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# Enhancing Performance of Power Allocation for VLC Networks by Non-Orthogonal Multiple Access-MIMO

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**ABSTRACT-** Visible light communication, or VLC, networks emerged as a viable option for data access, particularly indoors. Their cost-effectiveness, protection to radio frequency (RF) intrusion, and extraordinarily high data speeds make them a desirable option for the upcoming generation of indoor networking technologies. In this paper, we propose the Exponential Gain Ratio Power Allocation (EGRPA), an effective and low-complex power splitting method, to increase the attainable sum amount in Multiple Input Multiple Output (MIMO) VLC downlink networks. Using numerical simulations, we assess the enactment of an indoor 2x2 MIMO VLC downlink model for several users. We also use Non-Orthogonal Multiple Access (NOMA) for enhancing spectrum efficacy. The usefulness and resilience of the suggested power splitting approach are established by the simulation outcomes, especially in scenarios with a high user count. In particular, the EGRPA power allocation algorithm shows a sum rate enhancement of more than 38.7%, 7.86%, and 7.04% for a system with three users when compared to the GRPA method, Normalized Gain Difference Power Allocation (NGDPA) method, and Logarithmic GRPA (NLGRPA) method, correspondingly.

**Keywords:** MIMO, power splitting, sum rate, visible light communication, NOMA, orthogonal frequency division multiplexing.

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## 1. INTRODUCTION

The exponential rise in demand for wireless data services in recent years has presented several difficult problems for the current generation of wireless technology. Over the past few decades, there has been a sharp rise in the global population of mobile users who need access to high-data rate wireless services. In recent years, there are good pact of study into the extraordinary need for local wireless networks with huge connectivity, minimum dormancy, low-cost front-ends, and diversified data rates by reason of the rapid rise of IoTs and handy data depots [1]. Future high-speed networks would therefore greatly benefit from an effectual power distribution methodology in NOMA-based systems. Using lighting LED arrays as a regular and effectual method to upsurge system capability and attention, MIMO is frequently used in VLC systems.

The ultimate growing need for wireless data in the modern era is causing the RF band to become increasingly congested. It is difficult to meet these needs for a variety of reasons, hence wireless system solutions are desperately needed. LED-based VLC is thought to be a promising alternative for fast networks in the future because of its unique qualities, such as low energy consumption, protection to electromagnetic interference, license-free range, economic front-ends, and the latent for altitudinal frequency band recycle in nearby optical attocells [2,3].

However, the primary obstacle to creating fully functional VLC systems is the restricted intonation bandwidth of readily available LEDs. Several methods, including improved optical modulation, orthogonal frequency division multiplexing (OFDM), optical MIMO, and others, are projected thus far to enhance the capacity of VLC networks [4,5]. One LED transmitter is usually anticipated to enable huge connection in practical VLC systems. Multiple access is therefore vital in multi-user VLC networks. To maximize wireless connection, three different schemes have been proposed in [6- 8]: OFDM access, code division multiple access (CDMA), and space division multiple access (SDMA). Orthodox methods assign dissimilar handlers to wireless assets so as to prevent intrusion from nearby sources. Still, this spectrum partitioning ultimately lowers the achievable data rate. Moreover, these techniques cannot be easily implemented for intensity modulation and direct detection (IM/DD) in VLC networks.

Owing to its higher spectrum efficiency, NOMA by way of power province development is suggested recently for the upcoming 5G systems. Multiple users can concurrently access the entire system bandwidth in the power domain with NOMA thanks to successive interference cancellation (SIC) at the target and superposition code at the source [9,10]. Because NOMA-based VLC systems have been the focus of much research [11,12], and because VLC systems have high SNRs because of the close proximity of the transmitter and receiver, it is advantageous to employ NOMA in downlink VLC systems. When compared to the code domain, the power domain assisted NOMA based VLC system has the least computational complexity [13,14]. PD NOMA has been demonstrated to be appropriate for VLC downlink systems for a number of reasons. VLC systems that use LEDs as small cells to serve a limited number of users are able to meet the demands of PD NOMA, which is typically used to multiplex a small number of users. Second, because VLC systems typically have tight communication front-ends and strong LOS channel gain, PD NOMA performs better in high signal-to-noise ratio (SNR) conditions. Thirdly, in PD NOMA, the transmitter's channel state information (CSI) is the only factor that determines how power is allocated. However, compared to RF, channel estimate in VLC is far less error-prone [4].

