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Article

An Intelligent Quantum-Supported Resource Allocation Framework for Advanced Indoor Non-Orthogonal Multiple Access Optical Wireless Networks

S.Venkatesan

Department of Computer Science and Engineering, Adhiyamaan College of Engineering, Hosur 635130,selvamvenkatesan@gmail.com

Abstract: At present, non-orthogonal multiple access (NOMA) has become the most efficient technique to solve data rate (DR) requirements in visible light communication (VLC) systems. However, present NOMA systems show high interference and increase the peak-to-average power ratio (PAPR), especially in wider applications. To overcome this issue, several techniques have been undertaken in the past and provento better communication performance. However, the existing studies fail to provide a better quality of services (QoS) for the recent multi-carrier optical communication system (OCS). Hence, this study put forth a novel Generalized Frequency Division Multiplexing (GFDM) scheme to minimize the PAPR inan indoor-based NOMA-VLC system. To enhance the performance of the GFDM system, a novel offset-based quadrature amplitude modulation (OQAM) technique is introduced that enhances the signal quality and prevents the co-channel interference (CCI) problems effectively. Moreover, the proposed study introduces a novel quantum-enabled rabbit optimization (QRO) technique for solving resource allocation (RA) problems in the NOMA-VLC system. The proposed method is processed via the MATLAB platform and various performance measures like sum rate (SR), signal-to-interference noise ratio (SINR), and symbol error rate (SER) are analyzed and distinguished with various existing studies. In the simulation scenario, the proposed method achieves the SR of 178Mbps, SINR of 16dB, and SER of 10^{-8} compared to conventional techniques.

Keywords: Indoor Optical Communication, Non-Orthogonal Multiple Access, Light Fidelity, Generalized Frequency Division Multiplexing, Resource Allocation, Quantum Rabbit Optimization, Offset Quadrature Modulation

1. Introduction

Recently, visible light communication (VLC) becomes a most promising solution that effectively meets the data requirementsof larger communication systems [1]. VLCs provide illumination and communication simultaneously by modulating the light-emitting diode (LED) signals. Compared to existing systems, VLCs showbetter data rates (DRs), increased energy efficiency (EE), less power consumption, and low latency [2, 3]. Normally, light fidelity (LiFi) utilizesa VLC network to transmit wireless high-capable transmissions. A special light spectrum is used in the LiFi system that provides wider data rates ranging from 100Mb to 1GB under low and medium ranges [4, 5]. However, multiple users' access to the similar LEDs causes high multi-user interference within the VLC channels.

Hence, highly efficient techniques with greater reliability and increased spectral efficiency (SE) are essential for the deployment of VLC networks. Several existing studies reported OFDM and NOMA systems for enhancing communication performance in the VLC network [6, 7]. In NOMA-OFDM, the orthogonal subcarriers (SCs) are provided to multiple users without any interference hence, it is highly flexible in the resource allocation (RA) process [8]. Despite this, the SE of OFDM gets highly reduced especially while integrating with the VLC systems. Moreover, NOMA utilizes power domain multiplexing systems that can provide wider BW to all the users [9]. However, it increases the self-interferencesin the case of fifth-generation (5G) and beyond 5G optical wireless communication (OWC).

This results in increased peak-to-average power ratio (PAPR) production and destroys the transmission signal for future communication [10, 11]. To overcome this issue, a generalized frequency division multiplexing (GFDM) system is introduced that uses wider digital waveforms across multiple subcarriers (SCs) and time slots. The GFDM system transmits delay-free data blocks to each block containing SCs and sub-symbols. As a result, the reliability gets increases thereby allocating multiple resources in the form of time and frequency domains (FDs) [12, 13]. The GFDM uses an adjustable prototype filtering (PPF) technique that can effectively sharpen the signals thereby minimizing the out-of-band emission (OOBE) problems effectively. Also, the filter banks in the FFDM system are circularly convoluted based on time and FDs with less interferences. In order to achieve high SE performance, the GFDM uses distinct cyclic prefix (CP) over each data block [14, 15].

For modulating the SC signals, the GFDM uses a quadrature amplitude modulation (QAM) technique that removes the unwanted increase in interference and noises within the channel. However, QAM fails to compete with complex orthogonality when time-FD pulses are utilized. This results in increased CCI problems and hence efficient filtering schemes like physical prototype (PP) filtering, matched filtering (MF), and cosine filtering (CF) techniques are introduced in the GFDM system [16]. However, the use of the GFDM technique in the NOMA-based VLC system is lacking in existing studies. Several studies in [17, 18] pointed out the NOMA-OFDM system to maximize the recitation of VLC systems. However, studies do not provide better QoS to the users resulting in an increase in PAPR. Hence, this study introduces a novel hybridized NOMA-based GFDM-OQAM technology into indoor VLC systems to enhance communication performance efficiently.

Another major problem with the recent VLC systems is the allocation of resources to the available users by preventing inter-signal interference (IS) during signal transmission. To overcome this issue, several researchers have introduced optimization schemes for learning the channel features and allocating particular resources to the multiusers. In [19, 20], authors reported optimization schemes for performing resource allocation (RA) processes with minimal iterations. However, the existing optimizers easily fall into local optimal solution and fail to provide better communication performance to the users. Thus, this study also aimed to introduce a novel optimizer for allotting the resources to all the users that can support recent larger VLC systems.

