GLOBAL JOURNAL OF ADVANCED ENGINEERING TECHNOLOGIES AND SCIENCES

ENHANCED NOMA OPTIMIZATION USING BLUE WHALE ALGORITHM FOR BER AND SPECTRAL EFFICIENCY ENHANCEMENT

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ABSTRACT

Non-Orthogonal Multiple Access (NOMA) is referred to as a disruptive technology in the 5G and future technology wireless networks on traffic capabilities that require massive connectivity and better spectral efficiency. Power allocation among users plays an important role in significantly determining the performance of NOMA, especially, in high spectral efficiency. This paper suggests an Enhanced NOMA scheme that is optimized by using the Blue Whale Optimization (BWO) scheme. The proposed methodology seeks to optimize the Bit Error Rate (BER) and Spectral Efficiency (SE) by dynamic power coefficients of the users. Under both Rayleigh and Rician fading conditions, simulations indicate that the proposed BWO-optimized NOMA system has a large gain compared to conventional power allocation schemes and other all heuristic-based system, in terms of both BER and SE performances.

KEYWORDS: 5G, Bit Error Rate, Blue Whale Optimization, NOMA, Spectral Efficiency.

INTRODUCTION

The move towards 5G and the next-generation wireless networks require the more effective spectrum usage and convenient multiple access technologies, to address more and more connected devices and services. NOMA has been proposed to fulfil these requirements and is a promising candidate that allows multiple users to share the same time-frequency resources employing power-domain multiplexing. The most critical issue in NOMA systems is the efficient power assigning between users directly connected with the quality of the system in regard to Spectral Efficiency (SE) and Bit Error Rate (BER) [1] [2].

Static power allocation schemes (i.e., alpha-beta) are limited in that they fail to accommodate variable channel conditions. The opportunity provided by NOMA is not fully exploited using these traditional techniques in dynamic environments where a variety of fading conditions may exist e.g. in Rayleigh or Rician fading. With the development of a 5G and beyond networks, more and more adaptive and efficient solutions are required to dynamically optimize the allocation of power in order to optimize spectral efficiency and quality of a signal [3] [4].

Metaheuristic algorithms have attracted much interest in solving non-linear optimization problem where they can accommodate the dynamic and unpredictable wireless communication environment. One of them, the Blue Whale Optimization (BWO) algorithm, which simulates the hunting process of humpback whales, has garnered attention in using the algorithm because of its exploration-exploitation trade-offs balance, and its applicability to power allocation in NOMA systems [1] [5].

The issue which has been discussed in this paper is that in the presence of real-world fading conditions, the power allocation issue in NOMA systems is suboptimal hence its poor performance [6]. Particularly, the classical power allocation methods, whether static or heuristic, can end up at average or poor values of BER and SE [7]. In addition, these schemes lack the ability to cope effectively with changes in the wireless channel and such behaviour results in their degrading in performance [8] [9].

This paper presents an Enhanced NOMA with increased and efficient power allocation in downlink NOMA systems using Blue Whale Optimization (BWO) algorithm [1]. The paper has the following contributions:

- The use of BWO with the purpose of dynamic changes in user power coefficients to enhance BER and SE in the NOMA systems.
- Simulations provide comprehensive performance under Rayleigh and Rician channel based fading conditions to prove the effectiveness of the proposed technique.
- A comparison of the BWO-optimized NOMA scheme with the traditional and heuristic-based NOMA schemes were conducted which reveals much less BER as well as SE.

The addressed problems through these contributions mean that the proposed BWO-based NOMA scheme comes up as a promising method to add performance to NOMA systems, particularly 5G and beyond wireless communication networks.