The authors of [11] suggested approach as a viable option for high-speed VLC systems. While there have been reports of more sophisticated power allocation techniques for NOMA-VLC in [6,15,16], their processing expense is somewhat significant.

In addition to a large reduction in peak-to-average power ratio (PAPR), a secure non-orthogonal multiple access (NOMA) VLC system with orthogonal frequency division multiplexing (OFDM) modulation is provided. The public key, which is based on a 2D chaotic map, has two functions: it generates a set of phase-rotated candidate signals for the chaotic selected mapping (SLM) scheme, which selects the signal with the lowest PAPR for transmission, and it offers physical-layer security against eavesdroppers. Through chaotic data scrambling, the private keys further improve security and provide privacy for authorized users [17].

For indoor broadcasting communication systems, a mixed cooperative power line communication (PLC)/visible light communication (VLC) system is given [18]. The VLC links backhaul is provided by the PLC system. With the use of a relay and decode and forward (DF) protocol, data from the PLC link is transferred to the VLC link. Additive and log normally distributed fading sounds are applied to the PLC system. The end consumers are served by several access points (APs) that are part of the VLC network. The randomly dispersed user positions determine the channel characteristics of the VLC systems. To choose the access point that provides the end user at the VLC end with the highest instantaneous signal to noise ratio (SNR), the selection combining (SC) diversity combining approach is utilized.

Effective power allocation strategies with minimal computing complexity are essential for the possible broad application of the MIMO-NOMA technology in real-world VLC systems.
The contributions of this research are

- The EGRPA, an effective and low-complex power splitting method is proposed to increase the attainable sum amount in MIMO VLC downlink networks.

- Using numerical simulations, the enactment of an indoor 2x2 MIMO VLC downlink system for several users are assessed.

- NOMA is used to improve the system's spectrum efficacy. The usefulness and resilience of the suggested power splitting approach are estimated by the simulation outcomes, especially in scenarios with a high user count.

This manuscript is structured as follows; *Section 1* gives the introduction on MIMO - VLC downlink networks; *Section 2* details about the structure of the suggested model; *Section 3* provides the particulars of solution methodology; *Section 4* offers the data for simulation and in *Section 5*, the results are provided with relevant discussion. *Section 6* concludes this work with recommendation for future researches.

## 2. SYSTEM MODEL

This study examines an indoor VLC network with NOMA based service for N users. The 2×2 MIMO-NOMA assisted downlink VLC system for many users is exposed in *figure 1*.

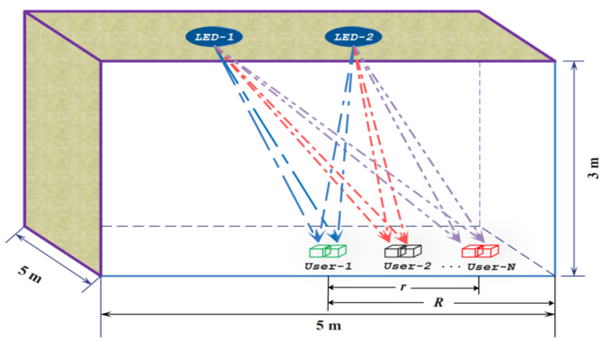


**Figure 1.** An example of a 2×2 NOMA aided MIMO architecture of downlink VLC system serving N user

Each user in this downlink MIMO-NOMA-VLC system has 2 PDs and is capable to make use of the entire LED modulation bandwidth. Besides, DC inclined optical OFDM modulation, or DCO-OFDM, is employed [5]. *Figure 2* displays the structure of the proposed model. Let's say that the input signals for LEDs 1 and 2 are x_1 (t) and x_2 (t), correspondingly.

