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Performance of Static Power Allocation in Indoor Room on VLC-NOMA System Using Modulation PPM

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Abstract

Visible light communication (VLC) is an emerging and promising technology that exploits the visible light spectrum for data transmission. However, one of the major challenges in VLC is how to efficiently allocate the scarce modulation bandwidth to multiple users while avoiding interference and maintaining signal quality. To tackle this challenge, we propose a novel scheme that combines non-orthogonal multiple access (NOMA) with static power allocation (SPA) and pulse position modulation (PPM) in VLC. We conduct simulations in a realistic indoor scenario with a 9x9x3 m room and a single 12-watt LED at the center, using a line of sight (LOS) channel with a field of view (FOV) of 70°. The results show that our scheme achieves superior performance, with user 1 and user 2 obtaining signal-to-interference noise ratio (SINR) values of 20 dB and 74 dB, respectively. Our scheme can effectively overcome the limitations of VLC, such as low data rate, limited coverage area, and high sensitivity to ambient light noise, and pave the way for future VLC applications.

Keywords: *visible light communication*; *non-orthogonal multiple access*; *pulse position modulation*;

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1. Introduction

The use of visible light communication (VLC) as a transmission medium in optical and wireless communications is becoming more prevalent due to its numerous advantages, including high bandwidth, low power consumption, and secure, interference-free communication. VLC uses visible light as a transmission medium and has two types of channels that affect its performance and reliability: line of sight (LOS) and non-line of sight (NLOS) [1]. VLC has several advantages over radio frequency communication, such as higher transmission speed that can reach hundreds of Mbps, better security due to the limited range and directionality of light, and lower costs because of the availability and energy efficiency of light emitting diodes (LEDs).

To achieve maximum success in using VLC, there are several technical requirements that must be met, including dimming matching and flickering immunity. VLC utilizes visible light emission from LEDs as its communication medium, with a frequency wavelength between 380 nm to 780 nm and frequencies between 400 THz up to 800 THz. Compared to radio frequency technology, VLC has several advantages, including faster transmission speeds, higher security, and lower costs. VLC technology can achieve a capacity 10,000 times greater than radio frequency (RF) technology [2] because it has much wider spectrum range of 400-800 THz.

The advent of LED technology has transformed VLC by affording a higher degree of control over light source modulation. With the use of LEDs, it is possible to modulate the light at high speeds, which is important for achieving high data rates in VLC systems. LEDs also have a longer lifespan and are more energy-efficient compared to traditional incandescent or fluorescent lamps, making them a cost-effective solution for VLC deployment [3]. Furthermore, the incorporation of LEDs in VLC systems provides enhanced flexibility in deployment scenarios, as they can seamlessly integrate with pre-existing lighting infrastructures. As a result, LED technology has played a significant role in the widespread adoption of VLC for various applications, including indoor positioning, data transmission, and intelligent transportation systems, among others [4].

Non-orthogonal multiple access (NOMA) is a multiple access technique that can balance throughput and fairness. Although VLC has a much wider spectrum range than RF, it still faces challenges in modulating the light signals efficiently and achieving

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high data rates. NOMA is applied to enhance user performance in the downlink network [5]. Among the NOMA techniques, the power domain stands out as particularly well-suited for application in VLC systems, especially in scenarios involving short distances and high signal-to-noise ratios (SNR).

NOMA offers more spectral efficiency through superposition coding. The advantages of greater spectral efficiency in NOMA make it superior to orthogonal multiple access (OMA) [6, 7]. In addition, NOMA offers several advantages, including spectral efficiency, energy efficiency, and high capacity. Due to these advantages, NOMA is considered a promising technology for 5G communications. NOMA combines multiple users at the same time and frequency, allowing for better resource utilization and increased system capacity [8].

