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Fiber wireless (FiWi) access network: ONU placement and reduction in average communication distance using whale optimization algorithm

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Abstract

Explosive growth in the field of Information and Communication Technology demands an access technology which can serve users better Internet speed in "anytime anywhere” manner. Fiber Wireless (FiWi) access technology is one of the existing technologies that fulfills the current demands of users in cost-efficient manner. Some of the important issues of the FiWi network are ONU placement and energy saving. ONU placement issue affects the deployment cost and network performance while energy saving is the need for green technology. On taking consideration of these two issues we propose a whale optimization algorithm for ONU placement for FiWi network. The proposed algorithm optimizes the position of ONUs in such a manner that all deployed wireless routers can connect to their primary ONUs with minimum possible average communication distance. Simulation is performed for varying number of wireless routers to check the worthiness of the proposed algorithm. Results show that the proposed algorithm reduces the average communication distance between ONU and its associated wireless routers hence, it may offer the best way to deploy energy efficient FiWi network.

Keyword: Electrical engineering

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1. Introduction

FiWi technology is the broadband access technology which combines the merits of the passive optical network in terms of huge bandwidth and wireless access technology in terms of mobility and cost efficiency [1, 2]. The basic architecture of FiWi, shown in Fig. 1 [3], is the integration of the optical backend and wireless front end.

The optical network unit (ONU) is the interface that combines these two networks and does the work of signal translation i.e. from wireless to optical for upstream communication and optical to wireless for downstream communication [4]. To access the network facility the user sends data to the nearby wireless routers. This router further sends data to its primary ONU and then primary ONU up-streams this data to OLT. The reverse mechanism takes place for downstream.

ONU placement, energy saving, network architecture and survivability are the key issues in FiWi network [5, 6]. ONU placement issue affects the network performance and cost of the network. In FiWi, ONU should be optimally placed such that with minimum ONUs all the routers can connect to the network. Survivability is defined as the ability to provide services to users if any failure occurs in the network. Issue of survivability is more crucial at the back-end of FiWi because back-end follows tree topology. It also affects network performance in terms of QoS and reliability. Another important factor for FiWi is energy saving issue in which energy can be saved by putting low-loaded ONU into sleep mode.

In [7] authors proposed a comprehensive survey of recent energy mechanisms on FiWi network. The survey includes different energy mechanisms such as ONU

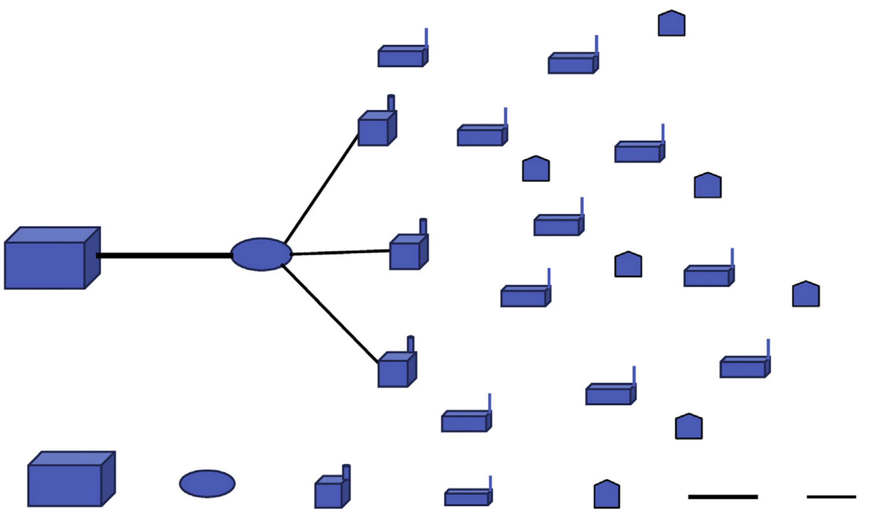

Fig. 1. Architecture of fiber-wireless access network [3].