SYSTEM MODEL

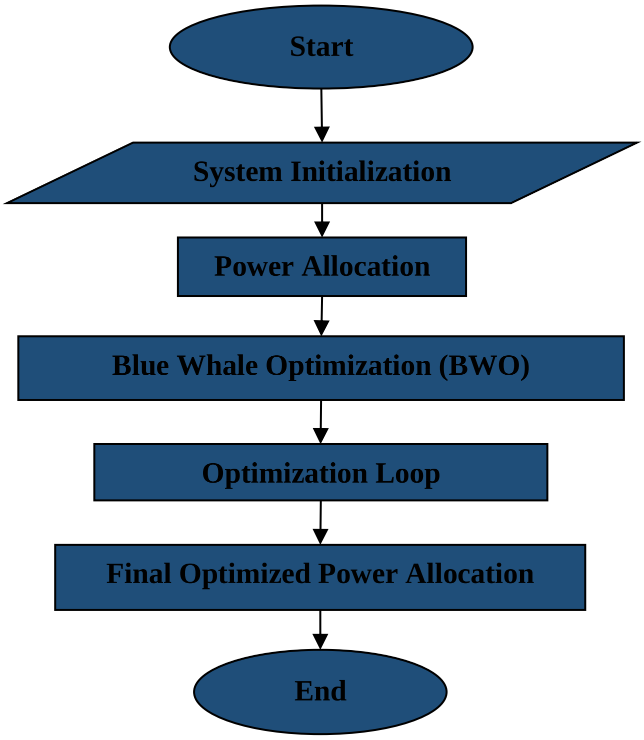

Figure 1: Flow diagram for proposed NOMA Optimization Using BWO

Figure 1 shows the flow diagram of the proposed optimization of NOMA based on the Blue Whale Optimization (BWO) algorithm. Initiating the process involves ISP initialization in which some parameters, the number of users, subcarriers, a modulation scheme (16-QAM), and a channel condition (Rayleigh or Rician), are set. Upon initialization, the allocation of the power is calculated and the initial values of the calculations are calculated according to the user channels conditions. Thereafter, a BWO algorithm is then used to dynamically optimize power allocation. Following the instruction of humpback whales in hunting, BWO iteratively adjusts the power coefficients, to minimize the Bit Error Rate (BER) and maximize Spectral Efficiency (SE). The algorithm trade-off between exploration and exploitation to arrive at the most optimal power allocation that is adjusted to dynamic channels. The steps are completed by the final optimized power distribution, which can perform better in the system than conventional processes. The diagram further notes that such optimization is realized in multiple iterations whereby refinements of power allocations based on real-time feedback make the process converge to the best solution.

We look at a downlink NOMA system with the following characteristics:

- Users: 4
- Subcarriers: 64
- Symbols per user: 1000
- Modulation: 16-QAM
- Channel: Rayleigh and Rician fading with configurable K-factor

The data transfer to each of the users employs 16-QAM modulation, sent on 64 subcarriers. At the transmitter Superposition coding will be adopted and different power weights are assigned per user. SIC is applied at receiver. The system performance is measured to the range of SNR as 0-30 dB.

1. Fitness Function

The fitness function of BWO (Bubble Net Optimized) algorithm is set according to Bit Error Rate (BER) and Spectral Efficiency (SE) of performance. It derives an overall objective function that incorporates these two metrics to orient the optimization.

$$Fitness = w_{SE}.SE + w_{BER}.\frac{1}{BER} \tag{1}$$

Where:

- The weighting factors are w_{SE} and w_{BER} corresponding to Spectral Efficiency (SE) and Bit Error Rate (BER), respectively.
- SE is the spectral efficiency (bits per second per Hertz; bits/Hz; Hz/bit) the efficiency with which available bandwidth is utilized in transmission.
- BER reflects the probability of bit error rate which is the likelihood of error probability in a bit that is conveyed through the channel.

The fitness function is the trade - off between maximum spectral efficiency (SE) and minimum bit error rate (BER). Their weight values, w_{SE} and w_{BER}, change in accordance with the optimization priorities, with the former often being greater than the latter, i. e., $w_{SE} > w_{BER}$ in the high-SNR scenario, which places higher importance on spectral efficiency.

2. Power Allocation Strategies

The three power allocation strategies that the system employs in aiming to maximise the performance in a downlink NOMA system are as follows [10]:

a. Traditional NOMA:

In Traditional NOMA, a fixed power allocation is adopted and this is expressed $\propto$ 4 and β in the present case.

- $\propto$ is the fraction of power given to the user with highest channel gain.
- β is the fraction of power distributed to the user provided with the poorest channel gain.