Motivation: Recently OWC-based VLC systems have become a most promising solution to several communication problems including high data rate requirements, high latency, increased bandwidth consumption, low throughput, etc. Normally, VLC utilizes visible lights to transmit the user signal from one end to another. Several existing studies have reported the advantage of VLC systems and proved better performance, especially in 5G and beyond 5G applications. However, the problems with PAPR maximization and stable RA process arelacking in past studies. At present, NOMA systems highly aid the VLC system in promoting optimal communication performance with optimal solutions. Also, the NOMA-OFDM technique has been studied in existing studies and provided reliable performance in integrating VLC technology. However, the OFDM suffers from increased DR sufficiency while implemented with multiple users. Thus, the GFDM technique has been introduced and become an alternative solution to OFDM systems that provides wider BW and prevents signal distortion problems. Another major issue is that the allocation of resources to all the users with less interference is highly complex for systems having multiple users. Motivated by this, the proposed study introduces a novel hybridized NOMA-based GFDM system along with the optimal RA scheme for the recent VLC system. *The major contributions of the proposed study are depicted as follows:*

- To propose a novel peak-to-averagepower ratio (PAPR) reduction technique (NOMA-GFDM-OQAM) and resource allocation (QRO) algorithm forthe VLC system.
- To introduce a multi-user hybridized NOMA-basedGFDM with a μ law companding technique for reducing the PAPR and signal distortion problems in the VLC system.
- To conquer a 64-bit-offset quadrature amplitude modulation (OQAM) scheme for improving the quality of the input signal and interferences within the users.
- To present a novel quantum-enabled Rabbit optimization (QRO) algorithm for allocating resources to multiple users by minimizing the unserved users.
- To analyze the proposed technique with existing techniques by considering various performance measures like sum rate (SR), symbol error rate (SER), signal-to-noise ratio (SNR), and number of unserved users.

The remaining sections are organized as follows: Section 2 interprets the literature studies related to PAPR reduction and RA techniques in the VLC system. Section 3 describes the system model of the VLC network. Section

4 determines the proposed methodology. Section 5 provides the results and discussion. Section 6 represents the Conclusion of the proposed study.

2. RELATED WORKS

Guo and Ye [21] defined the hybridized NOMA-OFDM technique was introduced for multiuser VLC system. In addition to this, a coordinated multiple transmission-based recursive coding technique was presented to reduce the interference and to maximize the SNR between the edged users. Moreover, the 2D power allocation (PA) technique was introduced to allocate the powers to all the users available on each sub-cell to reduce the SER performance. In the experimental section, the SER of 10^{-6} was obtained by this method. However, this method fails to reduce the PAPR problems when the number of users gets increases.

Chen et al. [22] established the fairness-based NOMA-OFDM technique for multiuser VLC systems. Here, the fairness index of the users was maximized using the discrete Fourier transform-spread-orthogonal frequency division multiplexing (DFT-S-OFDM) technique. Then, the interleaved subcarrier multiplexing (ISM) technique was introduced to solve the user unfairness issues caused due to limited BWs. Finally, the 2D PA technique was introduced to allocate powers to all the users under varying channel conditions. The overall bit error rate (BER) of 3.8×10^{-3} was obtained by this method. However, this method increases the CCI problems and fails to provide high DR to the paired users.

Chen et al. [23] determined the PA technique for the NOMA-based underwater (UW) VLC system. In this study, fractional transmit PA (FTPA) and the sine cosine algorithm (SCA) were introduced as the 2D PA technique for allocating powers to all the users in the NOMA-VLC system. For the simulation process, a downlink NOMA-based UWVLC system was constructed by utilizing blue LEDs over the deep-sea surroundings. In the experimental section, the system transmission rate (STR) performance was highly enhanced and comparatively minimized the problems faced at the time of the PA process. However, this technique faces increased early convergence problems due to poor optimal solutions.

López et al. [24] introduced the efficient PA technique for NOMA-based VLC systems. In this study, simple fair PA (SFPA) technique was introduced to allocate various resources, especially in a multiuser setup. The SFPA requires a minimal amount of channel features hence, the channel estimation (CE) problems were highly prevented. In the experimental section, the overall achievable rate of 79.5% and average SR of 174.5Mbps were obtained by this study. However, the channel fading problems were high while utilizing it with recent 5G or beyond 5G applications.

Wang et al. [25] put forth joint SC and PA schemes for indoor NOMA-OFDM-based VLC systems. In this study, whale optimization (WO) and genetic algorithm (GA) techniques were introduced to perform SC and PA processes effectively. Also, several other techniques like fixed PA (FPA) and gain ratio PA (GRPA) were considered to determine the performance of WO and GA techniques. In the experimental section, the throughput of 62.1%, 53.3%, and 67.2% were obtained for the varying SCs of 5, 2, and 16 respectively. However, the BW requirement was not completely satisfied for the faraway users at the time of the signal transmission process.

Problem statement

From the deep analysis of the existing literature, several issues have been identified for promoting better communication performance to the users. Nowadays, the need for high DRs and increased BW keeps growing due to the fast advancement in wireless applications. Recent VLC system aids the users to experience better DR performance compared to other WC systems. However, the increase in signal distortion and channel interferences in the VLC system highly reduces the user QoS. To tackle this issue, the NOMA-OFDM system has been integrated with the VLC system provides high BWs, and reduces the signal distortion problems, especially for wider applications. However, the OFDM system increases the PAPR and decreases the SE performance due to poor multiplexing of users. Currently, the use of the GFDM system has increased a lot due to its enhanced multiplexing property and better modulation process. However, the increase in PAPR and RA problems with the recent techniques remains unsolvable and efficient technique is necessary to achieve better QoSfor the users. Hence this study introduces a novel hybridized indoor VLC systems framework along with the optimal RA scheme for enhancing the communication performance in OWC systems. From the knowledge, the proposed model overcomes all the drawbacks faced by the existing studies and proves a better performance.

3. SYSTEM MODEL

Let us assume a visible light communication (VLC) channel system that utilizes resource blocks (RB) for each user in a small distribution unit. The RBs consist of a minute amount of resources that can be allocated to each user effectively. Varying bandwidth (BW) like 20MHz, 15MHz, 10MHz, 5MHz, 3MHz, 2Mhz and 1.4Mhz are considered according to the 3GPP standards. Also, by assuming the long-term evolution (LTE) standards, 180kHz and 20MHz are considered for a single and 100 RBs respectively. For the modulation purpose, quadrature amplitude modulation (QAM) is used which can provide a throughput of about 1Mbps. Figure 1 illustrates the VLC-based hybrid NOMA-GFDM system model.