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sleeping mechanisms, power saving modes (PSM), and some cooperative-based energy saving schemes. Authors of [8] developed an analytical framework for evaluating the capacity and delay performance of a wide range of routing algorithms in fiber wireless (FiWi) broadband access network based on different next-generation PONs and a Gigabit-class multi-radio multi-channel WLAN-mesh front-end. In [9] a comprehensive survey is discussed on different aspects of FiWi such as network architecture, QoS provisioning, scalability improving, reliability enhancing and energy saving. New trends on future smart FiWi networks are also identified and discussed in detail. In [10] authors deploy the ONUs in the network in such a way that the overall network throughput increases. In this paper for deploying ONU, a Tabu Search heuristic method is used. In [5, 11] authors proposed a load balance ONU placement (LBOP) algorithm considering peer-to-peer communication which works in two-steps namely placement of ONUs and load balancing among ONUs. In the ONU placement stage, deploy minimum ONUs under the constraint of hop number. In the load balancing stage, the load is transferred among the different ONUs to satisfy load balancing constraints. Bhatt et al [6] proposed a hybrid algorithm for ONU placement. This algorithm uses a genetic algorithm for position optimization of ONUs in the network and provides an efficient solution in terms of network cost. Sarkar et al proposed a simulated annealing algorithm [12] for ONU placement which works in five phases namely Initialization, Perturbation, Cost calculation, Acceptance, and Update. In the initialization phase, ONUs are placed using the greedy algorithm. Perturbation and cost calculation phases perturbed initial ONU positions and create a new position of ONUs. After that new cost with respect to old cost is calculated. Acceptance phase decides the acceptance of a new position of ONU on the basis of the cost phase. In the last phase, if there is no update in cost improvement than the algorithm gets terminated. In [13] the primal model is proposed for ONU placement which uses Lagrangian relaxation model to optimize the ONU position. Teaching Learning Based Optimization (TLBO) algorithm is proposed in [14]. This approach is a parameter-less approach, in which firstly, ONUs are placed at the center of the network grid and then further TLBO algorithm is applied to optimize the position of ONUs. In [15, 16], authors proposed an algorithm for ONU placement which gives a lower cost function value than the existing algorithm. For the same, a nature inspired algorithm, referred as the Moth Flame algorithm is used.

The literature reported so far is only focusing on network cost using ONU optimization but none of the authors reported the impact of ONU position on energy consumption of the network. The present work takes this issue into consideration and proposes a nature inspired whale optimization algorithm (WOA) for ONU placement. The algorithm not only gives optimum positions of ONUs but reduces energy consumption in terms of average communication distance among wireless routers and ONUs. The rest of the paper is organized as follows: Section 2 gives a detailed

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description of the proposed work along with algorithms. In Section 3 simulation results and their detailed analysis is done. Section 4 concludes the work with a future perspective.

2. Methodology

The proposed work is based on nature inspired algorithm namely whale optimization algorithm [17, 18] for ONU placement. This algorithm works in two steps:

1. Initial placement of ONUs followed by finding average communication distance between each of the ONU and its associated wireless routers.
2. Getting optimum position using WOA & finding average communication distance for each of the ONU.

2.1. Initial placement of ONUs followed by finding average communication distance between each of the ONU and its associated wireless routers

Firstly, wireless routers are placed randomly in the defined L×L FiWi network area. Then ONUs are placed in such a manner that with the present position of ONUs maximum wireless routers can be connected. Now set of wireless routers is formed for each of the ONU via limited hops according to Eq. (1). It means that a particular ONU can communicate to those wireless routers which are in its transmission range using limited hops.

$$ST_{WR}^{ONU} = WR_i | WH_{WR}^{ONU} \leq \mathrm{WH} \tag{1}$$

Where WR_i is indexing of wireless router, WH_{WR}^{ONU} is wireless hop from ONU to wireless router, WH is maximum wireless hop count and ST_{WR}^{ONU} is set of wireless routers connected to the ONU.

$$TD_{ONU} = \sum_{i=1}^{TN} \sqrt{\left((Onulocx_i - WRx_i)^2 + \, (Onulocy_i - WRy_i)^2\right.} \tag{2}$$

Where $Onulocx$, $Onulocy$ are the positions of ONU in x and y-axis. WRx, WRy are the position of routers in x and y-axis.

Now we find the total communication distance (TD) for each of the ONUs. Total communication distance is the summation of distances from an ONU to each wireless router connected to it which is shown in Eq. (2).

The average communication distance for an ONU (TAD_{onu}) will be

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$$TAD_{onui} = \{SUM[TD_{ONU}]/(\text{Total number of wireless routers connected to an ONU})\} \quad (3)$$

Steps involved for the first phase of the proposed work are given in algorithm 1.

Algorithm 1.

Input:	Network area of L x L length, Number of wireless routers (WR)
	Initially, WRs and ONUs placed randomly in the network in such a way that with the minimum number of ONUs all the routers can communicate
	for i = 1: ONU // ONU -Number of ONUs in the network
	Compute ST_{WR}^{ONUi} according to Eq. (1)
	for j = 1: length (ST_{WR}^{ONUi})
	K=ST_{WR}^{ONUi}(j)
	$TD_j = \sqrt{(Onulocx_i - WRx_k)^2 + (Onulocy_i - WRy_k)^2}$ according to Eq. (2)
	$TD = [TD_j]$
	end ***for***
	$TAD_{onui} = \{SUM[TD]/\text{length}\ (ST_{WR}^{ONUi})\}$ according to Eq. (3)
	end ***for***
Output	Total average communication distance for each ONU

2.2. Getting optimum position using WOA & finding average communication distance for each of the ONU

For further minimizing total average communication distance WOA is applied. WOA was proposed by Seyedali Mirjalili and Andrew Lewis [17, 18] in 2016. This algorithm was encouraged by the societal performance of Humpback Whale and its bubble net hunting strategy. The algorithm was tested on various mathematical and structural problems and it was found that the result obtained by this algorithm was much better than other existing algorithms. Moreover, its low number of parameters and lack of local optima entrapment in solving clustering problem motivated us to apply WOA for ONU placement in FiWi network.

