CEPAT Journal of Computer Engineering: Progress, Application and Technology
Vol. 1, No. 1, Month May, pp. 1-8
ISSN 2963-6728, DOI: https://doi.org/10.25124/cepat.v1i01.4818

Performance of Visible Light Communication Bit Error Rate with Power Allocation Strategy

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Article Info

Article history:

Received April 29, 2022
Revised May 9, 2022
Accepted May 11, 2022

Keywords:

Gain Ratio Power Allocation
Bit Error Rate
Power Allocation
Static Power Allocation
Visible Light Communication

ABSTRACT

Visible Light Communication (VLC) is a communication system that uses visible light as its transmission medium to transmit information signals with light emitting diode (LED) and LASER light sources using visible light between 400 THz (380 nm) to 800 THz (780 nm). VLC has several advantages over the use of radio frequencies in a system. Performance analysis is needed to prove these advantages. Performance analysis was carried out using a mathematical computational simulation using google colab with the python programming language. By taking into account the power allocation (α) strategy in the form of gain ratio power allocation (GRPA) and static power allocation (SPA). The interesting thing from this research is that the power allocation in the VLC system greatly influences the resulting performance. So, it can be locked that the SPA power allocation strategy can be adjusted by producing $\sum\alpha = 1$ and finding the optimal bit error rate (BER) value in the range of 10^{-6} to 10^{-3}.

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1. INTRODUCTION

Information and communication technology is growing in the era of industry 5.0. This can be seen with the emergence of many renewable technologies such as Optical Wireless Communication (OWC) technology which is a technology that can save the frequency spectrum while still producing a high data rate[1], such as visible light communication (VLC). Paper [2] studies about visible light communication and explains that VLC is a communication system that uses visible light as its transmission medium to transmit information signals from the transmitter using light emitting Diode (LED) and light amplification by stimulting emission of radiation (LASER). Thus, VLC is often used to refer to the former when an optical source emits in the visible wavelength band (380 nm–780 nm) and is also used for illumination/display [1].

VLC has several attractive features compared to radio frequency use, such as having a high bandwidth light source [3], high capacity, no electromagnetic interference, license-free spectrum, secure transmission, low cost with existing infrastructure and low energy consumption [4]. Then in section [5] it is stated that other advantages of VLC are also seen in the long service life, high efficiency of use, and relatively low power consumption.

Visible light communication (VLC) is considered as a complement to radio frequency communication (RF) technology in providing high-speed wireless communication into the user's room or also known as Indoor Visible Light Communication [6].

Based on studies [4] non-orthogonal multiple access (NOMA) is one of the schema files dual access, which was originally proposed for RF wireless communication and also investigated on VLC systems to increase capacity. NOMA Skema Scheme allows each user to share frequency, time and resources space, which can support massive connectivity, improve spectral efficiency and can increase system capacity. NOMA is also considered as a potential candidate to be offered as a VLC with high spectral efficiency in increasing its capacity [7]. The NOMA scheme also allows each user to share frequency, time, and space resources, which can support massive connectivity, increase spectral efficiency and increase system capacity [8].

NOMA on VLC systems can ensure higher throughput and fairness. In addition to power allocation and cancellation of critical interference in NOMA, the comparison of gain ratio power allocation (GRPA) versus static power allocation (SPA) is that GRPA will produce a large power allocation value when the distance from the source is far, in other words, the GRPA power allocation value is affected by distance. between transmitter and receiver while the power allocation value of SPA can be adjusted and set beforehand. GRPA and SPA were investigated for the NOMA VLC System and it was seen that the bit error rate (BER) could increase from the combination of NOMA and VLC. Likewise, in VLC NOMA it was investigated that the error rate assuming perfect and imperfect customer satisfaction index (CSI) availability. In addition, it was also shown that efficient user installation of the system can significantly increase the ergodic capacity and increase the number of users in the NOMA system [7]. In an Indoor system, NOMA VLC also has power allocation which is divided into 2 types, namely gain ratio power allocation and static power allocation.

