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Article

Artificial Rabbits Optimization for Optimal Multiple ONU Placement in FiWi Networks: Throughput and Blocking Probability Analysis

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Abstract: Fiber Wireless (FiWi) access networks have emerged as a promising solution for supporting the growing bandwidth requirements of next-generation communication systems. Efficient Optical Network Units (ONUs) placement significantly influences network throughput, blocking probability, and overall quality of service. The manuscript demonstrates a distance-based throughput model incorporating bandwidth and ONU capacity constraints using the Artificial Rabbits Optimization(ARO) algorithm. ARO is selected because of its strong capability to solve complex optimization problem such as ONUs placement problem by effectively balancing exploration and exploitation mechanism, leading to faster convergence towards the optimal solutions. The proposed algorithm evaluates throughput per ONU, total network throughput, average ONU to user distance, and blocking probability. Furthermore, the performance of ARO is compared with the existing Moth Flame optimization algorithm. Simulation results demonstrate that the proposed ARO-based ONUs placement strategy improves throughput, reduce average-to user distance, and reduce blocking probability as compared to ARO. The proposed research provides an effective baseline framework for future research in FiWi access networks such as survivability, energy efficiency, and intelligent resource allocation.
Keywords: Fiber Wireless networks, Artificial Rabbits Optimization, Moth Flame Optimization, throughput, blocking probability.

1. Introduction

The rapid growth of emerging technologies such as multimedia applications, Internet of Things (IoT), cloud computing, online gaming, and machine-to-machine communications has significantly increased the demand for high-speed, reliable and low latency broadband access networks [1-2]. Traditional communication network such as Digital Subscriber Line and cable modem are unable to satisfy the high traffic demands due to limited bandwidth, higher attenuation, limited scalability and inability to satisfy latency requirements of modern communication systems. Consequently, new generation access technologies such as Fiber wireless(FiWi) access networks are being explored to meet the growing demand of high capacity requirements with cost effective broadband solutions. FiWi networks combine the high bandwidth, low transmission loss and reliability of optical fiber networks with the flexibility and mobility of wireless communication systems. The optical network serves as a back-end providing large transmission capacity, whereas wireless network work as front-end access, offering mobility and ease of deployment. This integration enables FiWi networks to support high-speed data communication with improved coverage, enhanced Quality of Service and reduced infrastructure cost [3].

In FiWi networks, Optical Network Units (ONUs) device performs the modulation/ demodulation process by converting optical signals into electrical signals, thereby playing a critical role in connecting end users to the optical backbone network [4]. The performance of network mainly depends on ONUs placement, as improper placement may raise to traffic congestion, excessive transmission distance, uneven load distribution, and increased packet loss [5].

The objective of ONU placement is to maximize network throughput while minimizing blocking probability, deployment cost and network congestion.

Several optimization approaches have been proposed in the literature for ONU placement and resource allocation in FiWi networks. In [5-7], the authors implemented population-based Moth Flame Optimization (MFO) for the ONU placement and demonstrated that MFO achieves improved objective function value as compare to Simulated Annealing and Greedy algorithm. In recent trends, various metaheuristics algorithm has been developed such as Whale Optimization algorithm(WOA) [8], Harris Hawk Optimization (HHO) and Grasshopper Optimization algorithm (GOA) [9], Chaotic local search-based levy flight distribution (CLSBLFD) [10], Marin Predators algorithm (MPA) [11], Enhanced backtracking search algorithm(EBSA) [12], Arithmetic Optimization with Fuzzy-C Mean(AOFCM)[13], Hybrid Harris Hawks with Sine Cosine (HHH-SC) [14], Mountain Gazelle Optimization (MGO) [15], and many more. In [8], the WOA has been employed for ONU placement and reported improved performance compared with MFO and Greedy approaches. In [9], GOA and HHO implemented for ONU placement and the experimental results demonstrated superior performance as compare to WOA and MFO algorithm. The authors implemented CLS-LFD algorithm for ONU placement and obtained better performance with respect to convergence rate and cost functions than canonical LFD [10]. Similarly, the authors employed MPA for the same optimization problem and achieve better objective value as compare to MFO, WOA and HHO algorithm [11]. In [12-13], the authors proposed EBSA and AOFCM for the ONU placement and proved better performance than HHO, CLS-LFD, and BSA. Furthermore, the HHH-SC algorithm has been implemented as an efficient approach for the ONU placement problem and demonstrated outperforms than HHO, and Gray Wolf Optimization(GWO) [14]. To further improve the network performance, the MGO algorithm [15] was employed by incorporating different spiral trajectory techniques namely logarithmic, Archimedes and hyperbolic for the ONU placement and prove that logarithmic spiral based MGO returns low cost function followed by the hyperbolic and Archimedes spiral path. The findings indicate that logarithmic spiral path provides a better trade-off between global exploration and local exploitation, resulting in better network performance and improved ONU placement. Although these algorithms have demonstrated the promising solutions, ONU placement still represents a challenging non-linear, multi-objective optimization with constrained characterized due to its large search space and conflicting network performance metrics.