In WOA, first, we select the best search agent and local search agent in the network. The best search agent will be that ONU whose average communication distance is minimum in the network and local search agent will be the ONU itself. Now we displace the position of every ONUs in the network according to the best search agent. The algorithm works in an iterative manner and gives those positions of ONUs corresponding to which the average communication distance becomes minimum.

1. Encircling prey mechanism: In this approach (Fig. 2) the position of ONUs are displaced according to the following Eqs:

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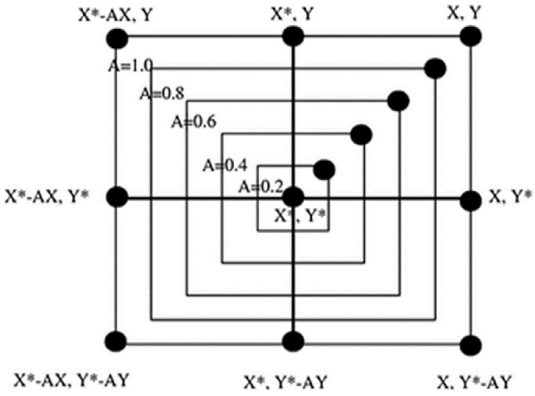

Fig. 2. Encircling prey mechanism of WOA [17]

$$D = C^*X1 - Onulocx \tag{4}$$

$$Onulocxn = X1 - A^*D \tag{5}$$

$$D = C^*Y1 - Onulocy \tag{6}$$

$$Onulocyn = Y1 - A^*D \tag{7}$$

Where X1 and Y1 are the positions of best search agent on X and Y axis. *Onulocxn* and *Onulocyn* are the new positions of ONUs. *A* and *C* are the coefficient vectors.

2. Spiral updating position: In this approach (Fig. 3) the position of ONUs are displaced according to the following Eqs:

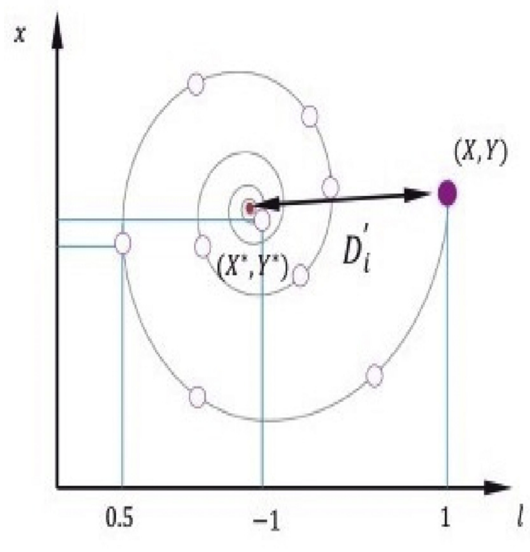

Fig. 3. Spiral updating position of WOA [17].

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$$D = X1 - Onulocx \tag{8}$$

$$Onulocxn = D.e^{bl}.\cos 2\,\pi l + X1 \tag{9}$$

$$Onulocyn = D.e^{bl}.\cos 2\,\pi l + Y1 \tag{10}$$

Where b is constant for defining the spiral shape, l is a random number between -1 to 1, D indicates the distance of the best search agent to a local search agent.

Now we make the area of each ONU in the network according to wireless routers connected to it. If WOA gives the new position of ONUs outside its area than the algorithm retains the old position of the ONUs otherwise it is relocated to the new position.

Main steps of the second stage of the proposed work are described in Algorithm 2 (a) and (b):

Algorithm 2. (a)-Displacement of ONUs with the help of whale optimization algorithm to get the optimum position (by encircling prey mechanism)

Input	The position of ONUs in the network, number of WRs
	Find X* best search agent i.e. ONU which has minimum average communication distance
	Remaining ONUs are the local search agent
	for i = 1: ONU_i
	Find the new position of ONU_i according to Eqs. (4), (5), (6), and (7) by encircling prey mechanism
	Repeat steps 2 to 10 of the algorithm 1 for finding average communication distance for each ONU i.e. TAD_{ONUi}
	end ***for***
Output	Total average communication distance for each ONU

Algorithm 2. (b)-Displacement of ONUs with the help of whale optimization algorithm to get the optimum position (by spiral updating position)