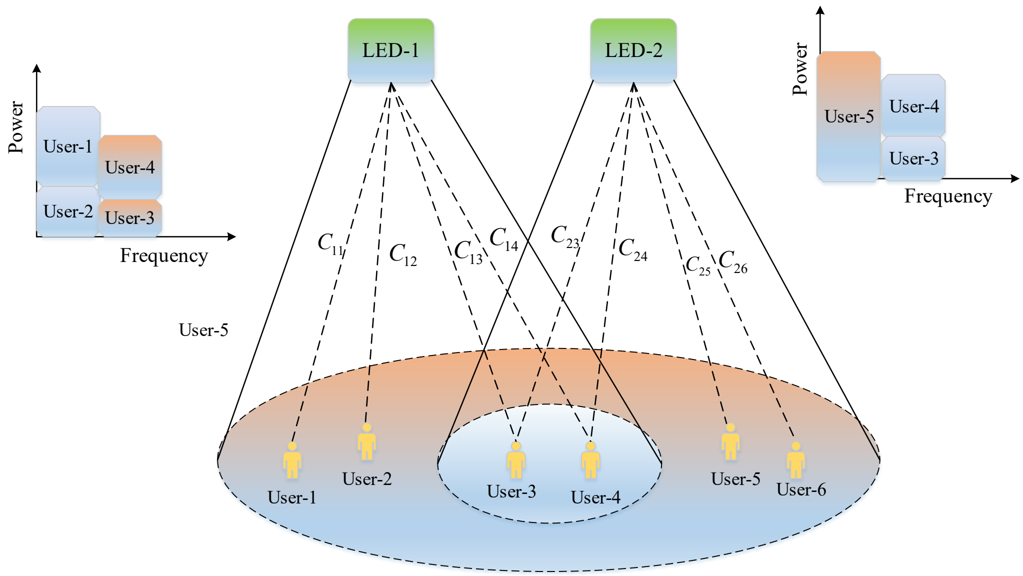

Figure 1: VLC based hybrid NOMA-GFDM system model

The VLC channel consists of two elements namely non-line of sight (NLOS) and line of sight (LOS). The channel gain for the LOS element can be mathematically formulated as,

$$K_{LOS} = \frac{(n+1)Z_{PD}}{2\pi D_x^2}\cos^n(\alpha)T_y(\delta)g(\delta)\cos(\delta) \tag{1}$$

Here, Z_{PD} indicates the photodetector (PD) area, n manipulates the transmitting Lambertian orders, D_x^2 indicates the distance between the user x and the LiFi, α indicates the irradiance angle, δ interprets the incidence angle, and $g(\delta)$ represents the concentrator optical gain and it can be mathematically represented as,

$$g(\delta) = \begin{cases} \dfrac{m^2}{\sin^2(\delta)}, & 0 \le \delta \le \delta_{0.5f} \\ 0, & \delta > \delta_{0.5f} \end{cases} \tag{2}$$

Here, m indicates the refractive index, and $\delta_{0.5f}$ represents the semi-grid field view of the PD. However, the NLOS elements are superposition to one another due to multiple reflections on the wall surface. The NLOS-based optical impulse response determines the initial order low-pass filter (LPF) using the transfer function and it can be mathematically formulated as,

$$K_{NLOS}(f) = \frac{\lambda Z_{PD}\exp(j2\pi f\Delta T)}{Z_{room}(1-\lambda)\left(1+j\dfrac{f}{f_c}\right)}, \tag{3}$$

Here, λ indicates the reflectivity of the wall, the ΔT delay between diffused signal $T_y(\delta)$ and LOS, Z_{room} indicates the room area, and f_c represents the cutoff frequency. The total optical channel gain can be interpreted as, $K = K_{LOS} + K_{NLOS}$. The signal-to-noise ratio (SINR) for the user x can be mathematically represented as,

$$SINR_{x,\kappa} = \frac{\left(K_{u,\kappa} P_o \Re\right)^2}{b_s N_0 + \sum_{\gamma \in \kappa} \left(K_{u,\gamma} P_o \Re\right)^2} \tag{4}$$

Here, P_o indicates the typical transmitted optical power for a LiFi access point (AP), $\Re$ indicates the PD responsivity, and b_s indicates the signal BW. Therefore, the data rate relationship between AP κ and user x can be evaluated based on lower bound (LB) capacity $w_{x,\kappa}$ and it can be mathematically expressed as,

$$w_{x,\kappa} \geq \frac{b_s}{2} \log_2\left(1 + \frac{e}{2\pi} SINR_{x,\kappa}\right) \tag{5}$$

Here, b_s indicates the signal BW, and e represents the error signal.

4. PROPOSED METHODOLOGY

Nowadays, Visual light communication (VLC) have paved the way for optimal communication performance by providing wider wavelengths, high data-rates especially for 5G and beyond applications. However, VLC systems are highly subjected to interference, signal distraction, data sufficiency for multiuser applications. As a result, the PAPR of the system gets increased resulting in low QoS to the users. Recently, the NOMA system has played an integral role in providing stable data rates to the available users with less complexity. Thus, the proposed study aimed to present a novel NOMA-based indoor VLC technique for enhancing communication performance, especially for multicarrier systems. In addition to this, a GFDM-OQAM technique is also integrated with the NOMA-VLC system to minimize the interference and signal distortion problems. In addition to this, the μ law companding technique is introduced in this study to minimize the PAPR problems in the GFDM-OQAM system. Finally, quantum enabled rabbit optimization (QRO) technique is proposed for performing resource allocation (RA) in a hybridized NOMA-based GFDM-OQAM system. The presence of the quantum concept helps the RO technique to learn the channel information accurately with less iteration and minimal time complexity.

4.1. Proposed Hybrid NOMA-based GFDM-OQAM for PAPR reduction

The proposed study introduced a NOMAsystem to enhance future communication performance efficiently. Compared to an orthogonal multiple access (OMA) system, NOMA works conveniently by providing higher data rates to weak users. In the NOMA system, the users having stronger channel gain are initially determined and before decoding their signal, interference is removed from the weak users. As a result, enough amount of resources can be allocated to both weak and strong users effectively. The users are multiplexed in the transmitting side based onthe power domain and hence the self-interference cancellation (SIC) is separated in the receiving end. Finally, the achievable sum rate for the users having strong and weak channel gains can be mathematically formulated as follows:

$$\begin{aligned} A_l &= S \times b_s \log_2\left(1 + SINR_l\right) \\ A_h &= S \times b_s \log_2\left(1 + SINR_h\right) \end{aligned} \tag{6}$$

Here, S represents the total RBs, and b_s indicates the BW of each RBs. Moreover, the two users having SINR can be mathematically formulated as,

$$SINR_l = \frac{P_l^s |C_l|^2}{N_0 b_s}$$
$$SINR_h = \frac{P_h^s |C_h|^2}{N_0 b_s} \quad (7)$$

Here, $P_l^s = P^s(1-\beta)$ and $P_h^s = P^s\beta$ indicates the allocated powers to both strong and weak users whereas, β represents the power ratio (PR). Moreover, P^s interprets the RB distributed power, N_0 indicates the noise spectral power density, $|C_l|^2$ and $|C_h|^2$ represents the channel powers (NP) for weak and strong users respectively. The channel powers are highly affected by various factors like channel fading, adjacent cell interferences, path losses, etc. This can be effectively prevented by introducing the GFDM/OQAM system in the NOMA model.