To perform analysis and calculation of performance in the system it can be done with mathematical computational analysis. Therefore, in this paper, a performance analysis will be carried out using BER as the main calculation parameter in the system by taking into account the two types of power allocation in the NOMA VLC indoor system.

2. METHOD

2.1. System Block Diagram

In this paper, the NOMA VLC indoor downlink network equipped with one LED and 5 users. So, for the block diagram in the system block diagram is as follows [9]:

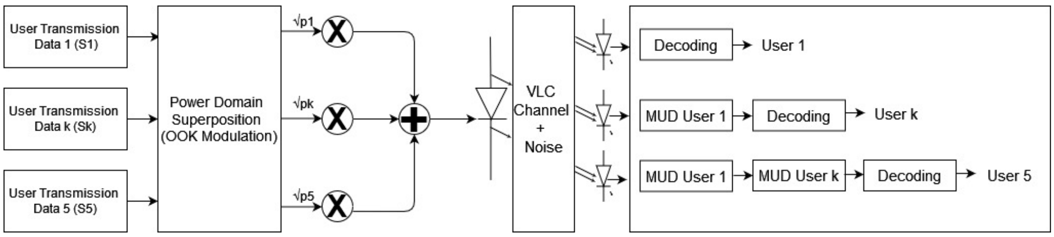

Figure 1. System Block Diagram

In this paper, the design of the NOMA VLC indoor system is carried out to analyze the impact happened to the performance of multi user detection with line of sight (LOS) channel. Based on Figure 1, there are three parts that make up the VLC system. LOS Channel, and a receiver containing: succesive interference cancellation (SIC), Modulation (MUD), decoding process and output. In this paper, the MUD scheme used is SIC. The diagram above illustrates that there are several block sections. for the flow diagram there will be data transmission from each user and then modulation will be carried out using the on off keying principle. for the value of p in the form of the value of the allocation of power owned by each user. then also influenced by noise and channel influences. then the last part of the block contains the final process of the flow diagram and the decoding process occurs to generate and interpret the data received from the data transmission process.

The following is a flow diagram in the designed system :

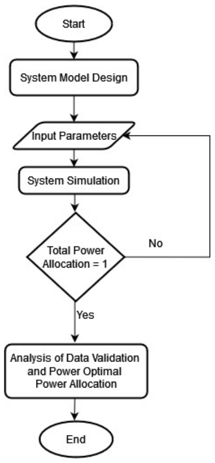

Figure 2. Flow Diagram

2.2. Input Parameters

In designing the Indoor NOMA VLC system in this paper, it is given some input parameters on the system that can affect the simulation results. In this final project, one LED lamp is used [9] with a transmit power of 5 watts with a bandwidth of 10 MHz [3]. On the receiving side using PIN photodiode. The photodiode used has silicon material. PIN photodiode has specifications field of view (FoV) of 70°, responsiveness of 0.8 [1]. For channel in this Final Project using LOS channel. The simulation parameters used in the Simulation in the Indoor NOMA VLC system are clearly shown and detailed in the table below:

Tabel 1. Input Parameters

Parameters		Value
Transmitter	Type	Light Emitting Diode
	Total	1 piece
	Power	5 watt
	Bandwidth	10 MHz
Receiver	Type	Photodiode
	Total	5 piece
	Responsivitas	80 %
	Area Detector Photodiode	0.000001 m^2
	Field of View	70 °
Other	Dimension	7 x 7 x 3 m^3
	Multiple Access	Non-Orthogonal Multiple Access
	Channel	Line of Sight
	Type of Power Allocation	Gain Ratio Power Allocation
		Statis Power Allocation

2.3. System Simulation Design

In this paper, a downlink system modeling [8] is carried out which using the LOS channel with 5 users where each user has different distances. For user 1 to user 5, the distances are 7 m,8 m, 9 m, 10 m, 11 m respectively. In detail, the simulation design of the Indoor system is described NOMA VLC is as follows:

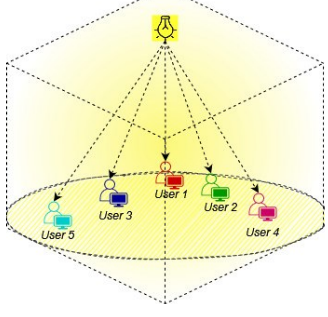

Figure 3. System Simulation Design Illustration

The simulation uses a room with dimensions of 7x7x3 m^3. The results of mathematical computational simulations using Google Colab using the Python programming language will be projected with curve images and several result tables.

2.4. Simulation Scenario Calculation
2.4.1. Channel Gain Calculation

Based on the type of channel, Visible Light Communication is divided into 2 types, namely LOS and NLOS channels. This channel serves as a medium so that the signal sent from the LED to the user can be received properly. However, this paper only focuses on using the LOS gain channel. The first calculation is to calculate the value of the optical concentrator. The purpose of calculating the optical concentrator is as one of the variables that will be used in calculating the VLC channel, as follows with the (1):

$$g(\varphi_k) = \frac{p^2}{sin^2(\varphi_c)} \quad (1)$$

For $g(\varphi_k)$ is the concentrator gain, while the value of p^2 is an index that is defined first upstream with a value of 1.5 and the value of φ_c is the value of FoV.

Next is to calculate the Lambertian emission equation that will be used in the channel gain calculation, here is the Lambertian emission equation.

$$m = \frac{-\ln(2)}{\ln(\cos(\psi\frac{1}{2})} \quad (2)$$

Line of Sight (LOS) channel is a type of channel where the signal is transmitted has no barrier until the signal is received, meaning that the signal sent directly received by the recipient without any obstructions. Channel LOS can be expressed in (3) below.

$$h_k = \frac{(m+1)cos^{m+1}(\psi_k)A_{det}}{2\text{п}d_{2k}} \quad (3)$$

Equation 3 is an equation that is used to determine the value of the VLC channel which will be one of the variables used to find the value of the received power. Meanwhile, to find out the acceptability value of each user in the system, it is written in (4).

$$p_{rx} = p_t \cdot h_k \cdot g(\varphi_k) \quad (4)$$

2.4.2. Noise Variance Calcuation

Noise is a nuisance element that is almost always involved in the communication system. The nature of the noise interferes with the information signal, so that the received information signal is not the same as the original signal. For total noise, which is the sum of shot noise and thermal noise [4], it is as follows in equation (5):

$$\sigma^2{}_{nk} = 2qB(h_kRP_k + I_{bg}I_2) + \frac{8\text{п}K_bT\eta A_{det}I_2B^2}{G} + \frac{16\text{п}^2K_b\Gamma\eta^2A^2{}_{det}I_3B^3}{gm} \quad (5)$$

where $\boldsymbol{q}$ is the electron charge, $\boldsymbol{B}$ is the bandwidth, $\boldsymbol{R}$ is the Photodetector Responsiveness, $\boldsymbol{h_k}$ is the channel gain, $\boldsymbol{P_k}$ is the transmit power, $\boldsymbol{I_{bg}}$ is the photocurrent generated from background radiation and $\boldsymbol{I_2}$ is the noise bandwidth factor. While the thermal noise equation with $\boldsymbol{K_b}$ is a Boltzmann constant, $\boldsymbol{T}$ is temperature, $\boldsymbol{\eta}$ is fixed capacitance photodetector, $\boldsymbol{A_{det}}$ is area detector, $\boldsymbol{G}$ is open loop voltage gain, $\boldsymbol{gm}$ is FET transconductance [4].