More recently, Artificial Rabbits Optimization(ARO) algorithm has gained attention due to its effective balanced between global exploration and local exploitation mechanisms through detour foraging and random hiding mechanism [16-17]. ARO algorithm are used in fault diagnosis of roller bearing, pressure vessel design, cantilever beam design, and many more [18]. The exploration phase aims to optimize the location of ONU while exploitation refine the search space aims to maximize network throughput, minimize blocking probability, improve load distribution among ONUs. In addition, ARO requires few control parameters and exhibits strong convergence characteristics making it suitable to determine the optimal placement of ONUs in FiWi network.

Despite the extensive research on optimization-based ONU placement in FiWi networks, most existing studies primarily focus on minimizing the distance-based cost function and enhancing optimization characteristics such as exploration and exploitation capability, convergence rate, fitness values, and computational complexity. Furthermore, limited attention has been given to evaluate the impact of ONUs placement on network-centric Quality of Service performance metrics such as throughput, user blocking probability, ONU-to-user association efficiency, and bandwidth utilization under different ONU to user deployment scenarios. Consequently, the impact of ONU placement on overall network performance remains insufficiently explored.

Therefore, this manuscript presents a performance analysis framework for FiWi networks considering deterministic and random ONU–user deployment scenarios. A distance-aware throughput model with ONU capacity and bandwidth constraints is implemented to analyze throughput and blocking probability. Furthermore, the research investigates the application of ARO algorithm for optimizing the ONUs placement while improving the network throughput and reduce blocking probability. Since throughput and blocking probability directly influence Quality of Service (QoS) in FiWi networks, a thorough performance evaluation is required to assess the effectiveness of different placement techniques [19-20].

The major contributions of the research are summarized as follows:

1. To develop and simulate network model using deterministic and random ONU-user placement including nearest ONU association, bandwidth constraint, ONU capacity, and distance-based throughput evaluation.

2. To evaluate the performance of ONU placement using ARO algorithm in terms of network throughput, blocking probability under four different placement schemes in FiWi networks. As per our knowledge the algorithm has not yet been explored in FiWi networks
3. To compare the performance of proposed ARO algorithm with existing metaheuristic algorithm such as MFO, demonstrating its effectiveness to improve network performance and resource utilization

The remainder of this paper is organized as follows. Section 2 presents the system model and problem formulation. Section 3 explains the proposed methodology and the implementation of the ARO algorithm. Section 4 discusses simulation results and analysis. Finally, Section 5 concludes the paper and outlines future research directions.

Table 1: list of notations used in research paper

Notation	Full Form
BWONU	ONU channel bandwidth
d	Distance between user and its serving ONU
Deuc	Euclidean distance between user and its associated user
Nb	Number of blocked users
Nt	Total number of users
Ru	Data rate of users
TONU	Throughput of an ONU
Tu	Throughput of users
(x_k, y_k)	users location
(X_i, Y_i)	ONUs locations
Ttotal	Overall network throughput
Pb	Blocking probability
$e^{\wedge}(-\alpha d)$	Exponential decay function
A	Path loss coefficient
B	Maximum available channel bandwidth (800 Mbps)

2. System Model

A two-dimensional network area of size 100 m × 100 m is considered. The network consists of four ONUs and hundred wireless users distributed within the network area. For the system model, the network area divided into non-overlapping segments called grid and the size of each grid is 10X10 m2. Each ONU has a maximum serving capacity of 20 users and if the number of connected users exceeds ONU capacity, excess users are blocked. The blocking probability(is define as the ratio of the number of blocked users(Nb) to the total number of users(Nt). A lower value of represents better resource allocation and improved QoS.