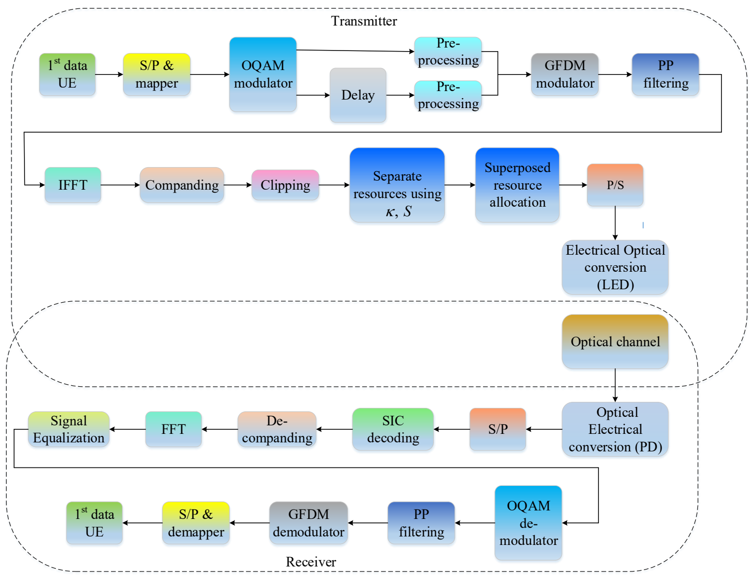

Figure 2: Block diagram of proposed hybridized NOMA based GFDM-OQAM system

Let us consider a novel GFDM, which is an improved version of orthogonal frequency division multiplexing (OFDM) that consists of N sub-carriers (SC) and L sub-symbols. The GFDM can transmit multiple signals to the frequency and timeblock structures efficiently. Here, the block-based structures are obtained by convoluting circularly with a single SC using a pulse shape filtering (PSF) scheme. Moreover, a time windowing mechanism in GFDM allows to block the stop band cyclic prefix (CP) and controls the BW consumption effectively. GFDM utilizes variable PSF techniques that can reduce inter-channel interferences and prevent orthogonality throughout the SC. Normally, GFDM uses quadrature amplitude modulation (QAM) for modulating the input signals. However, it destroys the time and frequency domain signal where the spectral efficiency (SE) performance is high. To overcome this issue, an offset QAM (OQAM) scheme is proposed in this study. The offset QAM allows the time and frequency domain signals for the user to have greater SE. GFDM-OQAM is highly effective for recent optical communication systems compared to OFDM-OQAM systems. Figure 2 represents the block diagram of proposed hybridized NOMA based GFDM-OQAM system.

The GFDM-OQAM uses the offset based mapping and its time is shifted to $N/2$ samples between quadrature and in-phase elements. Hence, the inter-signal and inter-channel interferences are highly reduced. In addition to this, the orthogonality of PSF is enhanced without the use of CP hence, the SE also gets improved efficiently. The proposed GFDM with an OQAM modulates the real value symbols and it is transmitted via each SC. Finally, the time-frequency signals are obtained and they can be mathematically formulated as,

$$h_{s,n}(k) = h\left[\left(k - \frac{NS}{2}\right) \bmod SN\right] \exp\left[\frac{j2\pi s}{S}\left(k - \frac{M_p - 1}{2}\right)\right] \quad (8)$$

Here, M_p indicates the exemplar filter length $h_{s,n}(k)$ is the inverse transfer function of $h_{s,n}(u)$ where k ranges from $0,1,2.....SN-1$. Moreover, S represents the total number of symbols and N indicates the total SCs. For optical communication in the LiFi system, the time domain (TD) signalmust be positive and real hence, OQAM is highly utilized in the proposed study. By super-positioning the symbols, the discrete-basedTD baseband outcome is obtained and it can be mathematically formulated as,

$$p(k) = \sum_{s=0}^{S} \sum_{n}^{N-1} z_s(n) h_{S,n}(k) \exp(\varphi_{n,s}) \quad (8)$$

Here, $z_s(n)$ indicates the real data produced during OQAM constellations, $(\varphi_{n,s})$ represents the phase difference between real data under time-frequency domains and it can be formulated as, $\frac{\pi}{2}(s+n)$. Compared to OFDM, GFDM highly reduces the peak-to-average power ratio (PAPR) problems in the case of both single and multicarrier systems. However, GFDM fails to prevent power consumption and signal distortion issues, especially for faraway users. This results in increased PAPR and it can be mathematically interpreted as,

$$PAPR(X(t)) = \frac{\max\limits_{0 \le t \le T_s}}{P_a} |X(t)|^2 \quad (9)$$

Here, $X(t)$ indicates the outcome from inverse Fourier transform (IFFT) and it can be obtained by, $X(t) = IFFT(p(k))$, and P_a indicates the average signal power obtained from $X(t)$.Also, the parameter T_s represents the symbol duration and it is formulated as, $T_s = NT$. To minimize the PAPR, the μ law companding technique is utilized in this study. It is the process ofcompressing and expanding the inputs into a linear form and it can be interpreted as,

$$g(v) = v_{\max}(t) \times Sgn(v(t)) \frac{\ln(\mu |v(t)| / v_{\max}(t) + 1)}{\ln(\mu + 1)} \quad (10)$$

Here, μ represents the companding parameter, $v(t)$ indicates the instantaneous incoming amplitude, and $v_{\max}(t)$ represents the highest amplitude of $v(t)$.The μ law companding technique is performed on the IFFT signals to reduce the PAPR production. However, clipping is done on the even SCs due to the modulation of odd SCs. Hence, the data transmitted on the odd SCs are not highly protected from distortions. Due to the presence of Hermitian limitations and odd frequencies, only $M/4$ are transmitted to the IFFT.