2.4.3. Power Allocation Calculation

Based on the NOMA principle, the optical power emitted from the LED is distributed according to the power allocation based on the channel gain conditions of each user. There are several modeling methods for multi-user power allocation, including gain ratio power allocation (GRPA) and static power allocation (SPA). In SPA power allocation is given randomly for each user who is in one system coverage. While in

GRPA, the allocation of power depends on the channel gain value obtained by each user [10].But still follow the rules of power allocation with a value of ∑α= 1.

2.4.3.1 Gain Ratio Power Allocation

For the general equation that the GRPA power allocation must have is in (6).

$$\alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < \alpha_5 \quad (6)$$

The value of this GRPA equation is obtained from several previous studies which show that the value generated by the power allocation system for each user has rules like the equation above. This right also shows that if it meets the rules in equation (6), it can be said that the results of the power allocation in the resulting system are correct.

2.4.3.2 Static Power Allocation

For the general equation that the SPA power allocation must have is in (7).

$$\alpha_1 > \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 \quad (7)$$

In equation 7 shows the rule for the spa allocation power value. The spa value that was initially determined must be in accordance with equation 7 so that a proportional power allocation value is obtained.

2.4.4. Bit Error Rate Calculation

In determining the value of the bit error rate in the system, it is necessary to validate the overall performance in the system. For the first performance calculation, the signal to noise ratio value is calculated in (8).

$$SNR = \frac{h_k(p_{rx}.R)^2.\alpha}{\sigma^2{}_{nk}} \quad (8)$$

Next is the equation for calculating the channel capacity value in the system, the following is the (9).

$$r_n = B.log(1 + SNR) \quad (9)$$

The next equation is to find out the value of the q-factor in the system, the q-factor equation is found in (10):

$$Q = \frac{10^{SNR/20}}{20} \quad (10)$$

To find out the overall system performance, it can be done by searching for the bit error rate value in the indoor NOMA VLC system. The obtained value is obtained by (11).

$$BER = \frac{\exp(Q^2/2)}{Q\sqrt{2\pi}} \quad (11)$$

3. RESULTS AND DISCUSSION

This section discusses the results of the simulation and analysis in this paper with the design of the NOMA VLC indoor system to determine the bit error rate value with the influence of power allocation strategies both GRPA and SPA. The process begins by doing a simulation with the parameters that have been determined in table (1). Each section will be discussed in more detail as follows:

3.1. Simulation Scenario Calculation

From the scenario on the NOMA VLC indoor system, the calculation process is carried out to run the simulation in order to get the performance value on the system. This calculation is carried out to find the performance value, distance between the sender and the receiver, and the channel LOS value.

Tabel 2. Simulation Calculation Result

User Distance	Channel LOS	Power Transmit	Noise	Power Allocation	
				GRPA	SPA
$7\ m$	$5{,}346 \,.\, 10^{-7}$	$-21{,}667$ dBm	$2{,}661 \,.\, 10^{-14}$	0,071	0,5
$8\ m$	$3{,}285 \,.\, 10^{-7}$	$-23{,}782$ dBm	$1{,}989 \,.\, 10^{-14}$	0,116	0,25
$9\ m$	$2{,}138 \,.\, 10^{-7}$	$-25{,}647$ dBm	$1{,}645 \,.\, 10^{-14}$	0,179	0,12
$10\ m$	$1{,}456 \,.\, 10^{-7}$	$-27{,}315$ dBm	$1{,}392 \,.\, 10^{-14}$	0,262	0,08
$11\ m$	$1{,}028 \,.\, 10^{-7}$	$-28{,}824$ dBm	$1{,}253 \,.\, 10^{-14}$	0,371	0,05

Table 2 shows the results of calculations from the scenario system, these results were obtained by performing mathematical computational simulations using Google Colab with Python programming language.

