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Proposed energy efficient clustering and routing for wireless sensor network

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ABSTRACT

Wireless sensor network (WSN) is considered a growing research field that includes numerous sensor nodes used to gather, process, and broadcast information. Energy efficiency is considered one of the challenging tasks in the WSN. The clustering and routing are considered capable approaches to solve the issues of energy efficiency and enhance the network's lifetime. In this research, the multi-objective-energy based black widow optimization algorithm (M-EBWOA) is proposed to perform the cluster-based routing over the WSN. The M-EBWOA-based optimal cluster head discovery is used to assure an energy-aware routing over the WSN. The main goal of this M-EBWOA is to minimize the energy consumed by the nodes while improving the data delivery of the WSN. The performance of the M-EBWOA is analyzed as alive and dead nodes, dissipated energy, packets sent to base station, and life expectancy. The existing research such as low-energy adaptive clustering hierarchy (LEACH), hybrid grey wolf optimizer-based sunflower optimization (HGWSFO), genetic algorithm-particle swarm optimization (GA-PSO), and energy-centric multi-objective Salp Swarm algorithm (ECMOSSA) are used to evaluate the efficiency of M-EBWOA. The alive nodes of the M-EBWOA are 100 for 2,500 rounds, which is higher than the LEACH, HGWSFO, GA-PSO, and ECMOSSA.

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1. INTRODUCTION

The huge amount of sensor nodes is spatially distributed in the wireless sensor network (WSN) for monitoring the environmental or physical conditions. Each sensor in the WSN collects the signal from the finite region. This collected signal is processed by the sensor and the sensed data is broadcasted to the base station (BS) [1]–[5]. The WSNs accomplish three essential tasks such as sensing, processing, and communicating. The communication task utilizes high energy than the remaining tasks [6]. WSN is subjected to various types of limits when compared to wired networks such as restricted communication distance, limited network communication bandwidth, and limited power resources [7]. Since, the WSN uses battery energy, energy consumption and restriction of sensors are specified as essential issues in the network [8]–[10]. WSN provides beneficial performances in unattended environments, harsh environments, environments with restricted resources, and other special environments [11]. Examples of the common citizen and military applications are environmental monitoring, battlefield surveillance, industrial process control, agricultural, medical care, and monitoring fire [12]–[16].

The combination of clustering and routing is an effective approach to lessen energy usage and improve life expectancy. In clustering, the sensors are grouped into a small set of nodes referred to as clusters. From each cluster, an adequate node is chosen as cluster head (CH) which is used to aggregate the data from the cluster members of the respective cluster. However, the CH selection is considered a most challenging task because an inappropriate CH selection affects the network performances [17]–[21]. In general, the nodes in the WSN are positioned at a long distance from a destination node. Accordingly, the data packets are transmitted through multi-hops, because of coverage and distance issues, because the direct data transmission between the CH to the BS using a single-hop inter-cluster communication affects the network performance, due to communication interference and collisions [22], [23]. Therefore, an effective routing is required for increasing the broadcasting to reach nodes that are far away from the sender node [24].

Daneshvar *et al.* [25] presented the grey wolf optimizer (GWO) based cluster heads (CHs) developed for WSN. An identified energy consumption and residual energy of the sensor were used to rate the solution while choosing the CHs. The developed GWO used a similar clustering process for successive rounds for improving energy efficiency. An unwanted clustering process was avoided to prevent redundant energy consumption. The developed GWO does not consider the quality of service (QoS) metric except for the lifetime. Deepa and Suguna [26] developed the optimized QoS-based clustering with multipath routing protocol (OQoS-CMRP) to reduce energy utilization in WSN. Moreover, the CHs were selected using the modified particle swarm optimization (MPSO) for creating the clusters. The developed OQoS-CMRP achieved an effective data transmission with acceptable energy utilization. The CH achieved higher energy because of the excessive overhead caused while transmitting the data packets.