Input	The position of ONUs in the network, number of WRs
	Find X* best search agent i.e. ONU which has minimum average communication distance
	Remaining ONUs are the local search agent
	for i = 1: ONU_i
	Find the new position of ONU_i according to Eqs. (8), (9), and (10) by spiral updating position
	Repeat steps 2 to 10 of an algorithm 1 for finding average communication distance i.e. TAD_{ONUi}
	end ***for***
Output	Total average communication distance for each ONU

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3. Results & discussion

In this work, we considered FiWi network with EPON at back-end and WLAN at front end. We assumed that at back-end, MPCP (Multi-Point Control Protocol) is used for upstream transmission between ONUs and OLT while broadcasting will take place for downstream traffic. In this paper, we are optimizing the positions of ONUs and minimizing average communication distance among wireless routers and ONU. Hence we constructed front-end of FiWi consisting of ONUs and wireless routers. Transmission between wireless routers and ONUs is assumed to follow TDMA mechanism. Wireless routers are assumed to be communicating using WLAN standard such as 802.11a/g/n. In the simulation scenario, we considered 1000*1000 m^2 area for front-end in which we randomly deploy wireless routers and ONUs. We set the location of ONUs on X-axis and Y-axis and then set the range of transmission for each wireless router. The ONUs and wireless routers can communicate to each other if they are in the transmission range of each other.

We illustrate the execution of the proposed algorithm with 50 wireless routers. Fig. 4 shows the random placement of ONUs which would be the output for the first phase of the proposed algorithm. Table 1 gives the set of connected wireless routers for each of the ONUs. It is clear from the table that few wireless routers are connected to more than one ONU. In this case, ONU which is nearer to that wireless router will participate to complete the communication. Now, we find average communication distance for each of the ONU according to Eq. (2), which is shown in Table 2.

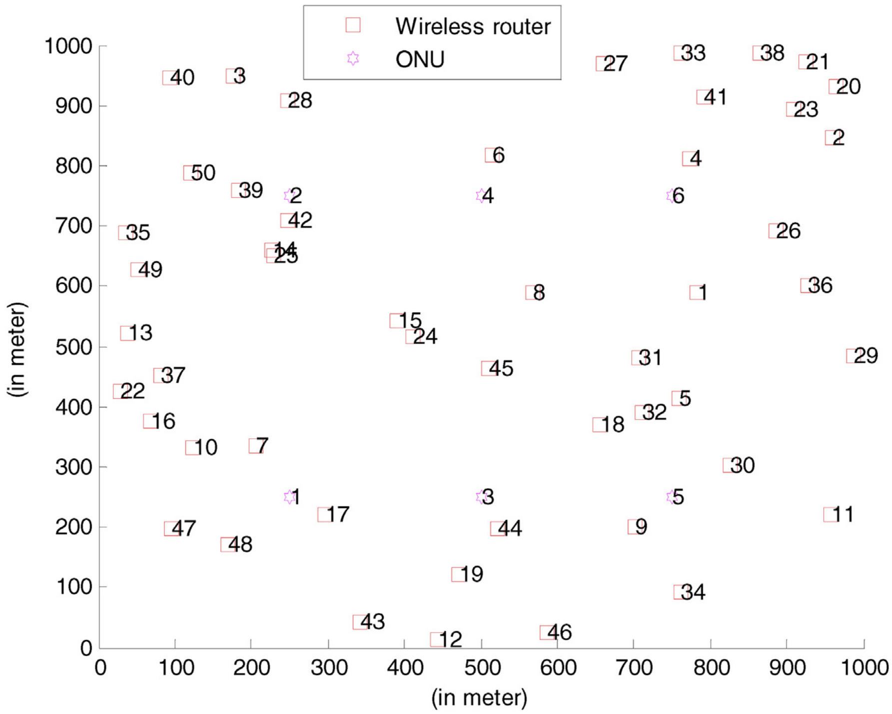

Fig. 4. Random placement of ONUs in FiWi network.

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Table 1. Set of wireless routers for each ONU.

S.No.	ONU_i	Number of Wireless Routers (WR) in set
1	ONU_1	$WR_7, WR_{10}, WR_{12}, WR_{16}, WR_{17}, WR_{19}, WR_{22}, WR_{24}, WR_{37}, WR_{43}, WR_{44}\ WR_{47}, WR_{48}$
2	ONU_2	$WR_{3,} WR_6, WR_{13}, WR_{14}, WR_{15}, WR_{24}, WR_{25}, WR_{28}, WR_{35}, WR_{39}, WR_{40}, WR_{42}, WR_{49}, WR_{50}$
3	ONU_3	$WR_5, WR_7, WR_9, WR_{12}, WR_{15}, WR_{17}, WR_{18}, WR_{19}, WR_{24}, WR_{31}, WR_{32}, WR_{34}, WR_{43}, WR_{44}, WR_{45}, WR_{46}$
4	ONU_4	$WR_4, WR_6, WR_8, WR_{14}, WR_{15}, WR_{24}, WR_{25}, WR_{27}, WR_{28}, WR_{39}, WR_{42}, WR_{45}$
5	ONU_5	$WR_5, WR_9, WR_{11}, WR_{18}, WR_{19}, WR_{29}, WR_{30}, WR_{31}, WR_{32}, WR_{34}, WR_{44}, WR_{46}$
6	ONU_6	$WR_1, WR_2, WR_4, WR_6, WR_8, WR_{20}, WR_{21}, WR_{23}, WR_{26}, WR_{27}, WR_{31}, WR_{33}, WR_{36}, WR_{38}, WR_{41}$