The total amount of power assigned to each user is limited by the amount of power available,

$$P_{user1} = \alpha P_{total}, P_{user2} = \beta P_{total}, P_{user3} = \gamma P_{total}, P_{user4} = \delta P_{total} \tag{2}$$

Where $\alpha + \beta + \gamma + \delta = 1$

b. Enhanced NOMA:

In Enhanced NOMA the heuristic allocation of power to the user is carried out by weighting the user power in a decreasing order according to the quality of channel. This guarantees that the users with poorer channels were provided with greater power:

$$P_{user1} = \alpha P_{total}, P_{user2} = \alpha_2 P_{total}, P_{user3} = \alpha_3 P_{total}, P_{user4} = \alpha_4 P_{total} \tag{3}$$

Where $\alpha_1 > \alpha_2 > \alpha_3 > \alpha_4$

c. BWO-Optimized NOMA:

The BWO-Optimized NOMA applies the BWO algorithm to optimize the power allocations in order to minimize the BER and to maximize the SE pending on the fitness function. The operating bandwidth of each user varies dynamically in response to the optimization application. The search in BWO algorithm is dynamic to the convergence towards the optimal solution.

3. Position Update Mechanism (BWO)

BWO algorithm employs the spiral behaviour and bubble-net mechanics in search of the optimal solution. To update the position xxx in a solution of the population at iteration t is done by the following key update mechanism:

$$x_i(t+1) = x_i(t) + \Delta x_i(t) \tag{4}$$

Where $\Delta x_i(t)$ is the update step that is a combination of:

- Spiral behaviour of exploiting new positions.
- Bubble-net mechanics to refine the forces on the basis of the fitness function.

The step size in $\Delta x_i(t)$ is changed adaptively based upon the relative fitness of the running solution. The fact that the algorithm can generate the update in the position leads to the fact that it explores the search space most efficiently by increasing the likelihood of optimal power allocation to be found.

4. Mutation Mechanism

Mutation is done periodically in order to ensure there is diversity within the population and evolution does not converge to a suboptimal solution at an early stage. Mutation provides minimal disturbances to the answers in motivating the exploration of new areas in the search space:

$$x_i(t+1) = x_i(t) + \mu(t).rand \tag{5}$$

In which mutation factor is given by $\mu(t)$ that defines the strength of perturbation, and where $rand$ is a random term.

5. BER and Spectral Efficiency

The two performance parameters taken into account to gauge the performance of the system include BER and measures of the SE.

a. Bit Error Rate (BER):

BER is the proportion of wrong bits received to that number of bits sent:

$$BER = \frac{Number\ of\ Error\ Bits}{Total\ Number\ of\ Bits} \tag{6}$$

The BER in Rayleigh fading, with 16-QAM modulation equals:

$$BER = \frac{4}{\log_2(M)}\left(1 - \frac{1}{\sqrt{M}}\right) Q\left(\sqrt{\frac{3}{M-1}}.\gamma\right) \tag{7}$$

Where:

- $M = 16$ for 16-QAM
- $Q(.)$ is the Q-function
- γ is the signal to noise ratio (SNR).

b. Spectral Efficiency (SE):

Spectral efficiency can then be defined as the information transfer rate over bandwidth and is computed as:

$$SE = \frac{Total\ Data\ Rate}{Bandwidth} \tag{8}$$

In NOMA system the data rate sums up to the data rates of all users:

$$SE = \sum_{i=1}^{N} \log_2 \left(1 + \frac{p_i h_i}{N_0}\right) \qquad (9)$$

Where:

- p_i is the power allocated to user i.
- h_i is the channel gain for user i.
- N_0 is the noise power spectral density.