Zhao *et al.* [27] implemented the CH selection using a modified low-energy adaptive clustering hierarchy (LEACH-M) algorithm. The threshold value of LEACH-M was computed according to the network address and remaining energy. These parameters were used to achieve stable and energy-saving cluster architecture. However, an important parameter distance was not considered in this LEACH-M. Nagarajan and Thangavelu [28] developed the hybrid grey wolf optimizer-based sunflower optimization (HGWSFO) to choose CHs based on energy and distance. The GWO’s coefficient vectors improved the efficiency of exploitation whereas the inefficiency in the GWO’s global search was solved by the SFO using the adjustable step size of the plants. The selection of CH is done only by using energy consumption and distance. Anand and Pandey [29] used the genetic algorithm (GA) to select CH for gathering the data from the remaining nodes, where it considered the distance and energy parameters. Further, the particle swarm optimization (PSO) algorithm depends on optimal routing paths that are chosen for all relay nodes to send data to the BS. The relay node selected by GA-PSO supports and facilitates communication between the sink and CH, which enhances energy efficiency. However, the GA does not consider an adequate fitness function during CH selection. Srinivasalu and Umadevi [30] developed the energy-centric multi-objective Salp Swarm algorithm (ECMOSSA) to accomplish the optimal CH and route discovery. The developed ECMOSSA minimized the node’s energy consumption that used to improve life expectancy. The ECMOSSA does not consider the network coverage during CH selection. If ECMOSSA considered the network coverage, then it is further used to enhance the scalability of the WSN.

The limitations found from the related works are higher energy consumption and inappropriate fitness function which affects the overall performance of the WSN. If the developed routing algorithm returns the path with a higher distance, then it causes higher energy consumption. Accordingly, the dead nodes are increased over the network which results in high packet loss. In order to overcome the aforementioned limitations, an effective cluster-based routing using a multi-objective-energy based black widow optimization algorithm (M-EBWOA) is developed for improving the energy efficiency of the WSN. The contributions accomplished in this paper are specified: i) An appropriate CH selection from the normal nodes is achieved by using the M-EBWOA followed by an optimal route via the CHs to BS also identified by using the same M-EBWOA according to the distinct fitness measures, and ii) The developed cluster-based routing decreases the node’s consuming energy while broadcasting the data. The life expectancy of the WSN is improved by designing the energy efficient WSN.

The remaining portions of this paper are arranged as: section 2 clearly explained the M-EBWOA based CH selection and routing path formation. The outcomes of the M-EBWOA are given in section 3. Further, the conclusion is made in section 4.

2. M-EBWOA METHOD

In this M-EBWOA, a WSN with improved energy efficiency is developed for improving life expectancy and data delivery. This M-EBWOA has three important processes such as selection of CH, cluster generation, and routing path generation. The M-EBWOA-based CH selection from the normal nodes and multi-hop routing is utilized for decreasing the energy usage of the nodes. The flowchart of the M-EBWOA is shown in Figure 1.

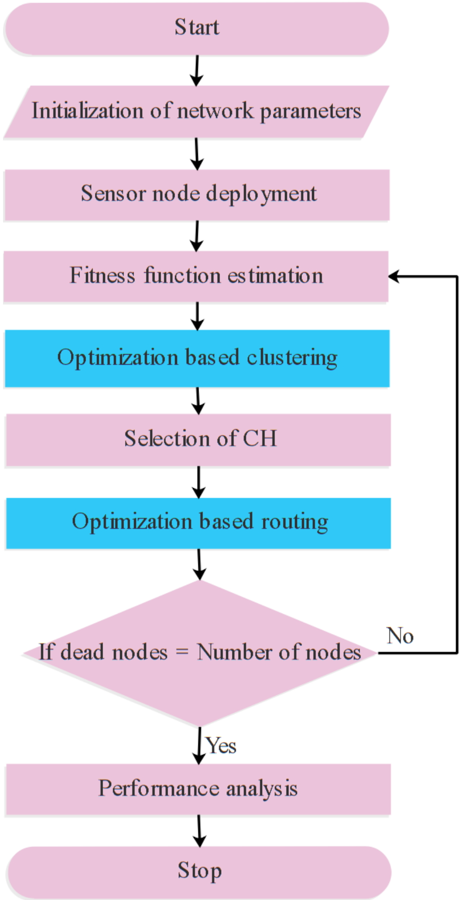

Figure 1. Flowchart of the M-EBWOA

2.1. Deployment of sensor

At first, the sensors are randomly organized in the network area. Next, the CHs from the normal nodes are selected using M-EBWOA, and clusters are formed in the network. Subsequently, the routing is also done by M-EBWOA. The CH selection and routing are explained in the following section.