To achieve efficient performance, NOMA requires accurate channel state information (CSI). CSI is an important aspect of NOMA because it determines the power allocation for each user, where users with better channel conditions receive less power compared to users with poor channel conditions. Therefore, proper channel estimation and tracking techniques are required to obtain accurate CSI, such as Least Squares (LS), Minimum Mean Square Error (MMSE), and Kalman filtering. These techniques help to estimate and track the channel state accurately to ensure proper power allocation and increase the overall system performance [9].

In this paper, we propose a novel scheme that combines non-orthogonal multiple access (NOMA) with static power allocation (SPA) and pulse position modulation (PPM) in visible light communication (VLC). NOMA is a technique that allows multiple users to share the same frequency band by using different power levels, while SPA is a method that assigns fixed power levels to each user based on their channel conditions. PPM is a modulation scheme that encodes data by varying the position of light pulses in a fixed time slot. By combining these techniques, we aim to improve the performance of VLC-based systems in terms of data transmission rate, reliability, and security.

This paper is structured into five sections, each discussing various aspects of the research. In the second section, we provide an overview of the methodology used in this study. This includes a detailed explanation of the system model, power allocation, superposition coding, successive interference cancellation, and channel model. In the third section, we describe the simulation parameters and performance metrics used in our research in more detail. We also discuss the simulation scenarios that were evaluated. In the fourth section, we present our analysis and discussion of the results obtained from the simulations conducted in two different scenarios. We provide an in-depth interpretation of the data collected and offer insights into the performance of the various parameters tested. Finally, in the last section, we summarize the findings of our research and draw conclusions based on the results obtained. We also discuss the implications of our research and highlight areas for future study.

2. Method

2.1. System Model

This simulation scenario aims to obtain optimal results for the bit error rate (BER) and signal interference to noise ratio (SINR) parameters. The analysis takes into consideration the received power at the receiver, SINR, and BER, which are influenced by the distance difference between user 1 and user 2. Fig. 1 illustrates a room with two users positioned at different distances. In this simulation scenario, the LED light directly shines on both users, carrying different information.

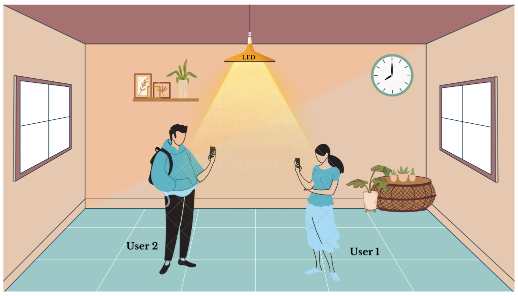

Fig. 1. Illustration model communication of VLC.

2.2. Simulation Scheme

The system design encompasses a room model measuring 9x9x3 meters, featuring a single transmitter, a centrally positioned 12-watt LED, and two users serving as receivers. At the transmitter side, we employ SPA as the test parameter to allocate power to the users, while on the receiver side, we utilize successive interference cancellation (SIC) as an input parameter for decoding the received signals from the users.

Fig. 2 illustrates the NOMA block diagram used in the VLC communication system. As seen in the image, the VLC system consists of a transmitter, an optical wireless channel, and a receiver. The transmitter uses Superposition Coding (SC) and PPM to encode and modulate the signals from multiple users. On the receiver side, the SIC technique is implemented to separate the signals from each user. The signal from the first user is decoded and subsequently subtracted from the received signal to eliminate its interference with other signals. This iterative process is repeated for each user until all signals are successfully decoded The power allocation technique in SC considers the channel condition of each user and allocates different power levels to achieve a balance between throughput and fairness. The modulated signals are transmitted using LEDs and received by the photodetector. The incoming signal will continue, and signal overlapping will occur. The decoded signals are then sent to their