The paired users having allocated power of κ_{ul} and κ_{uh} are superposed to produce NOMA signal in the VLC channel model. In the receiver section, SIC is considered as the user data and preserved as an interference. The signals are arranged based on SNR power and user fetches the stronger signal first by eliminating the weaker signal. After eliminating and fetching the received signal, the TD signal is converted into frequency domain (FD) signal by FFTs. Then, the FD signals are equalized and filtered using physical prototype (PP) filter to eliminate unwanted noise and interference at the receiver. Finally, the transmitting signals are demodulated and decoded using OQAM demodulators.

4.2 Resource allocation using QRO technique

In recent optical wireless communication (OWC) systems, allocating various resources like power, SCs, space, time, and frequency become highly complex, especially in multicarrier systems. To overcome this issue, several optimization schemes have been utilized in the existing studies and proved an optimal allocation outcome. Hence, this study proposes a novel quantum-enabled Rabbit Optimization (QRO) technique for allocating various resources to available users effectively.The proposed QRO technique optimally allocates the resources based on the behavior of rabbits by analyzing the channel conditionof each user to enhance the SE and service quality. Moreover, the presence of a quantum scheme helps to balance the exploration and exploitation process by selecting the most relevant channel features. The mathematically formulation of the proposed QRO is depicted as follows:

4.2.1. Initialization phase

In this stage, rabbit population, served users, unserved users, RB indices, and overall system gain are randomly initialized. It can be mathematically formulated as given below:

$$X_u = LB + (UB - LB) \times rand(1, \dim) \qquad u = 1,2,3....m \tag{11}$$

Here, X_u indicates the position of served and unserved users, UB and LB represents the upper and lower bounds of the users, m represents the size of the population, and $\dim$ indicates the control variables.

4.2.2. Exploration phase

In this stage, the rabbit undergoes two behaviors namely diversion foraging and random hiding. In diversion foraging, every rabbit individual moves to its relative location concerning another individual in the form of crawling and combined perturbation. The diversion foraging mechanism can be mathematically formulated as,

$$Y_u(i+1) = X_v(i) + N \times (X_u(i) - X_v(i)) + round((0.05 + a_1) \times 0.5)\mu, \quad u, v = 1, ..., v \neq u \tag{12}$$

$$N = z \times K \tag{13}$$

$$z(s) = \begin{cases} 1 & if \ s = h(k) \\ 0 & else \end{cases} \quad s = 1,....\dim \ and \ k = 1,....(a_2, \dim) \tag{14}$$

$$h = randper(d), \quad m_1 \approx M(0,1) \tag{15}$$

$$K = \left(e - \exp\left(\frac{i-1}{Max_{it}} \right)^2 \right) \times \sin(2\pi a_3) \tag{16}$$

Here, i indicates the present iteration, Y_u and X_u represents the new and existing location of rabbit u, μ indicates the standard normal distribution, and K indicates the traveling distance.Also, $round$ and $randper$ represents the rounding to the closest integer and random permutation ranges from 1 to $\dim$, a_1, a_2 and a_3 represents the random values ranges from 0 to 1 and Max_{it} represents the maximum iteration.

In random hiding behavior, the rabbit accommodates multiple burrows nearer to its shelter to protect themselves from enemies. It can be mathematically formulated as,

$$G_{u,v}(i) = X_u(i) + P \times H \times X_u(i), \ u = 1,.......m \ and \ v = 1,.......\dim \tag{17}$$

$$P = \frac{Max_{it} - i + 1}{Max_{it}} a_4 \tag{18}$$

$$H(s) = \begin{cases} 1 & if \ s = v \\ 0 & else \end{cases} \quad s = 1,....\dim \tag{19}$$

Here, $G_{u,v}(i)$ indicates the v^{th} burrow of the rabbit u, P interprets the obscuring parameter and it minimizes from 1 to $1/Max_i$ for each iteration with respect to arbitrary permutation and a_4 represents the arbitrary value ranges from 0 to 1. During this stage, the individual rabbit produces multiple neighborhoods and it reduces when the number of iterations increases. Hence, this approach is commonly termed arbitrary concealment and it can be expressed as,

$$Y_u(i+1) = X_u(i) + N \times \left(a_5 \times G_{u,v}(i) - X_u(i)\right), \quad u = 1,2,.....m \tag{20}$$

The rabbit's location gets updated when diversion foraging or random hiding behavior gets successful and it can be mathematically interpreted as,

$$X_u(i+1) = \begin{cases} X_u(i) & f(X_u(i)) \leq f(Y_u(i+1)) \\ Y_u(i+1) & f(X_u(i)) > f(Y_u(i+1)) \end{cases} \tag{21}$$

4.2.3. Exploitation phase

In this stage, the random hiding of the rabbit becomes an energy component and it can be mathematically formulated as,

$$L(i) = 4\left(1 - \frac{i}{Max_{it}}\right)\ln\frac{1}{r} \tag{22}$$

4.2.4. Quantum based RO

In quantum-based rabbit optimization (QRO), the binary values are used to indicate the channel features and they can be either removed or selected. Each feature in QRO is represented as quantum bits or Q-bit (q) that holds the value 0 or 1. The mathematical representation of Q-bit (q) can be depicted as,

$$q = \lambda + i\eta = \exp(i\varphi) = |\lambda|^2 + |\eta|^2 \tag{23}$$

Here, λ and η represents the probability value of Q-bit, φ represents the 'q' angle and it is indicated as, $\tan^{-1}(\lambda/\eta)$. By determining $\Delta\varphi$, the proposed QRO technique often changes the value of 'q' and it can be formulated as,

$$q(i+1) = q(i) \times r(\Delta\varphi) = (\lambda(i)\eta(i)) \times r(\Delta\varphi) \tag{24}$$

$$r(\Delta\varphi) = \begin{bmatrix} \cos(\Delta\varphi) & -\sin(\Delta\varphi) \\ \sin(\Delta\varphi) & \cos(\Delta\varphi) \end{bmatrix} \tag{25}$$

Here, $\Delta\varphi$ indicates the angle of rotation, and it is computed based on the best solution obtained from the fitness function. The initial rabbit population in which each solution contains w Q-bits and the overall solution X_v can be formulated as,

$$X_v = \left[q_{u1}|q_{u2}|......|q_{uw}|\right] = \left(\theta_{v1}|\theta_{v2}|......|\theta_{vw}|\right), \; v = 1,2,......c \tag{25}$$

Here, X_v indicates the superposition probability to compute whether the resources are properly allocated or not, w indicates the number of resources chosen for the allocation process.