In the second phase of proposed work, we apply WOA by using encircling prey mechanism as shown in Fig. 5 and using spiral updating position as shown in Fig. 6. The WOA gives the new positions of ONUs which are shown in respective figures by blue circles.

Tables 3 and 4 show the set of connected wireless routers for encircling prey mechanism and spiral updating position respectively.

The average communication distance corresponding to each of the ONUs is given in Tables 5 and 6 for encircling prey mechanism and spiral updating position respectively.

Table 7 shows a comparison of the average communication distances for random placement, WOA by the encircling prey mechanism and WOA by the spiral updating position. It also gives percentage improvement for WOA by encircling prey mechanism and spiral updating position with respect to random placement. It is clear from the table that WOA by spiral updating position gives the best position of ONUs in terms of reduced communication distance as compared to the rest of the two approaches. While WOA by encircling prey mechanism performs better as compared to random placement. In proposed mechanisms, ONU occupies a new position between the current ONU position and the best ONU position. In encircling prey mechanism, new position of ONU is found diagonally while spiral updating position hunts the new position of ONU spirally. Since more network

Table 2. Average communication distance for each of the ONU.

S.No.	ONU_i	Average Comm. Distance (in meter)
1	ONU_1	272.00
2	ONU_2	263.72
3	ONU_3	383.38
4	ONU_4	301.94
5	ONU_5	205.25
6	ONU_6	328.50

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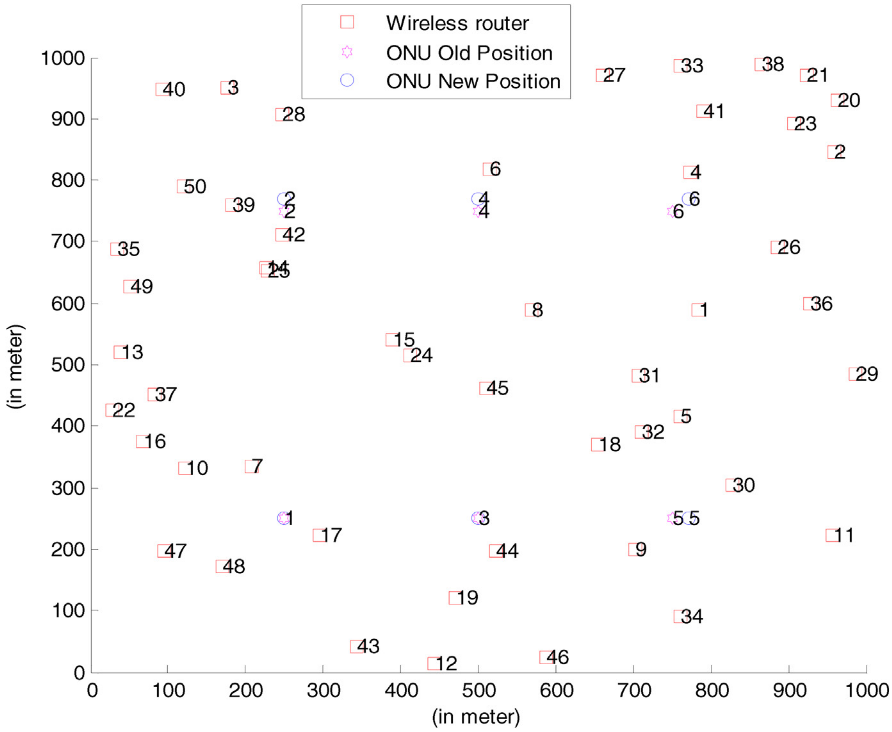

Fig. 5. ONUs placed in FiWi network by using encircling prey mechanism of WOA.