2.2. Cluster head selection using M-EBWOA

In this section, appropriate CHs from the normal nodes are selected using the M-EBWOA. The typical black widow optimization algorithm (BWOA) is one of the meta-heuristic approaches which is transformed as M-EBWOA for CH selection [31]. Generally, the BWOA imitates the mating behavior of black widow spiders, since the black widow is a group of species in Latrodectus. The process of choosing CH has three different steps which are explained as follows.

2.2.1. Representation and initialization

In this step, the candidate solutions are termed spiders which denotes the group of candidate CHs from the normal sensors. The dimension of widow is equal to the number of CHs. Each widow location is initialized with the ID of a random node among 1 and N, where the total number of sensors in the network is N. The (1) shows the i^{th} widow of the M-EBWOA.

$$x_i = (x_{i,1}, x_{i,2}, .., x_{i,NCH}) \quad (1)$$

where the location of the widow is $x_{i,d}$, $1 \leq d \leq NCH$ specifies the random candidate sensors among the total sensors.

2.2.2. Iterative process of CH selection using M-EBWOA

Generally, the BWOA imitates the mating behavior of black widow spiders since the black widow is a group of species in Latrodectus. The remaining processes that exist in the M-EBWOA are movement and pheromone update.

a. Movement

The motion of the spider is modeled as liner and spiral as shown in the (2).

$$\vec{x}_i\,(t+1) = \begin{cases} \vec{x}_*(t) - m\vec{x}_{r1}\,(t) & if\ rand() \le 0.3, \\ \vec{x}_*(t) - cos(2\pi\beta)\,\vec{x}_i\,(t) & in\ other\ case \end{cases} \quad (2)$$

where the new location of the spider is represented as $\vec{x}_i\,(t+1)$ that specifies the spider's motion; the best spider from the population is denoted as $\vec{x}_*(t)$; the floating value generated between the range of $[0.4, 0.9]$ is denoted as m; random integer number created in the interval of 1 and maximum size of search agents are denoted as $r1$; the selected $r1$ search agent is represented as $\vec{x}_{r1}$, with $i \neq r1$; a random float number generated in the range of $[-1.0, 1.0]$ is denoted as β and the current search agent is represented as $\vec{x}_i\,(t)$.

b. Pheromones

The pheromones emitted by the spider is essential for the courtship-mating. In this M-EBWOA, the male spiders are highly responsive for the sex pheromones received from the healthy females as those female spiders have higher fertility. Additionally, this is used to eliminate the risky mating attempt with hungry cannibal females. The male black widow spider prefers highly fertile females instead of female spiders with cannibalism. Hence, the male black widow prefers only the female black widow with higher pheromone. The calculation of spiders' pheromone rate is shown in (3).

$$Pheromone = \frac{fitness_{max} - fitness\,(i)}{fitness_{max} - fitness_{min}} \quad (3)$$

where the best and worst fitness in the current population is represented as $fitness_{min}$ and $fitness_{max}$ respectively, whereas the current fitness of spider i is denoted as $fitness\,(i)$. The results of (3) are the normalized value in the range of $[0,1]$. If the pheromone level of a female black widow is low, then it is referred to as a cannibal and it is replaced with another spider as shown in (4).

$$\vec{x}_i\,(t) = \vec{x}_*(t) + \frac{1}{2}[\vec{x}_{r1}\,(t) - (-1)^{\sigma} \times \vec{x}_{r2}\,(t)] \quad (4)$$

where female spiders with low pheromone is denoted as $\vec{x}_i\,(t)$; random values created between the 1 and total amount of black widows are denoted as $r1$ and $r2$, $r1 \neq r2$ and the random binary number is denoted as σ. The calculation of the fitness function used to measure the pheromone rate is explained in the following section.