3.2. Analysis of each User's Distance Curve Projection and Power Allocation

After knowing several important parameters that must be owned by every NOMA VLC indoor system, then an analysis of the results of the curve projection in the image related to the relationship between the distance between users and the power allocation generated by the gain ratio method of power allocation and static power allocation will be carried out. The following is the result of the projection in Figure 4. :

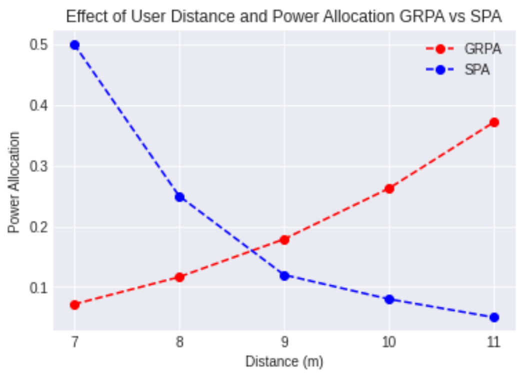

Figure 4. Projection of Relationship Curve between the Distance and Power Allocation of GRPA and SPA

Figure 4 illustrates that the relationship between the two resulting curves has different values. For power allocation, GRPA produces a curve with a positive correlation, in contrast to SPA, which has a negative correlation. If the distance between users in the system is far, the resulting GRPA allocation power will be even greater. However, if the distance in the system is far, the resulting SPA power allocation will be smaller. This is in accordance with the equation in power allocation (6) and (7).

3.3. System Performance Validation Calculation Results Curve

The following are some of the curves generated from mathematical computational simulations of the influence of GRPA and SPA power allocation on the signal to noise ratio, channel capacity, and qfactor values generated in the system. Here is the curve projection:

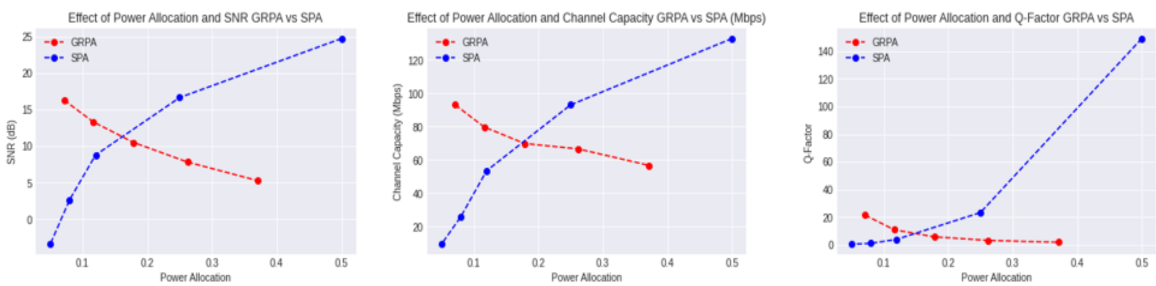

Figure 5. the Influence of Power Allocation Curve on SNR, Channel Capacity, and Q-Factor

Figure 5 shows that the power allocation relationship between GRPA and SPA has the same projections between each other. The red curve shows the power allocation for GRPA, while the blue curve shows the projection for SPA power allocation. For all GRPA curves, this is a negative correlation, this is because when the value of the given power allocation is large, the results of the validation of the data generated in the form of SNR, Channel Capacity, and Q factor are small. In contrast to the SPA allocation power curve which is positively correlated.

3.4. Curve Projection Analysis of Bit Error Rate and SPA Power Allocation

This section will show the projection of the BER relationship obtained based on the type of power allocation used in the system, namely GRPA and SPA.

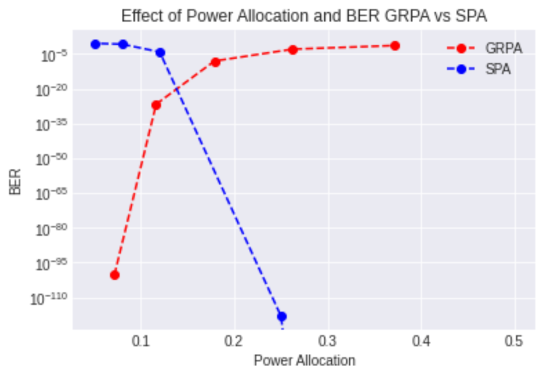

Figure 6. Curve Projection Analysis of Bit Error Rate and SPA Power Allocation

Based on Figure 6 above, it describes the results of the BER value of the system. It can be seen that the resulting value is not optimal and is not close to 10^{-6} up to 10^{-3} [9], therefore system optimization will be carried out by replacing and matching the SPA power allocation value, this is done based on the image projection according to the reference [11].