A. Users Association:

Users are associated with their nearest ONU based on Euclidean distance parameter. The Euclidean distance between the k^{th} user and i^{th} ONU is calculated as:

$$\text{Deuc} = \sum_{j=1}^{Ki} \sqrt{(x_k - X_i)^2 - (y_k - Y_i)^2\}} \qquad (1)$$

Average distance(Davg) between users and their associated ONU is

$$\text{Davg} = \frac{1}{\text{Nt}} * \left(\sum_{k=1}^{\text{Nt}} \text{Deuc}\right) \qquad (2)$$

B. ONU Capacity Constraint:

Each ONU can serve a limited number of users (C0=20). Let Ni represents the number of users associated with ONUi. The number of admitted users is

$$\text{Ni}\frac{\text{adm}}{\text{i}} = \text{Min}(\text{Ni}, \text{CO}) \qquad (3)$$

Excess number of users are blocked from accessing the network and the total number of block users is represented as

$$N_{block} = \sum_{i=1}^{N0} \max(0, Ni - C0) \quad (4)$$

C. Distance Model Throughput Model

The required throughput increases with decreasing user-to-ONU distance due to propagation losses. The throughput of each user depends on the allocated date rate (20 Mbps) and distance from the associated users. The distance-aware throughput can be expressed as:

$$Tu = Ru\ 〚e\text{^}(-\alpha d)〛 \quad (5)$$

The throughput of an ONU is

$$TONU = \sum_{n=1}^{N} Tu \text{ where } TONU \leq BWONU \quad (6)$$

D. Bandwidth Constraint

The effective throughput of an ONU_i is given by:

$$T\frac{eff}{i} = \min(TONU,B) \quad (7)$$

The total network throughput($Tnet$) is given as

$$(Tnet) = \sum_{i=1}^{N0} T\frac{eff}{i} \quad (8)$$

Assess the performance of metaheuristic algorithm such as ARO, and MFO for the ONUs placement in FiWi network under four different deployment scenarios: (a) Both ONUs and users are located in deterministic (b) Both ONUs and users are located in random style (c) ONUs are located in deterministic and users are located in random fashion (d) ONUs are located in random style and users are located in deterministic style.

3. Algorithms and its Implementation

A. ARO

It is a new bio-inspired metaheuristic algorithm inspired by social behaviour of rabbits. Each rabbit represents a candidate ONU placement solution. ARO mainly uses three strategies for searching purpose: detour foraging for global exploration, random hiding for local exploitation, and an energy shrink technique to balance exploration and exploitation during optimization [16].

a. Exploration Phase – Detour Foraging technique

The exploration phase of ARO is modelled as

$$\overrightarrow{v1(t+1)} = \overrightarrow{x_J(t)} + R1*(\overrightarrow{x_I(t)} - \overrightarrow{x_J(t)}) + round(0.5(0.05+r1))*n1 \quad (9)$$

Where R1(Running operator): $L1 * C1$ (10)

Running Length (L_1) $= e - e^{\{\frac{t-1}{T}\}^2} * \mathrm{Sin}(2\pi r2)$ (11)

$$C_l(k) = \begin{cases} 1 & \text{if } k1 = g1l \\ 0 & \text{otherwise} \end{cases} \quad (12)$$

Where k1=1, ……d and l =1, 2, ……, (r3*d) and g= randperm(d)

b. Exploitation Phase – Random Hiding technique

The exploitation mechanism is inspired by the behaviour of rabbits that randomly hiding in burrows near their nests.

$$\overrightarrow{b_{I,J}(t)} = \overrightarrow{x_J(t)} + H.g\ \overrightarrow{x_J(t)} \quad (13)$$

Hiding parameter

$$H = \frac{T-t+1}{T} * r4 \quad (14)$$

Position update during hiding

$$\overrightarrow{v_i(t+1)}=\overrightarrow{x_i(t)}+R*(r4\cdot\overrightarrow{b_{i,r}(t)}-\overrightarrow{x_i(t)}) \quad (15)$$

