrid algorithm for enhancing the performance of VLC-based systems. The hybrid strategy combined the On-off keying (OOK) method with the Pulse Width Modulation (PWM) to optimize performance parameters. The study designed the transmitter and receiver circuits for both modulation techniques to compare their performances. The key parameters studied were the BER, bandwidth and flickering to determine which modulation technique was better. MATLAB based simulations compared the modified algorithms with the original algorithms and proved the effectiveness of the proposed method.

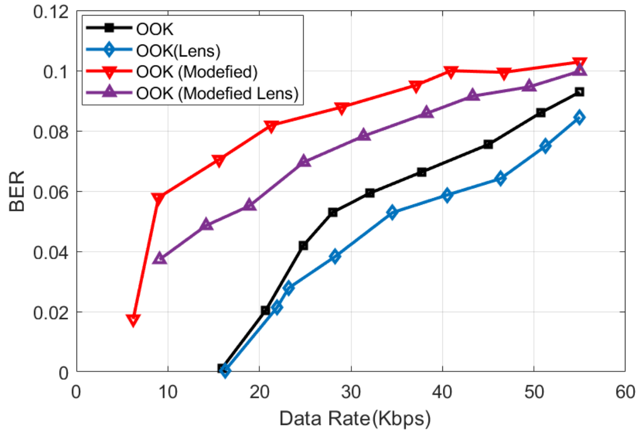


Figure 5: Comparison of Data Rate with BER

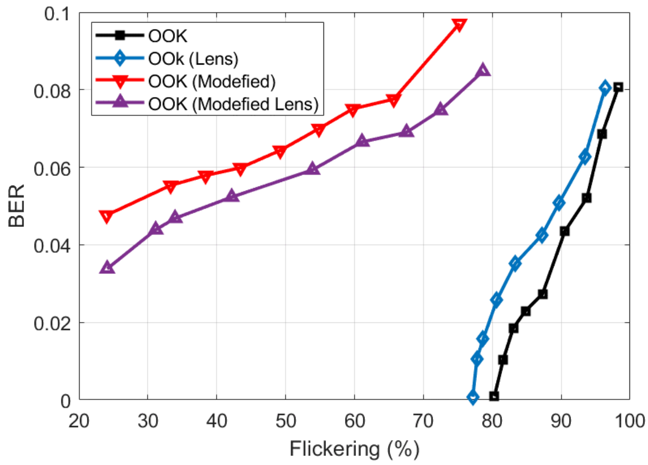


Figure 6: Comparison of Flickering with BER

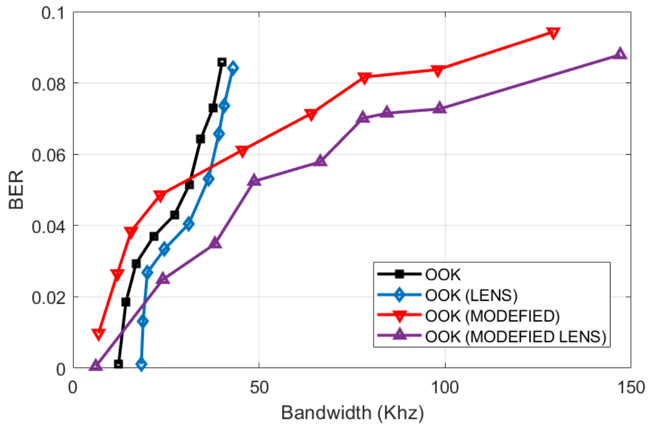


Figure 7: Comparison of Bandwidth with BER

## References


[1] Figueiredo, Monica, Luis Nero Alves, and Carlos Ribeiro. "Lighting the wireless world: The promise and challenges of visible light communication." IEEE Consumer Electronics Magazine 6, no. 4 (2017): 28-37.

[2] Matheus, Luiz Eduardo Mendes, Alex Borges Vieira, Luiz FM Vieira, Marcos AM Vieira, and Omprakash Gnawali. "Visible light communication: concepts, applications and challenges." IEEE Communications Surveys & Tutorials 21, no. 4 (2019): 3204-3237.

[3] Rehman, Saeed Ur, Shakir Ullah, Peter Han Joo Chong, Sira Yongchareon, and Dan Komosny. "Visible light communication: a

system perspective—overview and challenges." Sensors 19, no. 5 (2019): 1153.
[4] Zhao, Yan, and Jayakorn Vongkulbhisal. "Design of visible light communication receiver for on-off keying modulation by adaptive minimum-voltage cancelation." Engineering Journal 17, no. 4 (2013): 125-130.
[5] Yoo, Jong-Ho, Byung Wook Kim, and Sung-Yoon Jung. "Modelling and analysis of M-ary variable pulse position modulation for visible light communications." IET Optoelectronics 9, no. 5 (2015): 184-190.
[6] Pradana, Angga, Nur Ahmadi, and Trio Adionos. "Design and implementation of visible light communication system using pulse width modulation." In 2015 International Conference on Electrical Engineering and Informatics (ICEEI), pp. 25-30. IEEE, 2015.
[7] Alsalami, F. M., Ahmad, Z., Zvanovec, S., Haigh, P. A., Haas, O. C., & Rajbhandari, S. (2021). Statistical channel modelling of dynamic vehicular visible light communication system. Vehicular Communications, 29, 100339.
[8] Arfaoui, Mohamed Amine, Mohammad Dehghani Soltani, Iman Tavakkolnia, Ali Ghrayeb, Majid Safari, Chadi M. Assi, and Harald Haas. "Physical layer security for visible light communication systems: A survey." IEEE Communications Surveys & Tutorials 22, no. 3 (2020): 1887-1908.
[9] Minotto, Alessandro, Paul A. Haigh, Łukasz G. Łukasiewicz, Eugenio Lunedei, Daniel T. Gryko, Izzat Darwazeh, and Franco Cacialli. "Visible light communication with efficient far-red/near-infrared polymer light-emitting diodes." Light: Science & Applications 9, no. 1 (2020): 1-11.
[10] Lu, Xiao, Dusit Niyato, Hai Jiang, Dong In Kim, Yong Xiao, and Zhu Han. "Ambient backscatter assisted wireless powered communications." IEEE Wireless Communications 25, no. 2 (2018): 170-177.

**Boni Liu** female, lecturer, postgraduate, worked in Xi'an aeronautical college, engaged in education for more than ten years, research direction: electronics, communication and automation, published several academic papers, applied for 3 authorized patents, participated in the compilation of a textbook.