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$$x_i(t) = \sum_{n=1}^{N} \sqrt{\rho_{i,n}} s_{i,n}(t) + I_{DC} \quad (1)$$

where $s_{i,n}(t)$ is the target signal of the $n^{th}$ user in the $i^{th}$ LED and $\rho_{i,n}$ is the power assigned for the $n^{th}$ user. In order to ensure that each LED receives a consistent total electrical power $P_e$, the power constraint in *equation (2)* is restricted.

$$\sum_{n=1}^{N} \rho_{i,n} = P_e \quad (2)$$

where $P_e$ is the amount of electricity allotted to the $n^{th}$ consumer, which is usually unity. After a free-space broadcast, the $n^{th}$ user's acquired electromagnetic pulse is given by;

$$y_n = RP_o\varkappa \boldsymbol{H}_n \boldsymbol{x} + N_n \quad (3)$$

User 2 system is presented as;

$$y = [x_1\ x_2\ ][H_{11}\ H_{12}\ H_{21}\ H_{22}\ ] + [N_1\ N_2\ ] \quad (4)$$

Due of its simplicity, zero forcing (ZF) based MIMO de-multiplexing employing simple network overturn is employed to successfully convalesce the communicated data [5]. The assessed electromagnetic pulse at the $n^{th}$ user is derived via the inverse channel matrix as follows after ZF and power normalization:

$$x_n \approx \boldsymbol{x} + \frac{1}{RP_o\varkappa} \boldsymbol{H}_n^{-1} N_n \quad (5)$$

Assuming that only the LOS signal is taken into account and that each transmitter LED has a Lambertian radiation outline, the optical channel gain amid $n^{th}$ user with $j^{th}$ PD and $i^{th}$ VLC AP (LED) becomes [19, 20]:

$$h_{ij,n} = \frac{(\gamma+1)A}{2\pi d_n^2} (\phi)\ T_f(\Psi) g(\Psi)\ cos\ cos\ (\Psi) \quad (6)$$

where $A$ and $d_n$ are the detector zone of $n^{th}$ handler and the transmission space from $i$-th LED to $n^{th}$ user, respectively. $\Psi$ and $\phi$ are the incidence and irradiance slants of the $n^{th}$ handler, correspondingly, and $\gamma$ is the order of Lambertian emission relying on the transmitter semi-angle $\Phi_{1/2}$, which is given by;

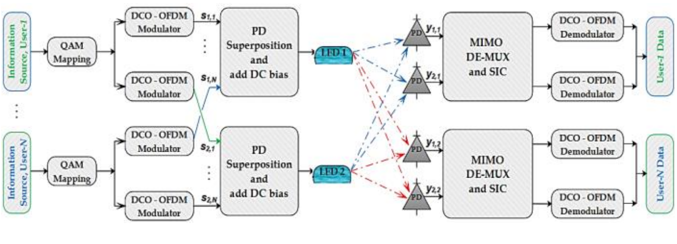


**Figure 2**. Structure of a 2x2 MIMO-NOMA VLC system with N users that uses DCO-OFDM modulation

$$\gamma = \frac{-ln ln\ 2}{ln ln\ (cos cos\ (\Phi_{1/2}))} \quad (7)$$

In addition, $T_f(\Psi)$ and $g(\Psi)$ are represented as the gains. Besides, for a compact parabolic concentrator model, the perfect gain with an acceptance angle $\Psi$ is given by;

$$g(\Psi) = \{ \frac{\eta^2}{(\Psi_{FOV})}, 0, \qquad 0 \le \Psi \le \Psi_{FOV}\ \ \Psi > \Psi_{FOV} \quad (8)$$