2.3. Derivation of fitness to choose the CH

The fitness functions considered in the M-EBWOA for selecting optimal CHs are 1) residual energy (f_1), 2) intra cluster distance (f_2), 3) distance between the CH and BS (f_3), 4) node degree (f_4) and 5) node coverage (f_5). These fitness functions are converted into a single objective as shown in the (5),

$$fitness = \gamma_1 \times f_1 + \gamma_2 \times f_2 + \gamma_3 \times f_3 + \gamma_4 \times f_4 + \gamma_5 \times f_5 \quad (5)$$

where $\gamma_1, \gamma_2, \gamma_3, \gamma_4$ and γ_5 denotes the weighted parameters allocated to each fitness parameter.

– During communication, the energy utilization of CH becomes high because it performs various tasks such as packet receiving, aggregation, and broadcasting over the network. Hence, the sensor with a large amount of energy is wanted as CH and the residual energy is expressed in (6).

$$f_1 = \sum_{i=1}^{NCH} \frac{1}{E_{CH_i}} \quad (6)$$

where the E_{CH_i} is the remaining energy of the i^{th} CH.

– The distance measures are considered in the fitness because the node's energy dissipation is mainly based on the transmission distance over the network. Hence, the node with less transmission distance is preferred for decreasing the energy whereas (7) and (8) expresses the distance measures.

$$f_2 = \sum_{j=1}^{NCH} \left(\sum_{i=1}^{I_j} dis(N_i, CH_j)/I_j \right) \quad (7)$$

$$f_3 = \sum_{i=1}^{NCH} dis(CH_i, BS) \quad (8)$$

where distance from i^{th} node to j^{th} CH and distance from i^{th} CH to BS are represented as $dis(N_i, CH_j)$ and $dis(CH_i, BS)$ respectively; An amount of normal sensors in the cluster j is specified as I_j.

– The amount of normal nodes belonging to the next-hop node is node degree which is expressed in (9). The node consumes less energy when it has less node degree in the network.

$$f_4 = \sum_{i=1}^{NCH} I_j \quad (9)$$

– Further, the node coverage is the last fitness function which is expressed in (10). This increases the network coverage and helps to achieve successful data transmission to the BS.

$$f_5 = \frac{1}{N}\sum_{i-1}^{N} r(N) \quad (10)$$

where $r(N)$ represents the radius covered by the node in a network.

2.4. Cluster formation

The normal sensors are assigned to the selected CHs in the cluster creation phase. Here, the cluster is created according to the residual energy and distance whereas the potential function used to form the cluster is expressed in (11).

$$Potential\ of\ sensor\ (N_i) = \frac{E_{CH}}{dis(N_i, CH)} \quad (11)$$

The formulated potential function is used to assign the normal sensor node to the CH with a smaller routing distance and larger residual energy.

2.5. Routing path generation using M-EBWOA

The generation of the routing path is also done by using the M-EBWOA method. The optimal fitness functions such as distance, residual energy, and node degree are considered for optimizing the generation of the transmission path. The steps processed in this routing stage are mentioned as:

– At first, the spiders are initialized with the possible paths from the source CH to the BS. Each spider dimension is equal to the number of intermediate nodes that exist in the path.
– Next, the position and pheromone update is done according to the fitness of each path. The information about position and pheromone update is already explained in the previous sections. The (12) shows the fitness used in the M-EBWOA based route generation.

$$fitness = \varphi_1 \times \sum_{i=1}^{NCH} \frac{1}{E_{CH_i}} + \varphi_2 \times \sum_{i=1}^{M} dis(CH_i, BS) + \varphi_3 \times \sum_{i=1}^{M} I_j \quad (12)$$

where φ_1, φ_2 and φ_3 are weighted parameters assigned to each objective of route generation. This helps to identify the optimal path; hence the energy consumption of the nodes is minimized by using this M-EBWOA based routing which helps to improve the life expectancy.

