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An Efficient Metaheuristic Technique for Wireless Sensor Network Integrated Micro Grid Environment Using Improved Whale Optimization Algorithm (Iwoa)

***Abstract*:** Wireless Sensor Network (WSN) nodes require careful power management to maintain long-term operation without regular battery changes. Battery replacement can be challenging and expensive in a microgrid scenario where sensors may be installed in remote or inaccessible areas. To extend the life of WSN nodes, energy-efficient design and power management strategies should be used. A potential strategy for effectively monitoring, controlling, and managing the distributed energy resources (DERs) inside a microgrid is the incorporation of WSNs with microgrids. This research work uses Improved Whale Optimization Algorithm (WOA) for optimizing the routing and performance. The humpback whale's hunting style served as the inspiration for the WOA, a metaheuristic optimization algorithm. WOA is an optimization technique that is used with MG and WSNs. During the optimization phase, WOA establishes a balance between exploitation and exploration. To increase the lifespan of a WSN in a microgrid, effective energy management is frequently needed. When considering the dynamic energy availability from renewable sources and the energy requirements of the microgrid components, WOA is used to optimise energy allocation and routing in WSNs. This may lead to increased energy efficiency and longer network longevity. The IWOA attains 97.5% PDR that is higher than the existing state of art techniques.

Keyword: Optimization, routing, energy consumption, lifetime, micro grid, WSN, hunting, and whale.

I. INTRODUCTION

Nowadays people are concentrating on distributed renewable energy resources because the energy consumption and utilization of natural resources are developing a lot. Microgrids (MGs) present in the organized distributed renewable energy resources will offer the benefits like flexibility and power grid disconnection [1, 2]. Hakimi & Moghaddas-Tafreshi (2014) considered MGs as the best solution for energy generation to satisfy the demand [3]. In microgrid unpredictability and irregular supply of energy is caused because of alteration in environmental conditions. The researcher (2013) stated that these environmental conditions create problems in microgrid operations in the process of efficient control realization and distributed renewable energy resources management [4]. Network, devices, microgrid environment and resources are monitored essentially in the management of effective operation [5, 6]. Scientific decision making in microgrids are discussed. Complete data information of current, voltage, humidity, temperature and frequency are required to organize microgrids [7].

In order to collect data information different sensors are used. For the analysis of data, several data type sensors are combined together in a microgrid monitoring system [8, 9]. The knowledge of distribution of power and loss of power is calculated to control the renewable energy resources utilization. Fault probability in microgrid is detected efficiently and quickly through humidity, density of smoke, frequency, temperature and other conditions [10, 11]. Various microgrid monitors are prepared with respect to various target points and these microgrids are monitored by several sensors. The target points are monitored by wired sensors in conventional methods of microgrid. Wired communication has difficulties like distance, lack of communication, requirement of maintenance and high capital cost [12].

It is applied in various applications because of its easier deployment and sensor node‘s multi-functionality. So, WSN is applicable in healthcare, tracking target, and monitoring environment. Target data is sensed by sensor nodes in every application and the information collected is transmitted to the sink node to proceed the operations [13].

For solving these monitoring problems, a suitable sensor for the monitoring process is organized instead using all sensor types for a single MGs. . Small coverage set is achieved by the data collection requirement. Network

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connectivity is lost because of reduced sensor utilization, and this problem is solved by coverage sets by various sensor cooperation. Monitoring process is improved by a single sensor and controls the consumption of energy in wireless sensors.

The advantages of wireless communication have been frequently categorized for distributed microgrids application [14]. WSN are applied for microgrids in a vast operating area. Remote monitoring of power system operation, fault identification and self- healing are achieved through WSN. Multiple techniques of wireless data communication are used by microgrids like Bluetooth, Zigbee, GSM and GPRS. The wireless technology is effective in conserving energy with less data rate in a shortrange. IEEE 802.15.4 standard is called Zigbee and it is widely used in microgrids. The researcher used a small size, cost effective and easy to install Zigbee. 20, 40, 100, 250 kbps are the data rates supported in the range of 30- 70 meters. Bandwidth of zigbee is low in the range of 20-250 kbps. It is not an issue for WSN applications as the data message to be exchanged is small, so the bandwidth available is enough [15].