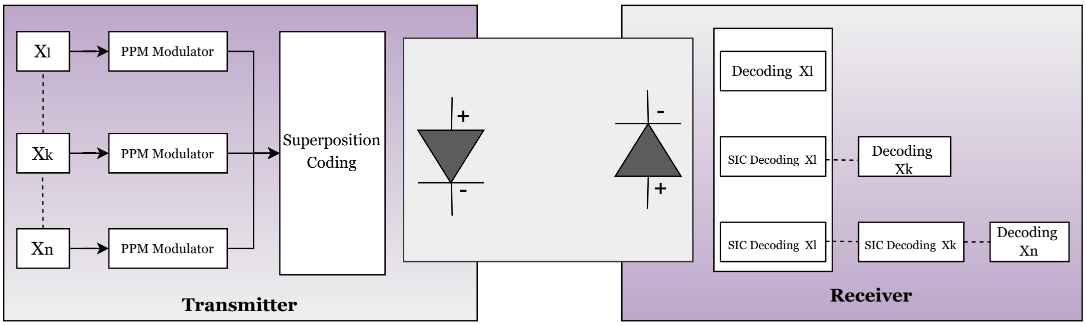

Fig. 2. Diagram block communication of NOMA-VLC.

respective destinations.

2.3. Power allocation

2.3..1 Static power allocation

SPA is a power allocation technique used in NOMA systems to allocate power among different users. It determines the power allocation factor based on the channel gain of each receiver. Receivers with higher channel gains receive less power, while those with lower channel gains receive more. The power allocation factor is set at the receiver and can have a value range between 0 and 1, where 0 means no power is allocated to the corresponding user and 1 means maximum power is allocated to the corresponding user

$$0 < \alpha < 1, \tag{1}$$

where α is power allocation.

2.3..2 Gain ratio power allocation

GRPA is a power allocation technique for NOMA systems that allocates power to each user based on the ratio of their channel gain to the sum of all users' channel gains. This approach enhances both the throughput and fairness of NOMA systems by allocating more power to users with lower channel gains while reducing power allocation to users with higher channel gains. The power allocation formula for the i-th user is given by

$$\alpha_i = \frac{h_i}{\sum_{i=1}^{M} h_i} P_t, \tag{2}$$

where P_t is the total transmitted power, α_i is the power allocated to the i-th user, h_i is the channel gain from the LED to the i-th user, and M is the number of users. The numerator is the channel gain of the i-th user, while the denominator is the sum of all user's channel gains. By using this ratio, the power allocation for each user is proportional to their channel gain and inversely proportional to the total channel gain of all users [11].

2.4. Successive interference cancellation

SIC is a robust technique used to decode individual signals from a composite of superimposed signals, effectively enhancing network capacity by efficiently managing interference. The SIC process involves detecting the user with the strongest signal first, then encoding and demodulating the signal before repeating the process until the user with the weakest signal is reached, minimizing interference along the way. The value of SIC in the receiver for a given signal can be calculated as

$$y_i = h_i \cdot x + N, \tag{3}$$

where i is initialized as the i-th user, h_i is the channel gain on the receiver, x is the sender's superposition code value, and N is initialized as the amount of noise

$$y_i' = y_i - (h_i \cdot x(i)), \tag{4}$$

where y_i' is the result of the signal received by the receiver.

2.5. Channel model

In this paper, we exclusively employ Line of Sight (LOS) configurations instead of Non-Line of Sight (NLOS) scenarios in VLC, as our objective is to attain a high data rate and minimize bit error rates for our proposed scheme. We also assume that there is no blockage or misalignment between the transmitter and receiver in our simulation scenario. The LOS channel requires an unobstructed path between the transmitter and receiver for signal propagation [12]. The Lambertian parameter (m) is a critical parameter in the calculation of the LOS channel model and is related to the full-width half maximum (FWHM) as follows:

$$m = \frac{\ln(2)}{\ln(\cos\theta_{\frac{1}{2}})}, \tag{5}$$

where the value of $\theta_{\frac{1}{2}}$ is the angle of the full width half maximum (FWHM). Then the equation for the LOS channel can be formulated as

$$h = \frac{(m+1) \cdot A_{det} \cdot \cos^{m+1}\phi}{2 \cdot \pi \cdot d^2}, \tag{6}$$

where ϕ is the angle between transmitter and receiver, A_{det} is the photodetector area on the receiving end, and d is the transmitter to receiver distance.