This mechanism improves local exploitation by searching around the current solution neighbourhood.

c. Energy Shrink Mechanism

The transition between exploration and exploitation is controlled using the energy factor:

$$A(t)=4(1-t/T)\ln(r1) \quad (16)$$

Decision rule:

- If $A(t)>1$Exploration (Detour Foraging)
- If $A(t)\leq 1 \rightarrow$ Exploitation (Random Hiding)

The energy factor gradually decreases with iterations, enabling the algorithm to shift from global search to local search adaptively.

Implementation:

Phase 1: It obtains the optimized throughput through minimum ONU to user distance association, distance based throughput modelling and ONU capacity constraints. This strategy reduces the transmission distance between users and ONUs, which improves signal quality and minimizes path loss. Minimum distance minimizes path loss and improves signal quality results increased network throughput. The throughput of each user is calculated by a distance-aware throughput model, where the obtained throughput decreases exponentially with increasing transmission distance. As a result, reduced communication distance leads to improved user throughput and enhanced overall network performance.

Phase 2: It considers the ONU capacity constraint by limiting the maximum number of users connected to each ONU. It helps to maintain stable network performance and avoid network congestion. Furthermore, the throughput of each ONU is restricted by the available channel bandwidth to achieve efficient bandwidth allocation.

Phase 3: The total overall network throughput is achieved by adding the throughput contribution of individual ONU. In addition, blocking probability and average user-to-ONU distance are analyzed as performance metrics to evaluate the effectiveness of the network model.

B. *MFO*

It is a bio-inspired metaheuristic model based on the natural navigation strategy of moths. In this technique, each moth represents a candidate solution whereas each flame denotes the best solution. The moth updates their positions around a flame using a spiral movement enabling to achieve exploration and exploitation process [5-6]. The throughput is indirectly achieved through optimal placement of ONUs. The algorithm minimizes the distance between ONUs and users, and the reduced distance improves signal quality and transmission efficiency, which ultimately increases to network throughput.

4. Result and Simulation Analysis

In the research, simulations are conducted on MATLAB(R2026a) online license version. The results are assessed through ARO, and MFO using identical conditions as shown in Table 2.

Table 2: Parameter Configuration for Algorithm Simulations

Algorithms	Iterations	Lower bound	Upper bound	Population size	Dimension
ARO	100,100,100,100,100,100	0,0,0,0,0,0	100	30	8
MFO	100,100,100,100,100,100	0,0,0,0,0,0	100	30	8

In the proposed research, the performance of proposed ARO algorithm was evaluated consisting of 100 wireless users distributed over 100 X100 meter2 network area. In the research, four ONUs are considered and each ONU has a maximum serving capacity of 20 users, resulting in maximum network capacity of 80 admitted users by keeping the channel bandwidth is 800 Mbps. Users were associated with minimum Euclidean distance metric while the throughput of each user was evaluated using the distance-aware throughput model. The optimization objective is to maximize network throughput while minimizing blocking probability and reduce ONU-to-user distance. The performance analysis is carried out under four different ONU deployment scenarios: deterministic placement and random placement. In the deterministic deployment strategy, the ONUs are located at predefined central locations within the corresponding regions, whereas in the random deployment strategy, the ONUs may occupy any arbitrary position inside the search space. Furthermore, the research investigates four different combinations of ONU and user distributions: (i) deterministic placement of both ONUs and users, (ii) random placement of both ONUs and users, (iii) deterministic ONU placement with randomly distributed users, and (iv) deterministic user placement with randomly distributed ONUs.