*Figure 3* illustrates the geometric mode of LOS transmission. Since multiple LEDs are utilized as opposed to single-LED NOMA, successive interference cancellation is carried out in relation to each LED. To carry out SIC, it is necessary to first define the users' relative decoding orders to every LED. Instead of using the separate optical channel increases of every user as utilized, we sort the users using the summation of every handler regarding every LED [11]. Assume, without losing generality, that N users are placed in the following decreasing order based on their channel gains:

$$\left(h_{1i,1} + h_{2i,1}\right) \ge \left(h_{1i,2} + h_{2i,2}\right) \ge \cdots \ge \left(h_{1i,N} + h_{2i,N}\right) \quad (9)$$

Since each user's power allocation is controlled by $\alpha_{i,n}$, the power provision constants of these $N$ users should fulfil

$$\rho_{i,1} \le \rho_{i,2} \le \ldots \le \rho_{i,N} \quad (10)$$

The decoding orders

$$O_1 < O_2 < \ldots < O_N \quad (11)$$

Optical-to-current conversion responsivity (R) converts optical power into a proportional current power.

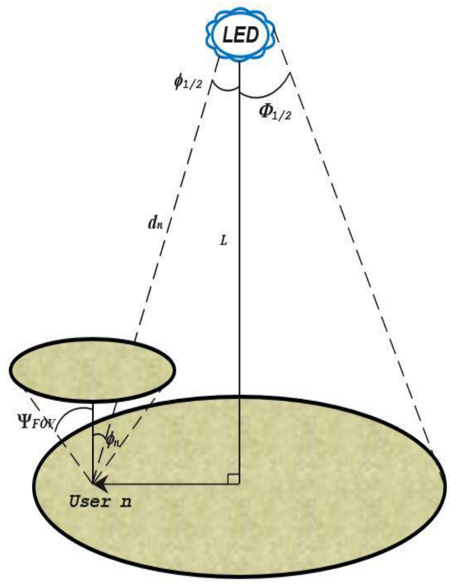


**Figure 3**. VLC channel via LOS link

Finally, the electrical signal established at the $n$-th handler after the elimination of DC component is stated as:

$$y_n = \eta R\sqrt{p} h_n \left( \underbrace{\sum_{i=1}^{n-1} \rho_i s_i}_{SIC} + \underbrace{\rho_n s_n}_{Desired\ signal} + \underbrace{\sum_{j=n+1}^{N} \rho_j s_j}_{Interference} \right) + \underbrace{N_n}_{AWGN} \quad (12)$$

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The received signal has four components. The first component is the interference caused by users whose channels have poorer quality than the $n$-th handler, that is eliminated by SIC. The $n$-th user's target signal makes up the second component. The third component, which is treated as noise, is interference from users who have better channel quality than the $n$-th user.

## 3. METHODOLOGY: POWER SPLITTING STRATEGY

Efficient stratification of optical power is vital in NOMA-VLC systems and it is a key challenge from designing cost-sensitive MIMO-VLC perspective. Due to the difficulty of achieving higher throughput and minimizing fairness problem among end users, optimal power allocation is the serious issue. In such NOMA aided MIMO VLC system, the primary aim is to analyze and validate the attainable data rates of the projected EGRPA algorithm by minimizing the power allocation complexity. For VLC networks, various power distribution schemes have been put forth. Among them are NGDPA, NLGRPA, FPA, GRPA, and S-GRPA. The primary target behind these different power splitting strategies are;

*i.* Since minimum power level is enough to decode signals for good channel condition users, we need to assign small fraction of power for those users.
*ii.* Allocating large fraction of power for bad channel condition users in order to filter out and decode their information's from the superimposed signal.