Table 1: Simulation parameters.

Parameter	Specification
Room Size	9 x 9 x 3 m
Transmitter	1 LED bulb
Model Channel	LOS
Bandwith	20 MHz
Area detector	1 cm^2
Fov	70°
Responsivity	0.55 A/W

2.6. Superposition code

NOMA uses a superposition code at the transmitter, which involves adding the input signals x_1 and x_2 after multiplying them by different strength levels. This superposition code is a coding technique that enables the trasmitter to transmit information from multiple users simultaneously. The superposition code allocates power to each user based on their channel conditions, where users with better channel conditions are assigned higher power levels. This concept of power allocation with superposition coding is fundamental to NOMA. The superposition code value for transmitting information can be calculated using the following equation:

$$x(n) = \sqrt{\alpha_1} \cdot x_1 + \ldots + \sqrt{\alpha_n} \cdot x_n. \tag{7}$$

3. Research

In this section, we analyse the performance using several metrics such as BER and SINR with various simulation parameters. These metrics are crucial in determining the effectiveness of the proposed VLC system with NOMA and different power allocation techniques. By evaluating these metrics, we can compare the performance of the VLC system with NOMA using different power allocation techniques and determine the optimal power allocation technique for the system. The results of the analysis will provide insights into the feasibility of using VLC with NOMA in practical applications and help in improving the performance of the system.

3.1. Parameter analysis

Table 1 presents the simulation parameters used in the implementation of the simulation. The field of view (FOV) is an important parameter in VLC systems as it defines the angular range within which the receiver can capture the light signal. In addition, we used an ordinary photodetector PIN with moderate responsivity and area detector values [13].

3.2. Signal to interference noise ratio

SINR is the ratio of the output signal to noise and interference at the receiver side.

$$\text{SINR} = \frac{(RMP_r)^2_{\text{user}}}{(RMP_r)^2_{\text{interferer2}} + \sigma^2_{\text{total}}}, \tag{8}$$

where P_r is the power received by the user and interferer in the system, R is the responsiveness, M is the detector gain, $F(M)$ is the noise figure and σ^2_{total} is the total .

3.3. Bit error rate

BER is an important metric used to measure the quality of digital communication systems. It expresses the ratio of data bit transmission errors per total data bits sent. The BER value depends on several factors, including the SINR and the modulation technique used. In this research, the existing PPM scheme is used, specifically the L-PPM where $L = 2^K$. Here, K represents the number of bits in the data being transmitted and is encoded into a single time slot. The PPM modulation itself is based on representing the information signal as the pulse position of the signal itself, with a fixed frame and time [14, 15]. Estimation BER from SINR value is express by

$$BER_{PPM} = \frac{1}{2}\,\text{erfc}\left(\frac{1}{2\sqrt{2}}\sqrt{SINR\frac{L}{2}\log_2 L}\right). \tag{9}$$

4. Analysis and discussion

In scenario 1, illustrated in Fig. 3, there exist varying distances between User 1 and the LED, and User 2 and the LED, with User 1 situated farther away from the LED compared to User 2. The graph shows the comparison between the results obtained using the SPA technique and the GRPA technique. The SINR values obtained for each user are also shown in the graph. With the SPA technique, user 1 obtains a SINR of 22 dB, while user 2 obtains a higher SINR of 64 dB. On the other hand, with the GRPA technique, user 1 obtains an SINR of 0.0 5dB, which is significantly lower than the value obtained with SPA, while user 2 obtains a much higher SINR of 82dB. These results show that the GRPA technique performs better than SPA in scenarios where users are located at different distances from the LED. This is because the GRPA technique considers the channel gains of both users and allocates power accordingly, whereas SPA only considers the channel gain of each user.