A. Throughput Analysis

The throughput achieved by individual ONUs and overall network throughput obtained using ARO and MFO as shown in Table 3. The obtained results demonstrate that the proposed ARO-based placement technique is consistently achieving higher throughput as compare to MFO under different placement strategy. For the deterministic placement of both ONU and users, ARO achieves a network throughput of 1141.83 Mbps while MFO obtains a network throughput is 1019.51 Mbps. This corresponds to an improvement of approx. 12% in overall network throughput. Similarly, for the random ONU and random user placement strategy, The ARO algorithm attains a throughput is 3084.94 Mbps whereas MFO achieves a throughput is 1033.87 resulting a significant improvement of network throughput is 66.48%, demonstrating the effectiveness of ARO in optimizing the network performance. The improved network performance of ARO is attributed due to its effective balance between exploration and exploitation mechanism which enable better ONUs placement. The optimized ONU placement further improves the efficiency of user association. Since users are connected to the nearest ONU based on Euclidean distance, the optimized placement reduces the transmission distance between ONUs and users. Consequently, reduction in transmission distance minimize the attenuation effect, which increases the overall network throughput of admitted users. The throughput analysis indicates that the proposed ARO algorithm is significantly enhanced under different optimized placement conditions compared to MFO. Furthermore, the balanced user distribution among ONUs avoid excessive loading of individual ONUs and enhances efficient utilization of available bandwidth resources.

Table 3: Evaluation of throughput variation for the multiple ONU placement using ARO and MFO

User distribution	Initial ONU Placement	Placement technique	ONU1	ONU2	ONU3	ONU4	Total
Deterministic	Deterministic	ARO	285.46	285.46	285.46	285.46	1141.83
		MFO	239.86	252.43	285.39	241.83	1019.51
	Random	ARO	718.47	711.86	744.80	658.39	2833.51
		MFO	242.05	276.00	238.45	278.85	1035.35
Random	Deterministic	ARO	273.25	296.16	270.19	286.15	1125.75
		MFO	262.10	266.66	271.06	261.48	1061.29
	Random	ARO	640.55	832.48	799.97	811.94	3084.94
		MFO	253.88	252.09	267.57	260.34	1033.87

B. Blocking Probability Analysis

Blocking probability is the probability that certain user’s request cannot be admitted due to ONU capacity limitations Since each ONU can handle a maximum of 20 users and only four ONUs are available, the network can accommodate a maximum of 80 users. Therefore, when the total number of users exceeds the available serving capacity, excess users are blocked. The results of blocking probability are demonstrated in Table 4. The proposed ARO algorithm resultant is 20 blocked users corresponding to a blocking probability of 0.20, whereas MFO has 4 blocked users corresponding to a blocking probability of 0.24. The reduction in blocking probability achieved by ARO is due to the optimized placement of ONU which enables the distribution of users more uniformly across available ONUs. This balanced allocation prevents overloading of individual ONUs and promotes efficient utilization of network resources. The results indicate that the proposed algorithm is capable to reduce network congestion and contributes directly to QoS. Overall, the proposed ARO algorithm obtains 16.7% reduction in blocked users compared with MFO, demonstrating its effectiveness in managing ONU capacity constraints.

Table 4: Analysis of Blocking probability and execution time of ARO and MFO

Placement technique	Blocked users	Average Blocking probability	Average Execution time
ARO	20	0.2	0.66
MFO	24	0.24	0.288

C. Convergence characteristic Analysis

The convergence behaviour of the proposed ARO algorithm is shown in Fig. 1., indicating the fitness value decreases rapidly during the initial iterations and it demonstrating the algorithm exhibits global search ability. This characteristic is mainly attributed to the detour foraging technique, which enables effective global exploration of the search space and allows the algorithm to search promising ONU placement regions. As the optimization progresses, the random hiding mechanism strengthens the local exploitation phase. Consequently, the fitness value gradually decreases at a slower rate and stabilizes after roughly 60 iterations. In the later stage, the steady convergence of the optimization process moves towards the global optimum or near optimal solution. Furthermore, the convergence curve representing minimal fluctuations in the final iterations, demonstrating the stability and robustness and of the proposed ARO approach.