GRPA has been suggested for multiuser NOMA VLC systems that are SISO or MIMO, and its performance was examined in [11]. The possible sum rate of indoor systems is improved by a successful power allocation technique called NGDPA is also suggested in [1]. As per the decoding sequence in *eq. (11),*

$$\rho_{i,n} = \left(\frac{\sum_{j=1}^{J} h_{ji,1} - \sum_{j=1}^{J} h_{ji,n+1}}{\sum_{j=1}^{J} h_{ji,1}}\right)^{n} \rho_{i,n+1} \qquad (13)$$

$$\rho_{i,n} = \left(\frac{\left(\sum_{j=1}^{J} h_{ji,n+1}\right)}{\frac{1}{2} loglog \left(\left(\sum_{j=1}^{J} h_{ji,1}\right)^2 - \left(\sum_{j=1}^{J} h_{ji,n+1}\right)^2\right)}\right)\rho_{i,n+1} \qquad (14)$$

Inspired by this innovative procedure, we proposed an efficient power splitting strategy termed as EGRPA so as to improve the power distribution efficiency among end users.

$$\rho_{i,n} = \left(\frac{e^{h_{ki,1}}}{\frac{1}{2}\left(\left(e^{h_{ki,1}}\right)^2 + \left(e^{h_{ki,n+1}}\right)^2\right)}\right)\rho_{i,n+1} \qquad (15)$$

where $h_{ki,1} = \sum_{j=1}^{J} h_{ji,1}$, $h_{ki,n+1} = \sum_{j=1}^{J} h_{ji,n+1}$, and by definition, $\rho_{i,1} + \rho_{i,2} + \ldots + \rho_{i,N} = 1$. Generally, the chief inducements after the projected EGRPA method lies on assigning small fraction of electrical power to decode the matching signal for consumers with improved optical channel conditions and allocating higher power level for bad channel condition users to filter out their signals.

## 4. SIMULATION

The proposed exponential power splitting strategy is analyzed for uniformly distributed handlers within a typical room. *Table 1* displays the parameters employed in the simulation analysis.

**Table 1. System and channel model strictures**

| Simulation Arrangement | Value |
|---|---|
| Room dimension (L × W × H) | $[5 \times 5 \times 3]m^3$ |
| Location of LED 1 | [-0.5,0,3] |
| Location of LED 2 | [0.5,0,3] |
| LEDs altitude | 3 m |
| Receiver altitude | 0.85 m |
| Output optical power per LED | 10 W |
| Modulation bandwidth | 10 MHz |
| **Transmitter Parameters** | **Value** |
| Modulation index (ϰ)<br>Semi-angle at half power ($\Phi_{1/2}$) | $0.160^0$ |
| **Receiver Parameters** | **Value** |
| PD area | $10^{-4}$ m$^2$ |
| PD responsivity (R) | 0.53 A/W |
| Receiver FoV semi-angle ($\Psi_{FOV}$) | 72° |
| Refractive index ( ) | 1.5 |

## 5. RESULT AND DISCUSSION

To confirm the efficacy of the proposed ELGRPA power splitting approach, we show numerical tests in this part. The geometric configuration is depicted in *figure 1*, with a vertical distance of 2.15 m between the LEDs and users and a spacing of 1 m between each LED. Once more, it is assumed that the transmitter LEDs are attached on the ceiling, down, and perpendicular to the users. Each LED has an output optical power of 10 W. Each user's two PDs are separated by 4 cm.

Furthermore, the regularized offsets of handler N in regard to handler 1 as r/R and handler n in regard to handler 1 as r/R are stated. The detachment amid users 1 and n is assumed to be r/R is expressed as $\frac{(n-1)r}{(N-1)R}$ [15].