The effective use of any resources can be achieved by optimization techniques. These techniques are called as metaheuristic optimization for few procedures at high level. Every point is converged to an individual point by individual objective function to find optimal solutions. Non deterministic polynomial time problems are addressed by the process of optimization. By using the deterministic method Non deterministic polynomial time problems are reduced. Depending on the problems, optimization techniques can be maximized or minimized by objective function given. If the points are converged by two or more points, then the optimal solution is more and the best point is selected by a multi-objective function .

II. RELATED WORKS

Zhao et al. (2021) proposed MMF/SVD-QR Mixed Matrix Decomposition Approach to optimize WSN: this approach reduces the gathered redundant information through the sensor in a coherent time. It removes redundant sensors and collects a small number of nodes to approximate raw data output to WSN; this process not only decreases the data required, but it also saves consumption of energy greatly and extends the life of the network. Experimental results verify that raw sensor data is more effective. The reconstruction data compression approaches from the WSN demonstrated that this method is effective [16].

Kaushal & Basak (2020) suggested a unique artificial neural network (ANN)-based control strategy for power quality control by IEEE/IEC standards. This method works swiftly, smoothly, and consistently, and its performance is compared to that of proportional-integral (PI) and fuzzy-PI controllers. Line impedance, communication delay, demand response, and off-nominal circumstances are used to validate the realistic microgrid topology. The proposed control methodology is examined in a realistic microgrid structure, and simulation results confirmed the proposed controller's efficiency under various test circumstances to select an ANN library [24].

One such bio-inspired metaheuristic algorithm, called Jelly Fish Search Optimisation (JFSO) [17], is based on how jellyfish in the water find food. When applying the Hybrid Artificial Bee Colony and Firefly Algorithm (HABCFA) to upgrade the network lifespan, clustering techniques are thought to be very ideal for efficiently using the resources with minimal overhead [18]. Author proposes Long Range Algorithm (LoRa) [19]. The wireless sensor network (WSN) connected to the Internet of Things (IoT) uses sensor nodes (SNs) with constrained hardware and energy sources for wide-area monitoring applications. The difficulties of remote access and the scattered nature of such a network make the task of designing an energy-efficient WSN more complex.

In terms of microgrid development various factors like converter design, MPPT algorithms, modes of operation of microgrids, stability improvements and energy management systems are largely addressed in many researches. Monitoring and control techniques have not been addressed much.

In the MG system, WSN are deployed to monitor different parameters such as voltage, current, power, frequency, temperature, wind speed, solar irradiation etc. WSN plays a vital role in communicating the data to the control unit. The ability of WSN to send data needs to be concentrated more in MGs. In WSN-based MG systems multi-channel Medium Access Control (MAC) protocols are utilized. The performance of WSN multi-channel protocols for homogeneous networks is not examined in detail though it tenders easy integration and coordination, in addition to consistency. To improve the communication parameters different optimization techniques have been used. Although several researches have been carried out for the development of the WSN in MG the following limitations identified are delay in communication, loss in data transmission, more energy consumption, less security over data, and reliability of the network.

III. IMPROVED WHALE OPTIMIZATION ALGORITHM (IWOA) FOR WSN WITH MG

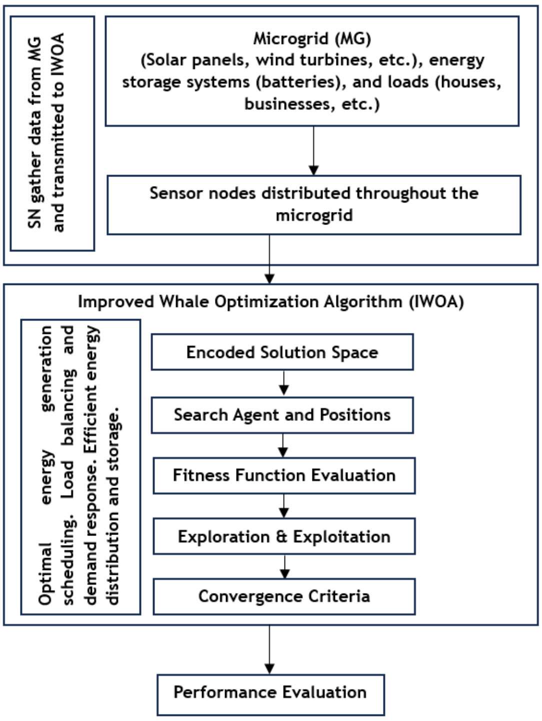
WSNs can be installed everywhere across the microgrid to gather information on energy production, consumption, storage capacity, and environmental factors. WSNs can make it easier to automate and control different microgrid components. The resilience of the electrical system is improved by the combination of WSNs with microgrids. WSNs are able to recognise and react to changes in energy supply, demand, or environmental factors, enabling the microgrid to be quickly adapted and reconfigured. The monitoring, control, optimization, and resilience benefits of integrating IWOA in WSNs with microgrids are substantial, and they support the efficient and long-term operation of distributed energy resources. This section explains the methodology of proposed methodology.