In the QRO, the RA is continuously done for the strong and weak usersuntil it satisfies the terminal condition. However before the updation process, X_v is changed to binary form X_{bv} and it can be mathematically represented as,

$$X_{bv} = \begin{cases} 1 & if \quad rand < |\eta|^2 \\ 0 & else \end{cases} \tag{26}$$

Here, $rand$ indicates the random numbers range between 0 to 1.

4.2.5. Fitness Function

For the optimal resource allocation (RA) process, various constraints like power and BW must be considered to increase the reuse of frequencies in the proposed NOMA system. Two major conditions are undertaken as the fitness function, one is to maximize the system throughput and the other is to minimize the unserved users. Figure 3 indicates the flowchart of proposed QRO based RA technique.

To satisfy these conditions, three major assumptions have been undertaken and it is depicted as follows:

- The power transferred between paired users (far and near) must be $P_l^s = P^s(1-\beta)$ and $P_h^s = P^s\beta$ respectively.
- The user having a lesser SINR of about 14dB and a bit error rate (BER) of greater than 10^{-3}, resources cannot be provided from the NOMA system.
- The users having a distance greater than the minimum distance $d_{\min}$ are eliminated from the NOMA system and resources will be allotted to users having lower priority.

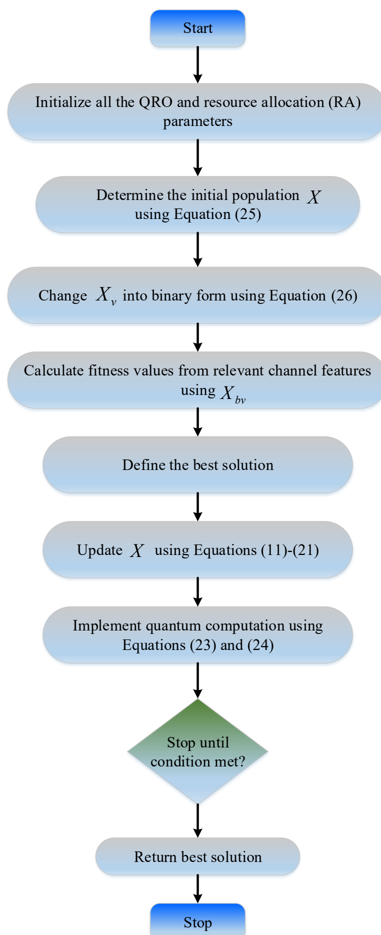

Figure 3: Flowchart of proposed QRO based RA technique

5. RESULTS AND DISCUSSION

The proposed method is processed and analyzed via the MATLAB simulation platform. For experimentation, a $16 \times 16 \times 4$ m indoor space is considered with a total coverage of 64 LiFi access points. Here, the users are uniformly placed over the room that consumes the data rate of 20Mbps. The separation distance and power transmission between two users are evaluated to choose the optimal β value and distance $d_{\min}$. It is also noted that the SINR must be less than 14dB with a BER of less than 10^{-3} in OQAM modulation. Table 1 represents the simulation parameters of the proposed method.

Table 1: Simulation parameters of the proposed method

Parameters	Values
Photodiode area Z_{AP}	$10^{-4}\ m^2$
Access point spacing	2m
Half-angle field view $\delta_{0.5f}$	60°
Optical filter gain $g(\delta)$	1
Half power semi-angle α	70°
PD reflective index m	1.47
Noise spectral power density N_o	$10^{-21}\ A^2 / Hz$
BW	10MHz
Length of IFFT	512
Total SCs	256
Optical power P_o	1 watt
Overlapping factor	8
OQAM modulation index	64
Total GFDM symbols	64
Data consumed per RB	1Mbps
Total RBs	100

5.1 Assessment measures

SINR is the measure of analyzing the signal, noise, and interference quantity in the proposed VLC system. It can be generally formulated as,

$$SINR = \frac{P^s |C|^2}{N_0 b_s} \tag{27}$$

Here, P^s represents the signal power, $|C|^2$ represents the channel power, N_0 represents the noise spectrum power density,and b_s represents the signal BW.

SER is defined as the ratio of total error symbols obtained to the total symbols utilized in the system. It can be represented as,

$$SER = \frac{E_s}{N_s} \qquad (28)$$

Here, E_s indicates the total symbols received with error and N_s represents the total symbols received in the receiver end.

The sum rate (SR) helps to analyze the overall capacity of the VLC system and it can be represented as,

$$SR = b_s \log_2 (1 + SINR) \qquad (28)$$

5.2 Performance analysis of proposed method over existing studies

In this section, the performance achieved by the proposed method is analyzed via graphical illustration. Various metrics like SR, SER, number of unserved users, and SNR are evaluated by comparing with existing OFDM, NOMA/OFDM, filter bank multicarrier (FMBC), and NOMA/FMBC systems. The clear analysis of the proposed outcome is depicted as follows:

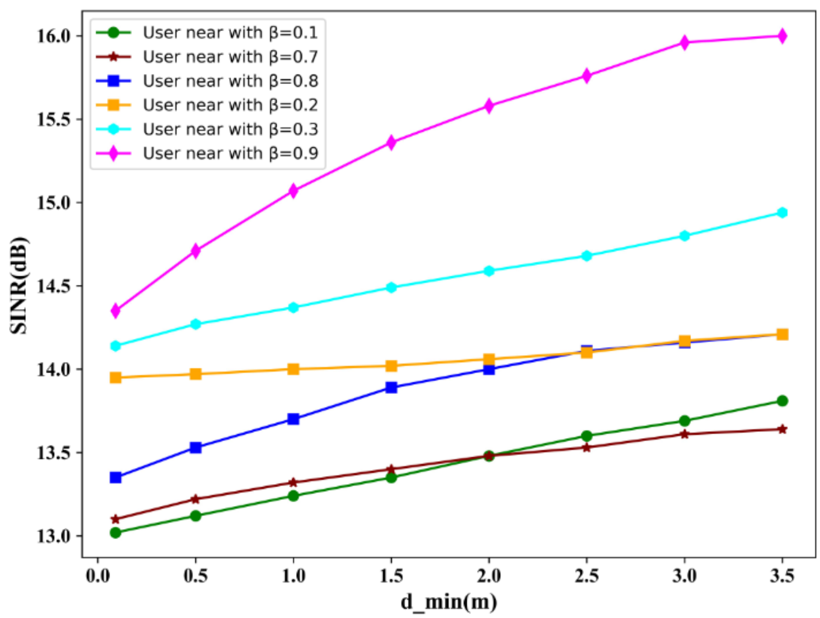

Figure 4: SINR for UE_l and UE_h with different PR versus separation distance $d_{\min}$

Figure 4 indicates the SNR performance for UE_l and UE_h with different PR versus separation distance $d_{\min}$. The graph shows the performance of the proposed method by altering the distance between paired users at different PR factors i.e., $\beta = 0.1, 0.2, 0.3, 0.7, 0.8 \, and \, 0.9$. From the deep analysis of the graphical illustration, the SINR performance increases more than 14dB for every paired user when the PR limits to $\beta = 0.9$. It is also noted that the SINR increases more than 14dB when the distance between the paired users becomes more than 2.5m. Normally, NOMA requires higher index modulation for reducing the SER performance under similar data rates. Even though PR factor limits to 0.9, several users access similar RBs, reducing the SE performance. Hence, maintaining a higher order modulation technique is necessary to increase the efficiency of the proposed system.

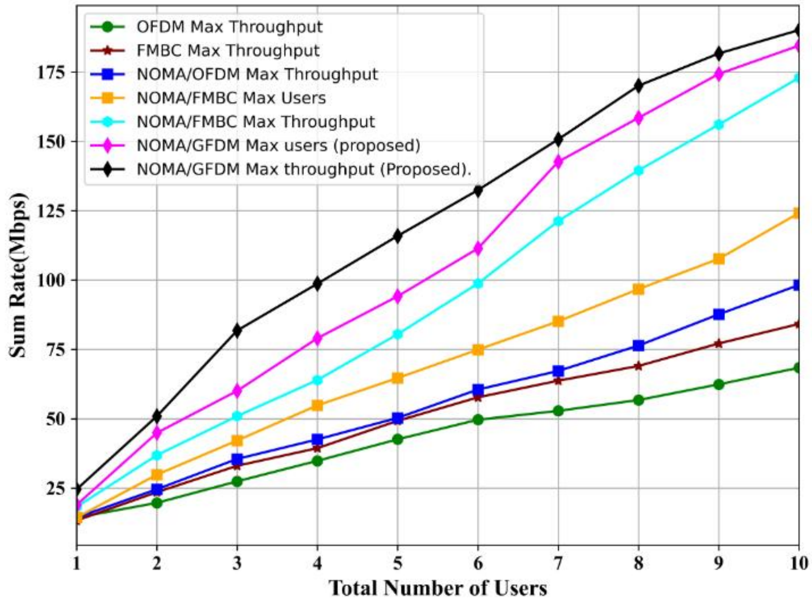

Figure 5: SR performance by varying users at $P_o = 1W$ and $RB = 100$

Figure 5 represents the SR performance by varying users having RB blocks $S = 100$. Some of the existing methodologies like FBMC, OFDM, hybridized NOMA-OFDM, hybridized NOMA-FBMC, and proposed NOMA-GFDM are considered for analyzing the overall throughput of the system. Compared to existing studies, the proposed hybridized NOMA-GFDM system provides better throughput even when the number of users increased. From the graphical interpretation, it is clear that the SR reaches 178Mbps while hybrid NOMA-OFDM, OFDM, FBMC, and hybrid NOMA-FBMC obtain the throughput of 100Mbps, 85Mbps, 70Mbps, and 175Mbps respectively. Hence, it is proved that the proposed NOMA-GFDM system attains an overall throughput of 178% compared to the conventional NOMA-OFDM system.

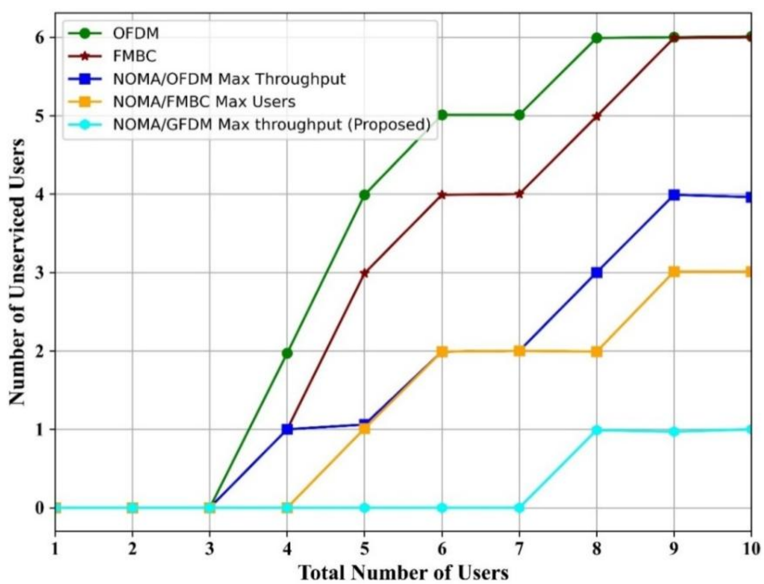

Figure 6: Number of unserved users by varying the users at $P_o = 1W$ and $RB = 100$

Figure 6 illustrates the number of unserved users by varying the users for RBs, $S = 100$. From the deep analysis of the graphical interpretation, it is noted that the number of unserved users increased when the number of users gets maximized. It is also noted that the number of unserved users is high compared to proposed GFDM-NOMA systems. The OFDM shows increased unserved users due to high interference and PAPR production when the number of users increased. The simulation outcome proves that the proposed system blocks only 10% of unserved users. However, the existing FBMC, OFDM, hybridized NOMA-OFDM, and hybridized NOMA-FBMC increases the unserved user blockage to 60%, 60.5%, 40%, and 30% respectively.