3. RESULTS AND DISCUSSION

The design and simulation of the M-EBWOA method are done using MATLAB R2018a whereas the system is operated with the i5 processor and 6GB RAM. The implemented M-EBWOA is used to develop an energy-efficient WSN for enhancing life expectancy. The specification parameters of the M-EBWOA method are mentioned in Table 1.

Table 1. Simulation parameters

Parameter	Value
Network size	200 × 200 m
Number of nodes	100
Energy to operate transmitter and receiver	0.5 J
Amplification energy to broadcast for a less distance	10 pJ
Amplification energy to broadcast for a huge distance	0.001310 pJ
Size of packet	4000 bits

3.1. Performance analysis

The M-EBWOA is analyzed based on alive and dead nodes, dissipated energy, packets sent to BS, and life expectancy. Here, the classical algorithm LEACH is developed using the same specifications as Table 1 for evaluating the M-EBWOA method.

3.1.1. Alive nodes

The set of sensors that contains energy to broadcast the packets is defined as alive nodes. Figure 2 illustrates the alive nodes comparison of the M-EBWOA method with LEACH. From the analysis, it is decided that the M-EBWOA method achieves higher alive nodes than the LEACH. For the instance, the alive nodes of the M-EBWOA at 1,000 round is 100 whereas the LEACH has 39 alive nodes. The lesser energy dissipation of the nodes using the M-EBWOA helps to retain the nodes alive for a longer time. However, the direct data transmission from the node to the BS leads to high energy dissipation which minimizes the alive nodes.

3.1.2. Dead nodes

In general, the dead nodes in the WSN are inversely proportional to the alive nodes. The set of nodes which exhausted while broadcasting the data is specified as dead nodes. The comparison of dead nodes for M-EBWOA with LEACH is shown in Figure 3. From the figure, it is known that the M-EBWOA has fewer dead nodes than the LEACH. For example, the dead nodes of the M-EBWOA at 1,000 round is 0 whereas the LEACH has 61 dead nodes. The single hop transmission of the LEACH leads to higher energy consumption which resulted in higher dead nodes. On the contrary, the multi hop clustering and routing developed by the M-EBWOA are used to minimize the dead nodes.