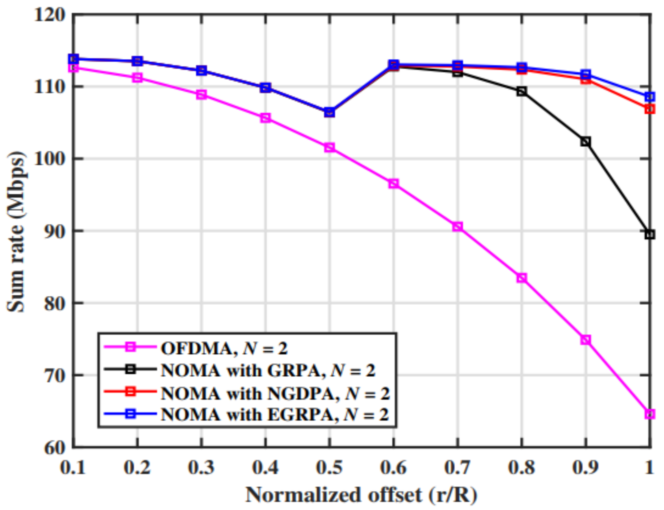


**Figure 4.** Attainable sum rate versus regularized offset by NOMA based, NGDPA and Proposed PA for two users

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*Figure 4* displays the possible sum rate versus normalized offset for two user's condition. It is evident that as r/R rises, the OFDMA-based VLC system's total rate keeps going down. On the other hand, when NOMA is used for all PA techniques (GRPA, NGDPA, and the suggested EGRPA), the sum rate rises.

As shown earlier, the total rate changes as r/R increases, reaching a relatively low sum rate at r/R=0.5. The three power splitting techniques can achieve virtually similar sum rates when the regularized counterpoise is smaller than 0.6. The GRPA approach has the fastest feasible sum rate drop speed when r/R is greater than 0.6. In contrast, the NGDPA and planned EGRPA algorithms have slower achievable sum rate decline speeds than GRPA. The NGDPA and EGRPA algorithms achieve 106.90 Mbps and 108.59 Mbps, respectively, at r/R=1, while the GRPA algorithm achieves 89.50 Mbps.

Consequently, the suggested EGRPA method performs better than any other. As *figure 5*, N=3, shows, the sum rate is consistent inside the bound of 0.1≤r/R≤0.6, and the suggested power allocation technique achieves 110.60 Mbps at r/R=1. Therefore, when utilizing NOMA with an exponential gain ratio PA as opposed to GRPA, NGDPA, and NLGRPA power splitting techniques, the achievable sum rate is much larger.

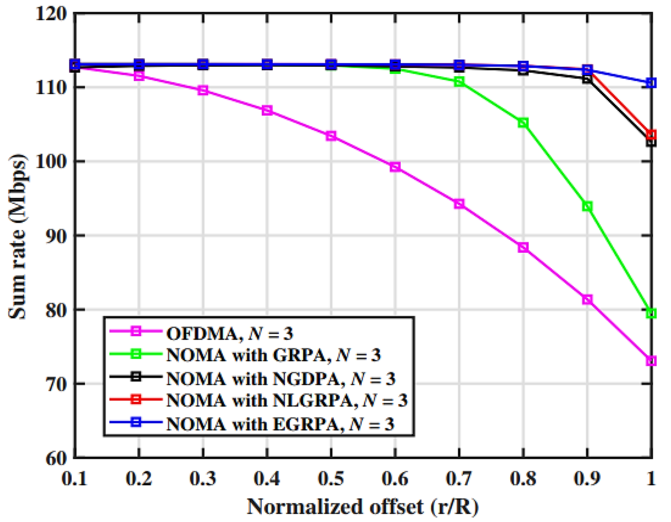


**Figure 5.** Attainable sum rate Vs regularized offset using NOMA based GRPA, NGDPA, NLGRPA and EGRPA for 3 users.

The attainable bit rate of every user is shown in *figure 6* as the aggregate attainable bit rates of the two LEDs. The attainable rate of each user is only marginally stable for both GRPA and EGRPA when 0.1≤r/R≤0.5. But certain fluctuation is occurred in case of NGDPA. At r/R=0.5, 2 users have similar channel circumstances, and as a result, the attainable rate is minimum because of the subpar enactment of NOMA. As normalized offset goes beyond 0.5, the achievable bit rate of user 1 increases dramatically, while it declines for user 2 in the opposite manner. This is because handler 2 has worse channel circumstances in regard to LED 1, especially as normalized offset is close to the edge, and it only receives better channel gain from LED 2 transmitter. As a result, user 1 has good performance comparable to user 2 for r/R≥0.5. Our proposed EGRPA algorithm outperforms all other power allocation strategies, specifically for user 1, which has good channel condition.