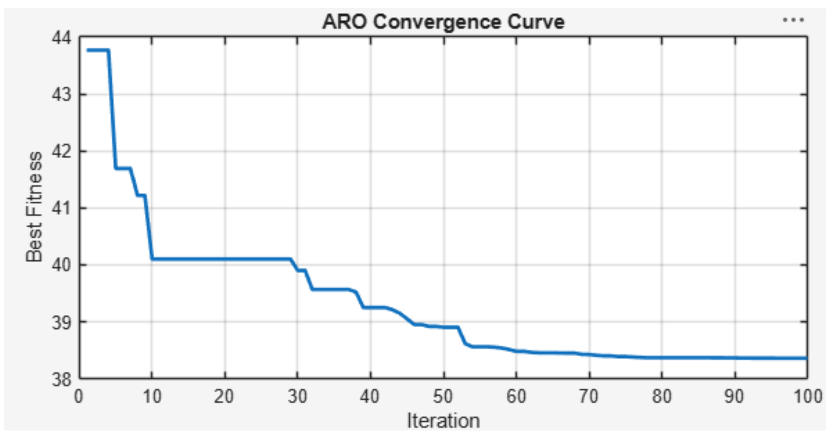

Fig. 1: Convergence Characteristic of ARO

D. Average ONU-to-user Distance Analysis

Average distance is the mean distance between users to its associated ONU after optimization process. Fig. 2 represents the average ONU-to-user distance comparison achieved through proposed ARO and MFO algorithm under different placement strategy. The results indicate that ARO algorithm is consistently achieving the minimum ONU-to-user distance compared to MFO across all placement strategy. The improvement is attributed to effectively balance between exploration and exploitation process, enables the algorithm to identify more suitable ONU location within search space.

By reducing the average ONU to user distance, path loss reduces and enhances signal quality, resulting improved network performance and increase achievable user throughput. Moreover, the minimum average distance promotes a balanced distribution of users among the available ONUs, reducing network congestion and enhancing resource utilization efficiency. In short, ARO consistently outperforms MFO across all placement conditions, demonstrating its robustness and adaptability to varying network topologies. Overall, the minimum average ONU-to-user distance is an effective strategy to improve QoS in FiWi access networks, as it directly contributes to higher throughput, minimum congestion and efficient resource utilization