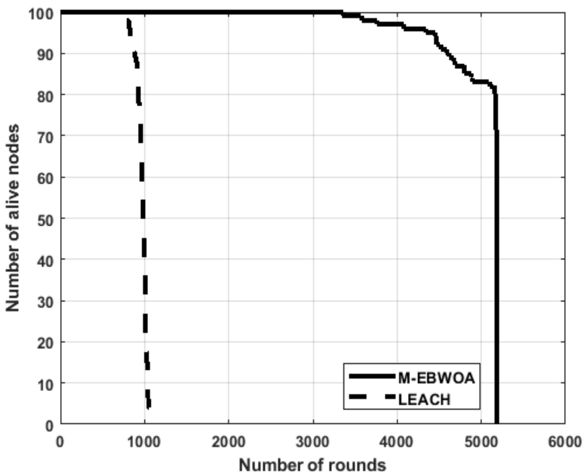

Figure 2. Comparison of alive nodes for M-EBWOA

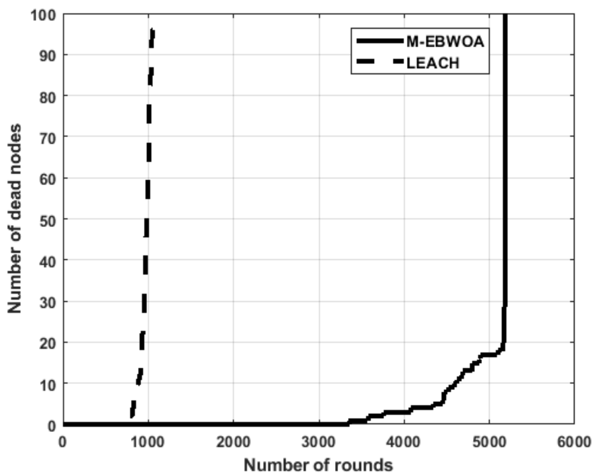

Figure 3. Comparison of dead nodes for M-EBWOA

3.1.3. Dissipated energy

Dissipated energy is the amount of energy consumed by all nodes while broadcasting and receiving the data packets over the network. Figure 4 shows the dissipated energy comparison of the M-EBWOA method with LEACH. From the analysis, it is concluded that the M-EBWOA method achieves less dissipated energy than the LEACH. For example, the dissipated energy of the M-EBWOA at 1,000 round is 9.42 J whereas the LEACH consumed energy of 49.36 J. The distance, node degree, and network coverage considered in the M-EBWOA is used to minimize the energy dissipation in WSN.

3.1.4. Packets sent to base station

This performance measure shows the number of packets successfully collected by the BS. The evaluation of packets collected by the BS for M-EBWOA with LEACH is shown in Figure 5. From Figure 5, it is known that the M-EBWOA receives a high amount of packets than the LEACH. For example, the packets sent to BS for the M-EBWOA at 1,000 round is 4×10^7 whereas the LEACH has 3.84×10^7 dead nodes. The fitness metrics considered in the M-EBWOA are used to improve the data delivery. The residual energy considered in the M-EBWOA is utilized for eliminating the node failure and link failure that supports improving the data delivery.

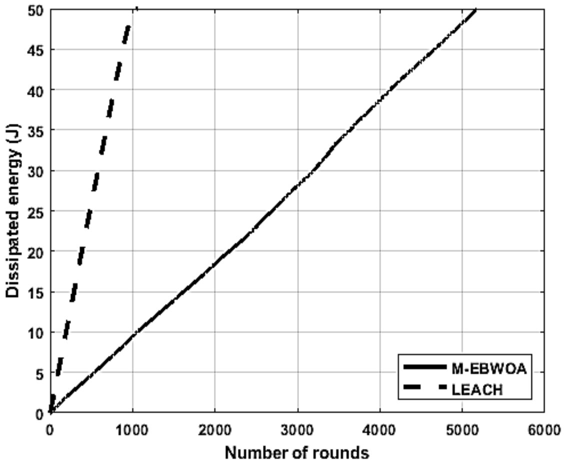

Figure 4. Comparison of dissipated energy for M-EBWOA

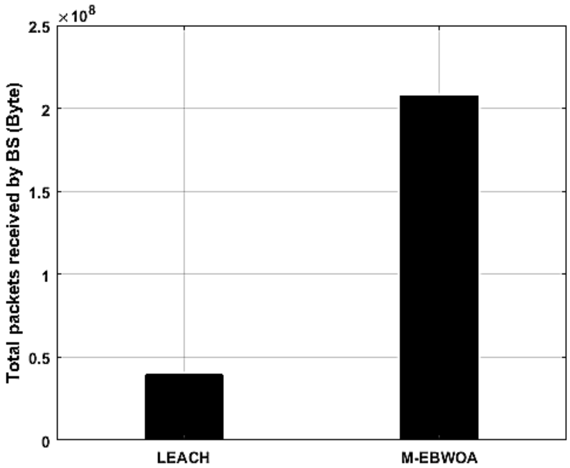

Figure 5. Comparison of packets sent to BS for M-EBWOA

3.1.5. Life expectancy

Life expectancy is used to measure how much time the network withstands during data transmission. This life expectancy is analyzed by three parameters such as i) the first node dies, ii) half node dies, and iii) the last node dies which are represented as first node die (FND), half node dies (HND), and last node dies (LND) respectively. Figure 6 shows the life expectancy comparison of the M-EBWOA method with LEACH. From the analysis, it is known that the M-EBWOA method achieves higher life expectancy than the LEACH. The development of energy-efficient WSNs using the M-EBWOA is used to increase life expectancy.