3.5. Analysis of the Bit error rate Curve Projection on changes in the SPA Power Allocation

To find BER results that are close to optimal, the first step is to match the BER value based on the user's distance to produce a BER value that is close to optimal or in the range of 10^{-6} up to 10^{-3} :

Tabel 3. Results of Changes in the Value of Power Allocation of SPA and BER Results

Distance (meters)	Power Allocation			BER		
	I	II	III	I	II	III
7	0,35	0,5	0,3	0	0	0
8	0,25	0,2	0,25	$5{,}770 . 10^{-119}$	$6{,}143 . 10^{-77}$	$5{,}770 . 10^{-119}$
9	0,18	0,15	0,2	$7{,}428 . 10^{-9}$	$1{,}183 . 10^{-6}$	$1{,}562 . 10^{-10}$
10	0,15	0,11	0,15	$4{,}192 . 10^{-2}$	$1{,}245 . 10^{-1}$	$4{,}192 . 10^{-2}$
11	0,07	0,05	0,1	$3{,}760 . 10^{-}$	$4{,}107 . 10^{-1}$	$3{,}258 . 10^{-1}$

The following is the result of the curve projection in the form of an image illustrating the relationship between the allocated power given in the system and the value obtained. The resulting value is already in the ideal bit error rate range of 10^{-6} up to 10^{-3} [9]. It is clearly illustrated in Figure 7.

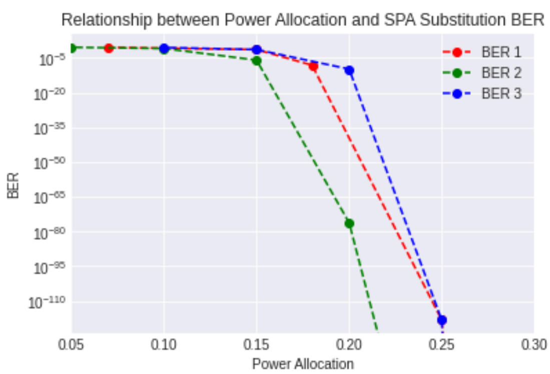

Figure 7. Curve Projection Relationship between changes in SPA Power Allocation and BER

Figure 7. illustrates that the resulting BER value is already in the ideal range of 10^{-6} up to 10^{-3} after optimizing by replacing and trying the SPA power allocation value. When optimizing or changing this value, it is based on ∑α= 1. Of the 3 curves formed, the value of the green colored curve with the label of 2 has a value that is in the ideal range. However, if the 3 curves in Figure 5. are averaged, they already have a minimum value. this shows that by implementing a power allocation strategy on the SPA can improve the performance of the indoor NOMA VLC system by producing a minimum value of air or ranging from 10^{-6} up to 10^{-3} [9].

4. CONCLUSION

Based on the performance of the Indoor system model NOMA VLC power allocation value (α) GRPA is more difficult to optimize because value α has already been generated through the calculation system. While the value of (α) SPA can be done changes with terms and conditions (α) feasible 1. BER value in the distribution of power allocation (α) SPA can be optimized by change the value of (α) so as to produce a BER value of 10^{-6} up to 10^{-3}. Expected to be able to perform mathematical computational simulations by measuring and testing performance completely and more in line with conditions in everyday life.

ACKNOWLEDGEMENTS

The authors thank those who have helped in the preparation of this article so that it can be published and add reading material in the academic field, especially with the topic of visible light communication.

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