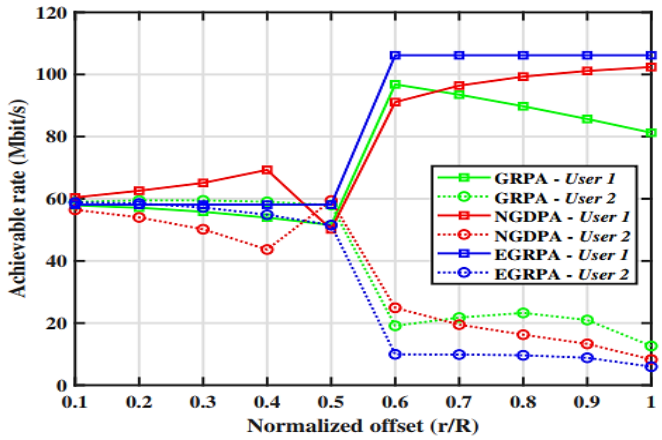


**Figure 6.** Attainable sum rate of GRPA, NGDPA and proposed EGRPA algorithm per individual users.

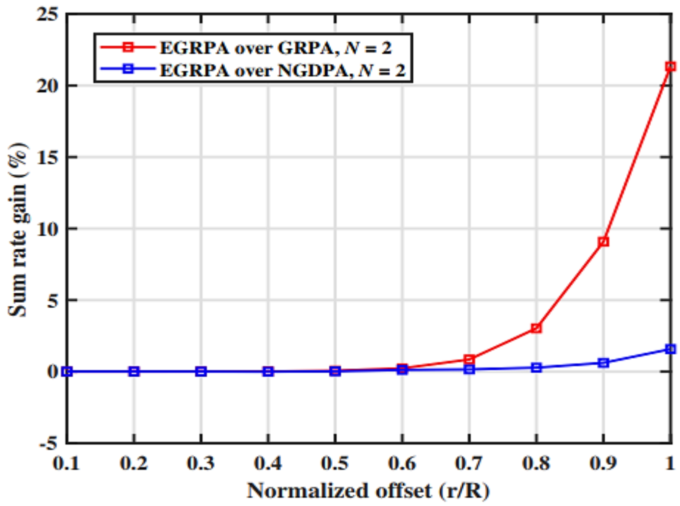


**Figure 7.** SRG of proposed two users.

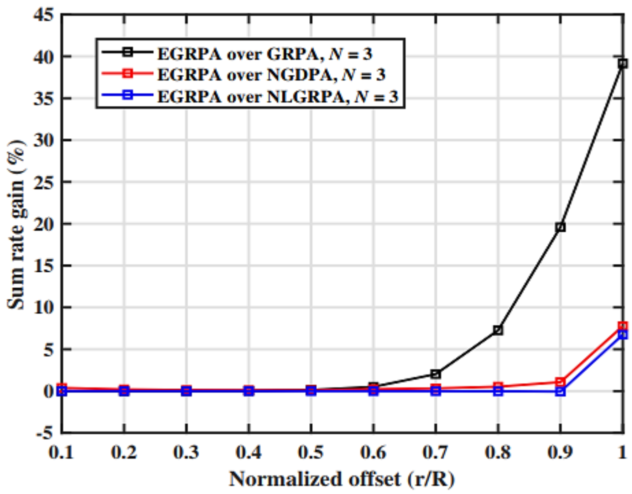


**Figure 8**. SRG for three users.

*Figure 7* displays the SRG of EGRPA above GRPA, NGDPA and NLGRPA for two users and the *figure 8* displays the SRG of EGRPA above GRPA, NGDPA and NLGRPA for three users. The sum rate gain for the proposed system yields better gain when compare with all other algorithms. The number of users is two and three for our research, but it gives not that much differences in the efficiencies of power allocation for Indoor downlink VLC networks. When r/R=1, user N placed at the edge, the attained sum rate gains of EGRPA over GRPA and NGDPA are 21.33% and 1.58%, respectively for two user scenario. Similarly, in case of three users, EGRPA achieved 39.15%, 7.76% and 6.74% rate gain performance over GRPA, NGDPA and NLGRPA, respectively. It is discovered that as the number of users rises and r/R is reasonably big, the aggregate rate gain becomes much important. In general, the proposed power allocation approach yields best performance in all circumstances.