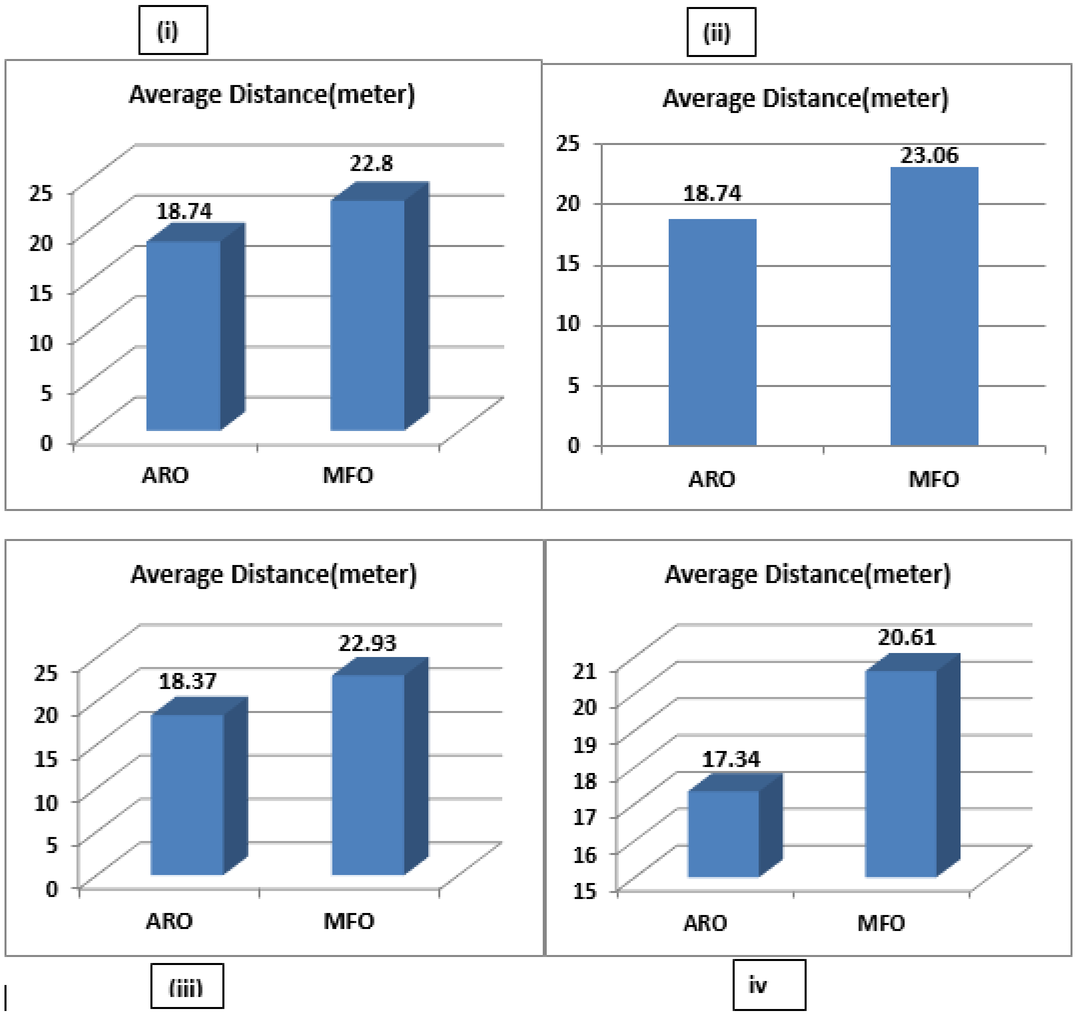

Fig. 2: Average ONU-to user distance analysis when (i) ONUs and users are located in deterministic (ii) ONUs located in random while users are in deterministic location (iii) ONUs located in deterministic location while users are in random style (iv) Both ONUs and users are located in random style

Overall, the simulation results ensure that the ARO algorithm provides an efficient and reliable solution for optimal ONU placement in FiWi networks. The proposed algorithm obtains higher throughput, lower blocking probability, and reduced average transmission distance compared with MFO. Therefore, the ARO-based optimization technique can be considered a promising solution for next-generation FiWi access resource management and network planning.

5. Conclusion

The research presents an ARO based swarm based optimization algorithm for the optimal placement of ONUs in FiWi network. Simulations has been performed to evaluate the performance of ARO algorithm under four different placement strategy by keeping bandwidth and capacity constraints. The objective of the research is to minimize the blocking probability while keeping maximum throughput. Simulation result demonstrate that ARO algorithm efficiently determines the optimal ONU placement positions by achieving a trade-off between throughput enhancement, resource utilization, and, user association efficiency. Performance evaluation demonstrates that proposed algorithm achieves higher network throughput and lower blocking probability compared with MFO. By maintaining exploration and exploitation capability, ARO successfully converge towards the optimum solution by keeping the fewer number of iterations. Future work will focus on incorporating user mobility, energy efficient ONU placement, dynamic traffic demands to further improve network performance using dynamic traffic conditions.