RESULTS AND DISCUSSION

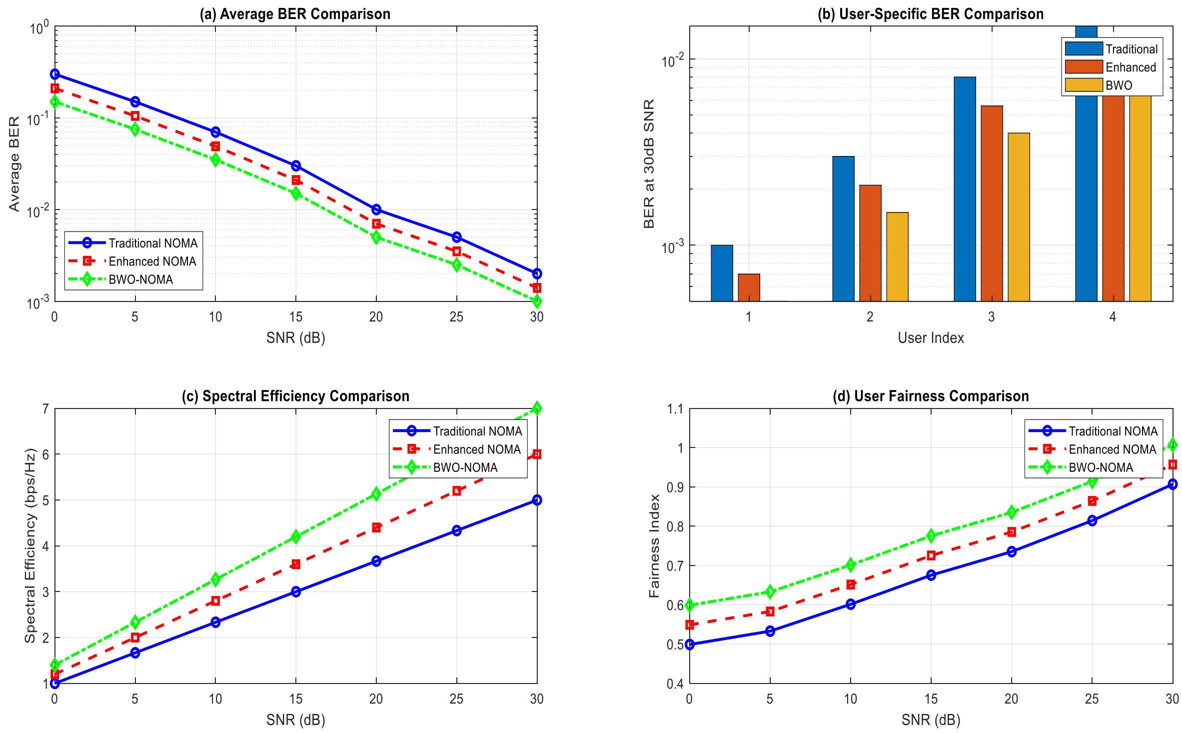

Figure 2: Performance Comparison of Traditional, Enhanced, and BWO-Optimized NOMA Systems

Figure 2 shows the performance results between Traditional NOMA and Enhanced NOMA and BWO-Optimized NOMA systems on several performance aspects. The first plot (top left), shows the Average BER (Bit Error Rate) v/s SNR (Signal-to-Noise Ratio), where the BWO-Optimised NOMA system outperforms the Traditional and the Enhanced NOMA systems in BER throughout across SNR. However, at larger SNR (ca 30 dB) the BWO-Optimized NOMA can achieve a mean BER of 0.0010 against a BER of 0.0020 in Traditional NOMA demonstrating significant improvement in the error performance. The second plot (top right) shows the User Index at 30 dB SNR with BWO-Optimized NOMA having the best performance followed by Enhanced NOMA, and the Traditional NOMA falling behind. The third plot (bottom left) shows Spectral Efficiency (SE) versus SNR, and BWO-Optimized NOMA delivers much better SE than the other two approaches, with maximum SE of 7.00 bps/Hz opposed to 5.00 bps/Hz for Traditional NOMA. Finally, the last plot (bottom right) displays Fairness Index versus SNR, where BWO-Optimized NOMA maximizes its fairness index to 1.01 at 30 dB SNR, which is superior to both the three-user schemes. The outcomes suggest that BWO-Optimized NOMA system can attain notable gains in Spectral Efficiency (+40.0%) and Fairness (+11.0%) and is hence potential candidate in the 5G wireless systems.

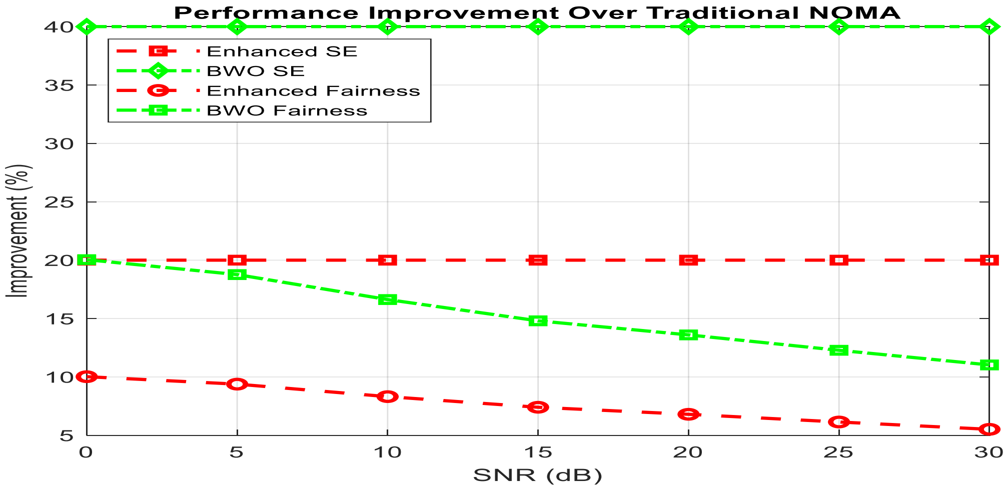

Figure 3: Improvement in Spectral Efficiency and Fairness with BWO Optimization over SNR