In Fig. 4, we can see that the SINR values for both users in scenario 2 are relatively high for both SPA and GRPA methods. For user 1, the SPA method provides an SINR of 22dB while GRPA provides an SINR of -2.5dB. Similarly, for user 2, SPA gives an SINR of 74dB and GRPA provides an SINR of 94dB. This indicates that in scenario 2, the SPA method is more efficient in allocating power than GRPA. Additionally, the SINR values obtained for user 2 in both methods are significantly higher than those obtained for user 1, which indicates that the channel gain of user 2 is much better than that of user 1. This may be due to the difference in the distances between the LEDs and the users. Furthermore, it's noteworthy that the SINR values obtained in scenario 2 exhibit relative stability, indicating the effectiveness of the power allocation methods in ensuring consistent transmission

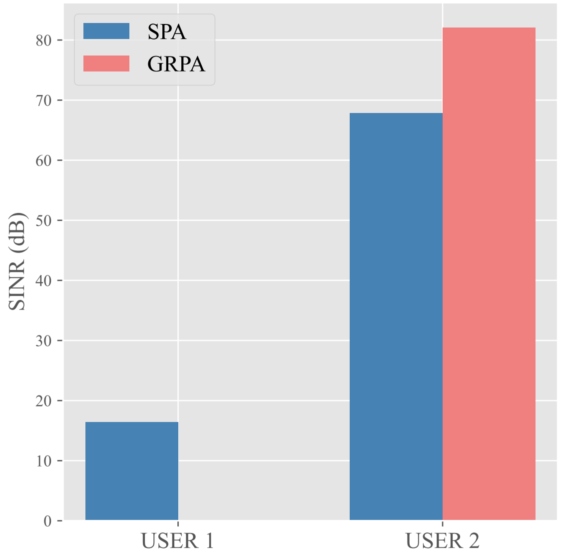

Fig. 3. SINR result at first scenario.

quality.

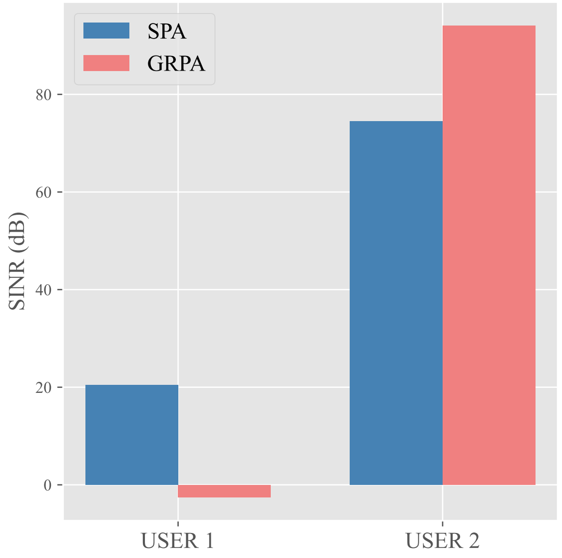

Fig. 4. SINR result at second scenario.

The BER values were estimated for 4, 8, and 16 PPM after calculating the SINR. For user 1, the 4-PPM resulted in a value of 3.2e-6, while 8-PPM resulted in 2.72e-15, and 16-PPM resulted in 1.31e-37. It was observed that the higher the PPM level, the better the results obtained. On the other hand, for user 2, the best BER was obtained at 16-PPM. The symbol in PPM is different from that of bipolar symbol modulation. In unipolar modulation, a higher number of symbols have the potential for lower errors due to perfect synchronization. However, in cases of imperfect synchronization, it may lead to more error bits.

5. Conclusion

The results of the simulation showed that the use of SPA provided better results compared to GRPA, especially for user 1. This is because SPA provides a greater allocation of power for longer distances and a smaller allocation of power for shorter distances. All BER values for SPA with PPM modulation fulfil the requirement of being less than 10^{-3}. It was observed that the higher the PPM level, the better the BER results . The best BER was obtained when using 16-PPM modulation. Therefore, we can conclude that the proposed VLC system with SPA and 16-PPM modulation can provide reliable and stable communication for both users, even at longer distances. Further studies can be conducted to investigate the performance of the proposed system under various scenarios and conditions.

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