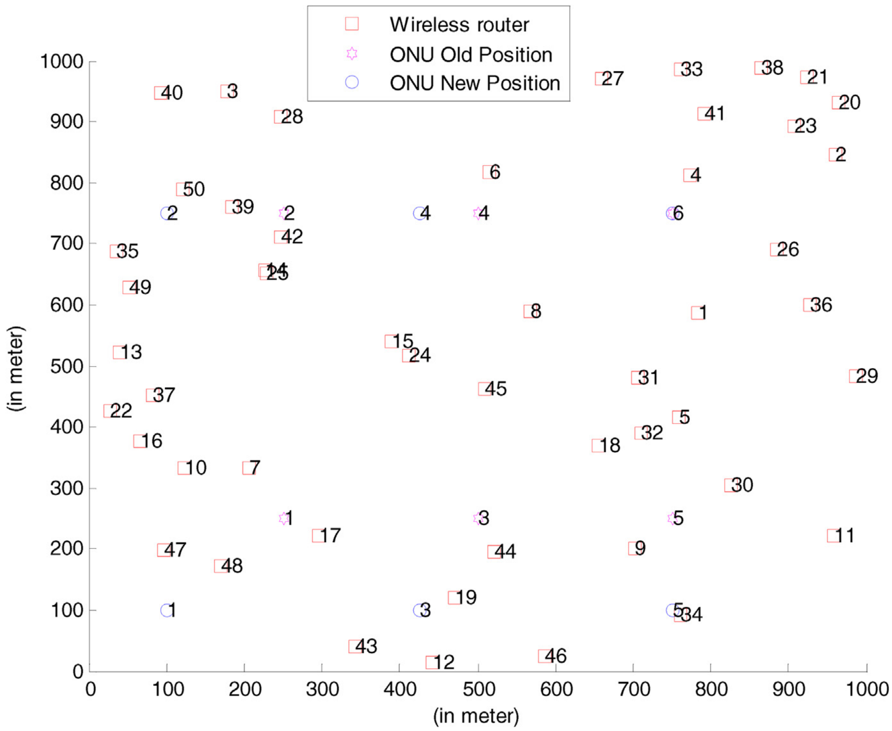

Fig. 6. ONUs placed in FiWi network by using spiral updating position of WOA.

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Table 3. Set of wireless routers for each of the ONU by using encircling prey mechanism.

S. No.	ONU_i	Number of Wireless Routers (WR) in set
1	ONU_1	$WR_7, WR_{10}, WR_{16}, WR_{17}, WR_{19}, WR_{22}, WR_{37}, WR_{43}, WR_{44}, WR_{47}, WR_{48}$
2	ONU_2	$WR_3, WR_6, WR_{13}, WR_{14}, WR_{15}, WR_{25}, WR_{28}, WR_{35}, WR_{39}, WR_{40}, WR_{42}, WR_{49}, WR_{50}$
3	ONU_3	$WR_9, WR_{12}, WR_{17}, WR_{18}, WR_{19}, WR_{24}, WR_{32}, WR_{43}, WR_{44}, WR_{45}, WR_{46}$
4	ONU_4	$WR_4, WR_6, WR_8, WR_{14}, WR_{15}, WR_{24}, WR_{25}, WR_{27}, WR_{28}, WR_{42}$
5	ONU_5	$WR_5, WR_9, WR_{11}, WR_{18}, WR_{29}, WR_{30}, WR_{31}, WR_{32}, WR_{34}, WR_{44}, WR_{46}$
6	ONU_6	$WR_1, WR_2, WR_4, WR_6, WR_8, WR_{20}, WR_{21}, WR_{23}, WR_{26}, WR_{27}, WR_{31}, WR_{33}, WR_{36}, WR_{38}, WR_{41}$

Table 4. Set of wireless routers for each of the ONU by using spiral updating position.

S. No.	ONU_i	Number of Wireless Routers (WR) in set
1	ONU_1	$WR_7, WR_{10}, WR_{16}, WR_{17}, WR_{22}, WR_{43}, WR_{47}, WR_{48}$
2	ONU_2	$WR_3, WR_{13}, WR_{14}, WR_{25}, WR_{28}, WR_{35}, WR_{37}, WR_{39}, WR_{40}, WR_{42}, WR_{49}, WR_{50}$
3	ONU_3	$WR_9, WR_{12}, WR_{17}, WR_{19}, WR_{43}, WR_{44}, WR_{45}, WR_{46}, WR_{48}$
4	ONU_4	$WR_6, WR_8, WR_{14}, WR_{15}, WR_{24}, WR_{25}, WR_{28}, WR_{39}, WR_{42}$
5	ONU_5	$WR_5, WR_9, WR_{11}, WR_{18}, WR_{19}, WR_{29}, WR_{30}, WR_{32}, WR_{34}, WR_{44}, WR_{46}$
6	ONU_6	$WR_1, WR_2, WR_4, WR_6, WR_8, WR_{20}, WR_{21}, WR_{23}, WR_{26}, WR_{27}, WR_{31}, WR_{33}, WR_{36}, WR_{38}, WR_{41}$

Table 5. Average communication distance for each ONU using encircling prey mechanism.