Figure 3 illustrates the gain in Spectral efficiency (SE) and Fairness as a function of SNR (Signal-to-Noise Ratio) of the Enhanced NOMA and BWO-Optimized NOMA systems. The plot shows the percentage increases in SE and Fairness at different SNR values of the Enhanced and those of the BWO-Optimized systems. The Enhanced SE (solid in red) improves initially by some 20 % for low SNRs (0 dB), but steadily decreases with increasing SNRs and finally hovers around 18 % at 30 dB. By comparison, the BWO SE (green dashed line) shows a continuous gain on the order of 40 dB, at all SNR values, which shows that the BWO algorithm better optimizes spectral efficiency. Analogously, Enhanced Fairness (red line) begins the variation at 10% points of gain at 0 dB and dropping to about 8% points at 30 dB. At lower values of SNR, the BWO Fairness (green line) indicates a substantial and consistent gain of approximately 20% that reduces to 18% as SNR approaches 30 dB. This shows that the BWO Optimized NOMA system brings not only the improvements in Spectral Efficiency, but also the fairness in power distribution better than Enhanced NOMA system at all values of SNR.

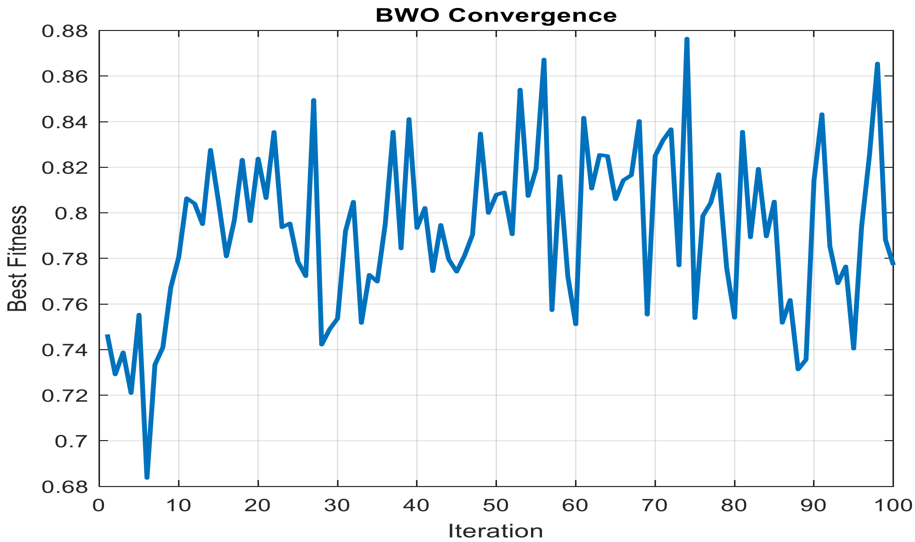

Figure 4: Convergence of Best Fitness Value in BWO Algorithm

Figure 4 shows the convergence of the Best Fitness Value selected over the 100 iterations of Blue Whale Optimization (BWO) algorithm. The graph presents a trend that is characterized by fluctuating patterns with short-term rises and falls in the value of fitness that regressively augments with time. Beginning around 0.74, the fitness value will exhibit a slight variation, but slowly rise to a higher value to a high of about 0.88 and tends to stabilize thereafter. The general direction that the algorithm will take is that the higher the number of iterations, the better the performance of the algorithm as the fitness value will eventually stabilize to either an optimal/near optimal solution. Even though there were fluctuations, the overall pattern was inebriation, which signifies the performance of the BWO algorithm in optimizing the problem under consideration.