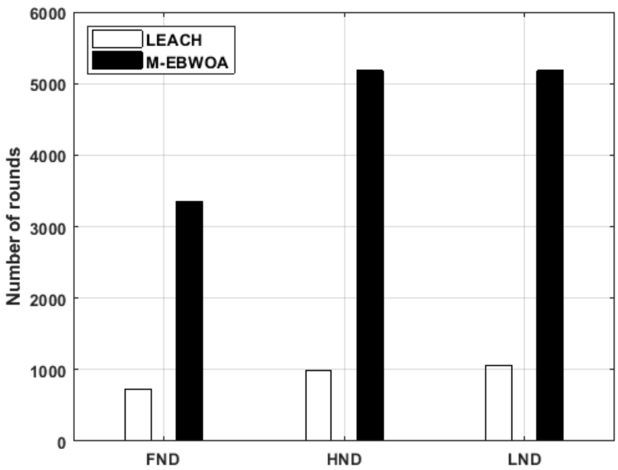

Figure 6. Comparison of life expectancy

3.2. Comparative analysis

This section shows the comparison of the M-EBWOA method. Existing research such as HGWSFO [28], GA-PSO [29], and ECMOSSA [30] are used to evaluate the M-EBWOA method. Table 2 provides the comparative examination of the M-EBWOA with HGWSFO, GA-PSO, and ECMOSSA. From the comparison, it is concluded that the M-EBWOA achieves better performance because of its optimal fitness function. The existing research on HGWSFO and GA-PSO achieves lesser performances because it does not consider an adequate fitness function. Moreover, the ECMOSSA failed to consider the network coverage during the CH selection which leads to affecting the energy efficiency of WSN. An appropriate CH selection and multi-hop routing developed by the M-EBWOA is used to minimize the energy efficiency of the WSN. Therefore, an energy-efficient WSN developed using the M-EBWOA improves the alive nodes and energy consumption of the overall network.

Table 2. Comparative analysis of M-EBWOA method

Performance measures	Methods	Rounds 500	1,000	1,500	2,000	2,500
Alive nodes	HGWSFO [28]	100	100	100	100	0
	GA-PSO [29]	100	100	96	61	37
	ECMOSSA [30]	100	100	100	0	0
	M-EBWOA	100	100	100	100	100
Dead nodes	HGWSFO [28]	0	0	0	0	100
	GA-PSO [29]	0	0	4	39	63
	ECMOSSA [30]	0	0	0	100	100
	M-EBWOA	0	0	0	0	0
Dissipated energy (J)	GA-PSO [29]	35	70	110	125	140
	ECMOSSA [30]	15.6630	30.9425	44.9563	50	50
	M-EBWOA	4.6676	9.4295	13.8985	18.4515	23.0091
Packets sent to BS (Byte)	GA-PSO [29]	4×10^4	8×10^4	8.5×10^4	12×10^4	14×10^4
	ECMOSSA [30]	2.1×10^4	4.3×10^4	6.6×10^4	7.5×10^4	7.5×10^4
	M-EBWOA	2×10^7	4×10^7	6×10^7	8×10^7	1×10^8

4. CONCLUSION

In this research paper, the M-EBWOA-based CH selection and routing path identification are done for improving the WSN's life expectancy. The M-EBWOA is optimized with unique fitness values while selecting the CHs followed by the clusters formed using the potential function including energy and distance. After that, the route from the source CH to the BS is identified using the M-EBWOA, since the selection of the node with high residual energy as the next hop avoids the node failure which results in higher data delivery. Moreover, the M-EBWOA with distinct fitness measures improves energy efficiency and life expectancy. The results illustrated that the M-EBWOA outperforms well than both LEACH, HGWSFO, GA-PSO, and ECMOSSA. The alive node count of the M-EBWOA is 100 for 2,500 rounds which is huger than the LEACH, HGWSFO, GA-PSO, and ECMOSSA. In the future, the novel optimization algorithm can be used for improving the performance of the WSN.

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