S.No.	ONU_i	Average Comm.Distance (in meter)
1	ONU_1	210.37
2	ONU_2	207.38
3	ONU_3	229.33
4	ONU_4	243.99
5	ONU_5	178.22
6	ONU_6	313.96

Table 6. Average communication distance for each ONU using spiral updating position.

S.No.	ONU_i	Average Comm. Distance (in meter)
1	ONU_1	144.73
2	ONU_2	198.29
3	ONU_3	129.16
4	ONU_4	187.46
5	ONU_5	187.21
6	ONU_6	308.50

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Table 7. Comparison of average communication distance and its percentage improvement for 50 wireless routers.

ONU_i, Where i = 1:6	Random Placement (Before WOA)	WOA by Encircling Prey Mechanism		WOA by Spiral Updating Position	
	Distance (in meter)	Distance (in meter)	Percentage improvement w.r.t. Random Placement	Distance (in meter)	Percentage improvement w.r.t. Random Placement
1	272.00	210.37	22.65	144.73	46.79
2	263.72	207.38	21.36	198.29	24.81
3	383.38	229.33	40.18	129.16	66.31
4	301.94	243.99	19.19	187.46	37.85
5	205.25	178.22	13.16	187.21	8.78
6	328.50	313.96	4.4	308.50	6.08

area is covered by ONU in spiral updating position as compared to encircling prey mechanism. Hence it provides optimum positions of ONUs, which results in terms of reduced average communication distance. This is to be noted that WOA by encircling prey mechanism and spiral updating position optimizes the position of individual ONU while ensuring connectivity of respective wireless routers to the corresponding ONU.

In order to validate the results obtained for 50 wireless routers, we further simulated the proposed algorithm for varying number of wireless routers i.e.40, 60, and 70, as

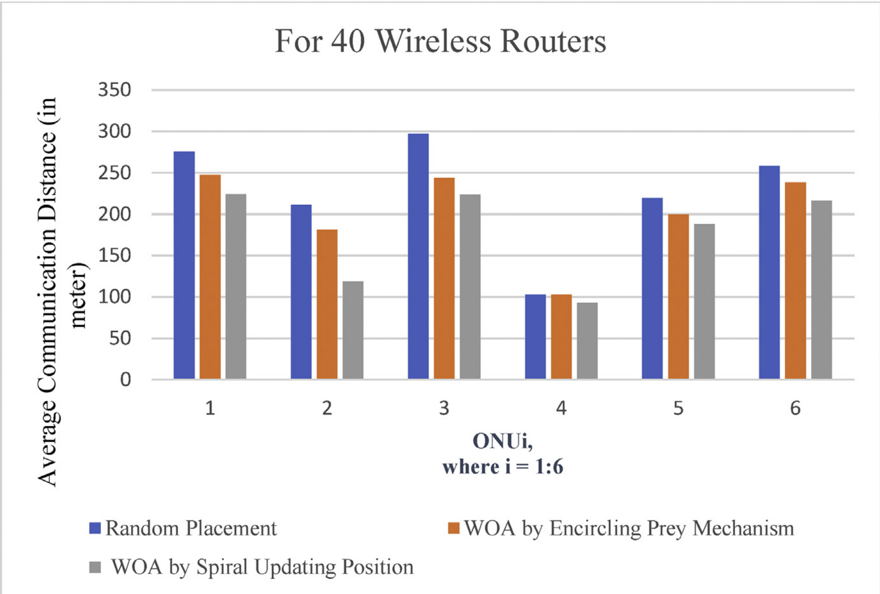

Fig. 7. Average communication distance vs. ONU_i for 40 wireless routers.

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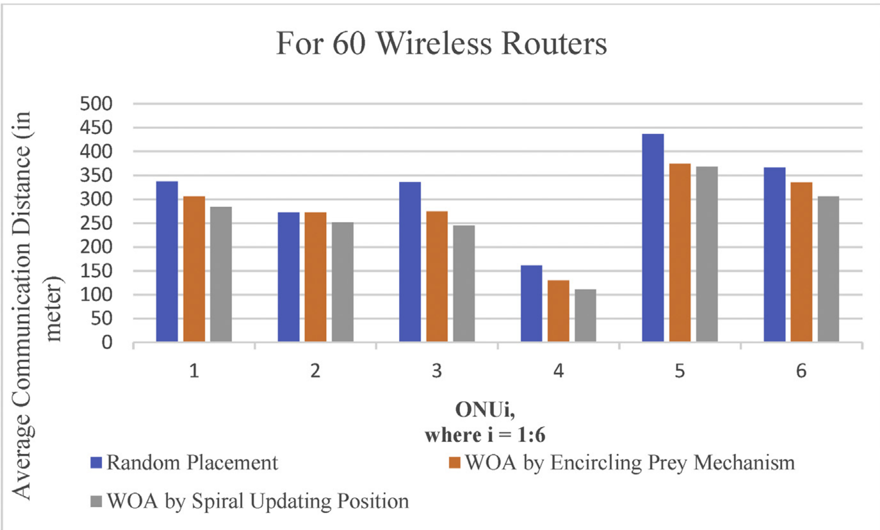

Fig. 8. Average communication distance vs. ONU_i for 60 wireless routers.