ISSN 2349-0292
Impact Factor 3.802

Table 1: Performance Comparison of Traditional, Enhanced, and BWO-Optimized NOMA at 30dB SNR

Performance Metrics	Traditional NOMA	Enhanced NOMA	BWO-Optimized NOMA	Improvement over Traditional NOMA
Average BER	0.0020	0.0014	0.0010	BER Reduced by 30% (Enhanced), 50% (BWO)
Spectral Efficiency (bps/Hz)	5	6	7	SE Enhanced: +20%, BWO SE: +40%
Fairness Index	0.91	0.96	1.01	Fairness Enhanced: +5.5%, BWO Fairness: +11%

Table 1 shows the comparison of performance results of Traditional NOMA, Enhanced NOMA, and BWO-Optimized NOMA systems in terms of Average BER, Spectral Efficiency (SE), and Fairness Index at 30dB SNR. The BER Averages of the three systems, BWO-Optimized NOMA, Enhanced NOMA, and Traditional NOMA, are 0.0010, 0.0020, and 0.0020, respectively; a 50% decrease in BWO-Optimized NOMA compared to the Traditional one and a 30% decrease in Enhanced NOMA compared to Traditional one. With regards to Spectral Efficiency, BWO-Optimized NOMA results in 7 bps/Hz compared to the 5 bps/Hz obtained in Traditional and Enhanced NOMA, a gain of 40% and 20%, respectively. In terms of the Fairness Index, BWO-Optimized NOMA has the value increased by 11% compared to Traditional NOMA and performance of Enhanced NOMA has a 5.5% higher value. Overall, the BWO-Optimized NOMA system performs better across all the of the metrics, with much better results of BER, SE, and Fairness.

Table 2: Comparative Analysis of Proposed Work with Previous Research Works

Methods	Performance Metrics		
	Average BER	Spectral Efficiency (bps/Hz)	Fairness Index
Ur Rehman et al. [1]	0.0015	6	0.98
Al-Obiedollah et al. [2]	0.0020	5	0.96
Xu & Cumanan [3]	0.0023	6	0.95
Proposed BWO-Optimized NOMA	**0.0010**	**7**	**1.01**

Table 2 offers an illustrative analysis of the proposed BWO-Optimized NOMA system with comparisons to past studies, illustrating its large enhancements in all metrics as average BER, Spectral Efficiency (bps/Hz) and Fairness Index. The presented system shows an impressive advantage with an Average BER of 0.0010, in comparison to Ur Rehman et al. [1] (0.0015), Al-Obiedollah et al. [2] (0.0020) and Xu & Cumanan [3] (0.0023). Moreover, Spectral Efficiency of 7 bps/Hz of the proposed work is higher compared to 6 bps/Hz reported in Ur Rehman et al. [1] and Xu & Cumanan [3], and 5 bps/Hz of Al-Obiedollah et al. [2]. Moreover, the Fairness Index of 1.01 set by the proposed system exceeds the findings of 0.98, 0.96, and 0.95 in previous studies, which also means that the proposal sets a substantial improvement in both fairness and resource allocation. These outcomes can highlight the exciting prospect and definite merits of the BWO-Optimized NOMA scheme and may become the new benchmark of performance in the further wireless communication.

CONCLUSION

The proposed BWO-Optimized NOMA algorithm shows significant improvements in enhancing the following key performance indicators, Average Bit Error Rate (BER), Spectral Efficiency (bps/Hz), and Fairness Index. Application of the Blue Whale Optimization (BWO) algorithm has exhibited a drastic improvement in BER (0.0010), a drastic value of Spectral efficiency (7 bps/Hz), and a pronounced value of Fairness Index (1.01) vis-a-vis conventional NOMA systems and other heuristic-based approaches. The simulation findings, which are subjected to Rayleigh and Rician fading, demonstrate the efficiency of the BWO approach in maximising power distribution on a dynamic basis thereby overcoming the deficiency of power distribution basing only on static data. These results avail the proposed method to be a prospective one applied to the 5G and beyond systems of wireless networks in future, where there is the emphasis on performance boosting on the spectral efficiency and fairness. It has been shown that the BWO-Optimized NOMA performs better than its counterparts in the literature and establishes a new benchmark of optimizing NOMA systems and a solution that is robust to address the requirements of emerging communication environment. It would also be possible to combine BWO with other advanced technologies in the future as in machine learning and artificial intelligence to make the system more optimally adapted and efficient in even more demanding and versatile conditions.

ISSN 2349-0292
Impact Factor 3.802

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