References

1. X. Yu, X. Li, and W. Zhou, "Broadband fiber-wireless integration for 5G+ communication," APL Photonics, vol. 3, no. 11, Art. no. 111101, 2018, doi: 10.1063/1.5042364.
2. H. Zhang, Y. Hu, R. Wang, Z. Li, P. Zhang, and R. Xu, "Energy efficient frame aggregation scheme in IoT over fiber-wireless networks," IEEE Internet Things Journal, vol. 8, no. 13, pp. 10779-10791, 2021, doi: 10.1109/JIOT.2021.3051098.
3. N. Sharma and P. Singh, "Review of survivability techniques in fiber-wireless networks to achieve uninterrupted connectivity," AIP Conf. Proc., vol. 3410, Art. no. 020005, 2026, doi: 10.1063/5.0329074.
4. H. Emami and M. Balafar, "A comparison framework to survey the ONU placement methods in FiWi access networks," Opt. Fiber Technol., vol. 79, Art. no. 103341, 2023, doi: 10.1016/j.yofte.2023.103341.
5. P. Singh and S. Prakash, "Optical network unit placement in fiber-wireless access networks by moth-flame optimization algorithm," Opt. Fiber Technol., vol. 36, pp. 403-411, 2017, https://doi.org/10.1016/j.yofte.2017.05.018
6. P. Singh and S. Prakash, "Performance evaluation of moth-flame optimization algorithm considering different spiral paths for optical network unit placement in fiber-wireless access networks," in Proc. Int. Conf. Information, Communication, Instrumentation and Control (ICICIC), 2017, pp. 1-6, doi: 10.1109/ICOMICON.2017.8279172
7. P. Singh and S. Prakash, "Adaptive hybrid path search MFO algorithm for optical network unit placement in fiber-wireless access networks," in Proc. Int. Conf. Recent Advances in Interdisciplinary Trends in Engineering and Applications, 2019, pp. 1-5.
8. P. Singh and S. Prakash, "Optical network unit placement in fiber-wireless access networks by whale optimization algorithm," Opt. Fiber Technol., vol. 52, Art. no. 101965, 2019, https://doi.org/10.1016/j.yofte.2019.101965
9. P. Singh and S. Prakash, "Optimizing multiple ONU placement in fiber-wireless access networks using grasshopper and Harris hawks optimization algorithms," Opt. Fiber Technol., vol. 60, Art. no. 102357, 2020, https://doi.org/10.1016/j.yofte.2020.102357
10. H. Emami, M. Alipour," Chaotic local search-based levy flight distribution algorithm for optimizing ONU placement in fiber-wireless access network," Optical Fiber Technology. vol. 67, Art. no. 102733, 2021 https://doi.org/10.1016/j.yofte.2021.102733
11. P. Singh and S. Prakash, "Implementation of Marin predators algorithm for optimizing the position of multiple optical network units in fiber-wireless access networks," Opt. Fiber Technol., vol. 72, Art. no. 102971, pp. 1-14, 2022,https://doi.org/10.1016/j.yofte.2022.102971.
12. H. Emami, "ONU placement in FiWi network using enhanced backtracking search algorithm", 4th West Asian Symposium on Optical and Millimeter-wave Wireless Communications (WASOWC), 2022, pp. 1-6, doi: 10.1109/WASOWC54657.2022.9797912.
13. H. Emami, S. Pashazadeh, M. A. Balafar, "A novel fuzzy-based algorithm for ONU placement in FiWi broadband access network", Opt. Fiber Technology, vol. 80 Art. no. 103414, 2023.
14. H. Abdulrab, F. Hussin, I. Ismail, M. Assaad, A. Awang, H. Shutari, "Hybrid Harris Hawks with Sine Cosine for Optimal Node Placement and Congestion Reduction in an Industrial Wireless Mesh Network", IEEE Access, vol. 11, pp. 2500 – 2523, 2023, doi:10.1109/ACCESS.2023.3234109.
15. N. Sharma, P. Singh, and J. Singh, "ONU placement optimization in FiWi networks using mountain gazelle algorithm with hyperbolic, Archimedes and logarithmic spirals," J. Inf. Syst. Eng. Manage., vol. 10, pp. 796-806, 2025, doi: 10.52783/jisem.v10i33s.5650.
16. L. Wang, Q. Cao, Z. Zhang, S. Mirjalili, and W. Zhao, "Artificial rabbits optimization: A new bio-inspired meta-heuristic algorithm for solving engineering optimization problems," Eng. Appl. Artif. Intell., vol. 114, Art. no. 105082, 2022, doi: 10.1016/j.engappai.2022.105082.
17. N. Thieu and N. Nguyen, "Artificial rabbit optimizer," in Encyclopedia of Engineering Optimization and Heuristics, A. J. Kulkarni, E. Mezura-Montes, and H. Bonakdari, Eds. Singapore: Springer, 2025, doi: 10.1007/978-981-96-8165-5_55-1.
18. X. Qu and Z. Jia, "Multi-strategy enhanced artificial rabbits optimization for prediction of grades in tourism service communication courses," Sci. Rep., vol. 15, Art. no. 23854, 2025.
19. A. Mirzaeinnia, M. Mirzaeinia, and A. Rezgui, "Latency and throughput optimization in modern networks: A comprehensive survey," IEEE Commun. Surveys Tuts., early access, pp. 1-32, doi: 10.48550/arXiv.2009.03715
20. P. Chen and M. Reisslein, "FiWi network throughput-delay modeling with traffic intensity control and local bandwidth allocation," Opt. Switching Netw., vol. 28, pp. 8-22, 2018, doi: 10.1016/j.osn.2017.11.001.