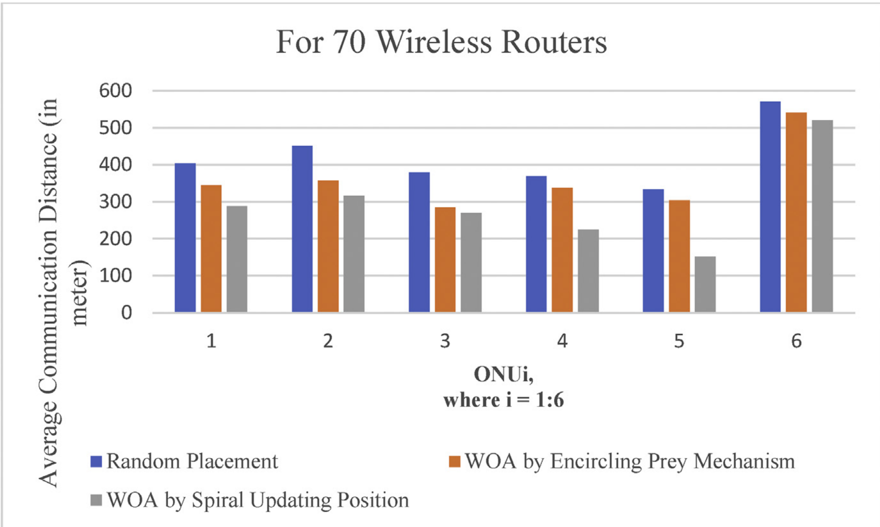

Fig. 9. Average communication distance vs. ONU_i for 70 wireless routers.

shown in Figs.7, 8, and 9 respectively. Due to varying number of wireless routers, average communication distance is also varying as shown in Figures. However for all number of wireless routers, spiral updating position performs best in terms of reduced average communication distance. Hence results lead to the same inference as for 50 wireless routers.

We also calculated percentage improvement for encircling prey and spiral updating position with respect to random placement for number of wireless routers equal to 40, 60 and 70 which is shown in Table 8. Likewise Tables 7 and 8 clearly depicts

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Table 8. Percentage improvement for the varying number of wireless routers.

ONU$_i$, Where i = 1:6	Percentage Improvement for 40 wireless routers w.r.t. Random Placement		Percentage Improvement for 60 wireless routers w.r.t. Random Placement		Percentage Improvement for 70 wireless routers w.r.t. Random Placement	
	WOA by Encircling Prey Mechanism	WOA by Spiral Updating position	WOA by Encircling Prey Mechanism	WOA by Spiral Updating position	WOA by Encircling Prey Mechanism	WOA by Spiral Updating position
1	10.2	18.66	9.1	15.78	14.44	28.59
2	14.09	43.8	0	7.56	20.97	29.88
3	18.02	24.68	18.26	27.13	25.07	29.069
4	0	9.74	19.75	30.96	8.45	39.06
5	9.02	14.34	14.33	15.66	8.9	54.57
6	7.74	16.25	8.36	16.24	5.28	8.79

the improvement for the proposed algorithm with respect to random placement. The proposed algorithm with spiral updating position gives a substantial amount of improvement as compared to the encircling prey mechanism.

These results conclude that for proposed algorithms optimum positions of ONUs are obtained in the respective network area for different number of wireless routers. Optimum positions of ONUs results in decreasing average communication distance hence energy consumed in transmission will also be reduced.

4. Conclusion

In the proposed work, we focus on minimizing the average communication distance among ONUs and wireless routers in the network. By minimizing the average communication distance, we can save the transmission energy and power required in the network. By taking this consideration we apply the proposed algorithm namely WOA by encircling prey mechanism and spiral updating position to the network. It is found that WOA by spiral updating position places all ONUs at an optimum position hence results in the most suitable optimization algorithm. Hence to develop green FiWi network WOA by spiral updating position proves itself the best candidature however WOA by encircling prey mechanism offers moderate candidature as compared to random placement.

Although, the proposed work minimizes average communication distance but does not evaluate actual energy saving in the network. Hence these calculations may be the extension of the proposed work. Further, we can calculate network performance parameters such as throughput, end to end delay and packet delivery ratio for the proposed and existing algorithms.

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Declarations

Author contribution statement

Uma Rathore Bhatt: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Anita Dhakad, Nitin Chouhan: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Raksha Upadhyay: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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