*Table 2* shows the comparative results of proposed method with the existing methods for three user case.

**Table 2. Comparative results for SR and SRG**

| OFDMA, NLGRPA | | | | Proposed Method | | | |
|---|---|---|---|---|---|---|---|
| Sum Rate (Mbps) | | Sum Rate Gain (%) | | Sum Rate (Mbps) | | Sum Rate Gain (%) | |
| *r / R* | Value | *r / R* | Value | *r / R* | Value | *r / R* | Value |
| 0.1 | 112 | 0.1 | 0 | 0.1 | 112 | 0.1 | 0 |
| 0.2 | 111 | 0.2 | 0 | 0.2 | 112 | 0.2 | 0 |
| 0.3 | 110 | 0.3 | 0 | 0.3 | 112 | 0.3 | 0 |
| 0.4 | 106 | 0.4 | 0 | 0.4 | 112 | 0.4 | 0 |
| 0.5 | 104 | 0.5 | 0 | 0.5 | 112 | 0.5 | 0 |
| 0.6 | 100 | 0.6 | 0 | 0.6 | 112 | 0.6 | 0 |
| 0.7 | 94 | 0.7 | 0 | 0.7 | 112 | 0.7 | 2.6 |
| 0.8 | 88 | 0.8 | 0 | 0.8 | 112 | 0.8 | 7.5 |
| 0.9 | 82 | 0.9 | 0 | 0.9 | 111 | 0.9 | 20 |
| 1.0 | 73 | 1.0 | 7 | 1.0 | 110 | 1.0 | 40 |

The unique contributions of the results obtained from EGR-based power allocation in MIMO-VLC downlink networks lie in their ability to optimize resource utilization, enhance fairness and QoS provisioning, adapt to channel variations, address practical implementation considerations, and provide a benchmark for comparison with existing approaches. These contributions collectively advance the state-of-the-art in VLC communication systems and pave the way for more efficient and reliable wireless communication solutions.

## 6. CONCLUSION

In order to assign the appropriate power level among end users in NOMA assisted MIMO-VLC downlink networks, an EGRPA mechanism that takes use of the users optical channel circumstances has been developed in this research. While associated to alternative traditional power allocation techniques like GRPA, NGDPA, and NLGRPA, the suggested EGRPA power splitting method exhibits a suitable enhancement according to the attainable sum rate. Expressly, the EGRPA power allocation algorithm shows a sum rate enhancement of more than 38.7%, 7.86%, and 7.04% for a system with three users when compared to the GRPA method, NGDPA method, and NLGRPA method, correspondingly. Moreover, the computational difficulty of an EGRPA strategy is reduced. Given this, the suggested MIMO-NOMA system, which is based on the EGRPA scheme, is a viable option for future high-speed VLC systems. In future, the recommendations on adaptability, machine learning, user-centric approaches, security, and integration with other technologies may be considered. It's important to consider the evolving landscape of VLC technology and tailor research efforts to address emerging challenges and opportunities in the domain. The significance and impact of the results of EGR-based power allocation in MIMO-VLC downlink networks lie in their potential to enhance spectral efficiency, QoS provisioning, coverage, reliability, energy efficiency, and support for emerging applications, thus advancing the state-of-the-art in VLC technology and wireless communication as a whole.

**Author Contributions:** The authors confirm contribution to the paper as follows: study conception and design: Natarajan C, Janorious Hermia J; data collection: Amutha J; analysis and interpretation of results: Geetha M; draft manuscript preparation: Madhavan R, Bhuvanesh A All authors reviewed the results and approved the final version of the manuscript.

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**Conflicts of Interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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