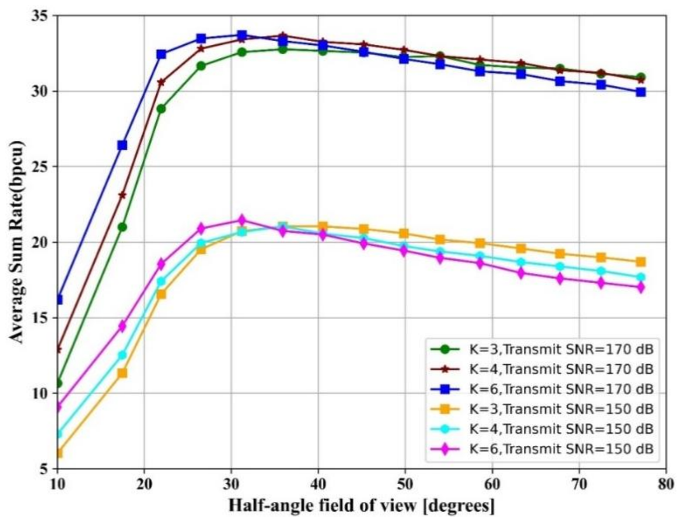

Figure 7: Average SR versus Half angle field view for proposed QRO-RA with different users and transmit SNRs

Figure 7 defines the average SR versus Half angle field view for proposed QRO-RA with different users and transmits SNRs. For the analysis process, two transmit SNR values are considered by increasing the users to $K = 3,\ 4,\ and\ \ 6$. For the transmit SNR of 150dB and $\delta_{0.5f} = 80^{\circ}$, the average SR obtains the value of 18dB, 17dB, and 16dB for $K = 3,\ 4,\ and\ \ 6$ respectively. For the transmit SNR of 170dB and $\delta_{0.5f} = 80^{\circ}$, the average SR obtains the value of 32.3dB, 32dB, and 30dB for $K = 3,\ 4,\ and\ \ 6$ respectively.

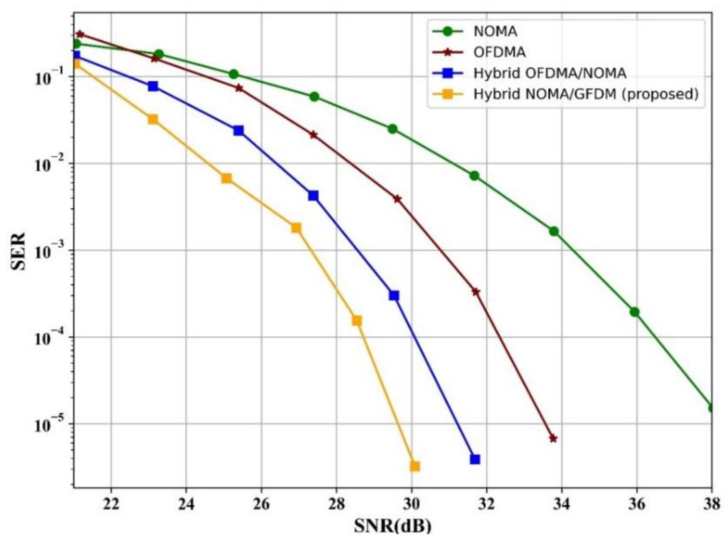

Figure 8: SER performance for the various systems

Figure 8 shows the SER performance for the various systems for the VLC systems. For analyzing the SER performance, the SNR and the transmitting power for each PD are kept constant. In addition to this, the noise variance is also kept constant for every paired user. By gradually altering the SNR, the noise variance is adjusted to a minimum or maximum according to the number of users considered for the system. From the deep analysis of the graphical representation, the proposed GFDM-NOMA system achieves better SER performance compared to existing studies.

The PR factor is comparatively compared to the existing hybridized NOMA-OFDM system resulting in increased SE performance.

6. CONCLUSION

The proposed study introduced a novel hybridized NOMA-based GFDM-OQAM system for the recent indoor-aided VLC system. The proposed NOMA-based GFDM-OQAM system highly supported the OWC systems even when the number of users increased. In addition to this, the proposed μ law companding technique reduced the self-channel and co-channel interferences efficiently. The presence of OQAM in this study strengthened the signal quality and reduced the PAPR maximization problems. Moreover, the proposed study introduced a novel quantum-enabled rabbit optimization (QRO) technique to allocate the resources to all the available users in the NOMA-VLC system. The proposed QRO technique accurately learned the channel information and provided the optimal RA to all the users using an effective global best solution. The proposed method is compared with various existing methodologies like NOMA, FBMC, NOMA-FBMC, OFDM, and NOMA-OFDM systems and has proven outstanding communication performance. The proposed method is processed in MATLAB simulation platform and performance measures like SR, SER, SINR, number of unserved users, and average SR are evaluated by varying users, separation distance, and PR factor. In the experimental section, the proposed method achieves the SR of 178Mbps, SINR of 16dB, and the number of unserved users reduced to 10% compared to conventional techniques. The proposed method hybridized NOMA-based GFDM-OQAM system in VLC highly supports various applications, especially in underwater WCs, Internet of Things (IoT) platforms, video streaming, etc. However, the proposed study failed to analyze the performance of the hybridized NOMA-based GFDM-OQAM system under imperfect and perfect channel state information (CSI) conditions. Also, the proposed method failed to estimate the channel condition in the VLC optical channel model. In the future, novel quantum-integrateddeep learning (DL) techniques will be introduced to perform channel estimation (CE) under perfect and imperfect channel conditions. In addition to this, the proposed indoor VLC-aided hybridized NOMA-based GFDM-OQAM system will be extended by utilizing it with a UW communication system, and its performancewill be evaluated.

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