Network Model

In microgrid transmission networks cables are used for long distance communication. The drawbacks associated with wired communication like long distance, power loss, and data transmission can be overcome by WSN. For efficient transmission and to improve coverage area of the network, sensor deployment is adopted as the principle. So, many power lines, equipment and electrical appliances are incorporated by the sensor nodes. Transmission of data is carried out with minimum cost in WSN. For smooth transmission of data, suitable structural and functional characteristics are present in the microgrid with a distributed sensor network. Microgrid and WSN are integrated and built by an edge computing network with tree structure. Figure 3.1 presents the overall architecture of WSN.

From the figure 3.1 explains the overall architecture of Wireless Sensor Network integrated MicroGrid, the sensor nodes gather data from microgrid and transmitted to IWOA, the algorithm undergoes the optimal energy generationscheduling, load balancing and demand response, efficient energy distribution and storage.

Main grid with relatively independent characteristics relates to a WSN by the technology of edge computing. Various generation stations are interconnected with feeders in microgrids. Detection of fault and monitoring of status is equipped by the sensor nodes in every feeder. Automatic meter reading and price of electricity in the real scenario is monitored by a sensor node present in the user device.



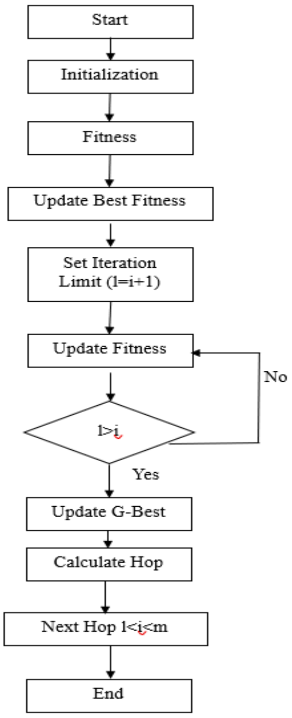


Figure 3.1. Overall Architecture of WSN integrated MGFigure 3.2. Flowchart of IWOA

Electrical parameters like current, voltage, frequency and power are monitored in microgrids by involving the sensor nodes in the power line. Group of sensor nodes in a particular location forms a cluster. In every cluster, a sensor node having maximum energy acts as the CH. It receives data from every sensor node. Many sensor nodes and cluster heads are incorporated in each feeder. Cluster head is aggregated with data by the sensor nodes and the data is sent to the sink node which is a data storage unit. All the data gathered is transmitted to the BS from the sink node.

Routing with Whale Optimization

Finding the shortest route to transfer data is an important process in WSN. Different optimization techniques are used to achieve the shortest route. In the proposed research whale optimization is used, as they are the largest predators. A mathematical model was established with a meta-heuristics method and its performance was evaluated.

Encircling prey

Prey‘s location was detected by Humpback whales and it encircles the prey, because of the unknown character of the search space. Prey‘s position (target D) was established and represented in the following Equation 1 and 2

$\widetilde{D} = \left|C\vec{X}(t) - \vec{X}(t)\right|$------------------------(1)

$\vec{X}(t = 1) = \vec{X}(t) - \vec{A}.\vec{D}$------------------------(2)

Where, t defines present iteration, coefficient vectors are represented by A and C, X defines search agent and is used to find the significant solution for identification of prey‘s position. By using the equations (3) and (4) coefficient vectors are identified.

$\vec{A} = 2\vec{a}.\vec{r} - \vec{a}$------------------------(3)

$\vec{C} = 2.\vec{r}$------------------------(4)

Where r is the radius of the sensing region. In accordance with the count of iteration, the constant a is linearly decreased in the Equation 3.3 to evaluate the phase of exploration. Multipath routing method was incorporated to identify the alternative paths for every node destination present in the network.

Information analysis linked to spectrum availability of radio communication involves probability-based routing. By the probability model incorporation, decision of routing is obtained by calculating the network‘s routing probability G(P) value which is represented in Equation (5).

$G(P) = \begin{cases} 1, & p \leq p_0 \\ 0, & p > p_0 \end{cases}$------------------------(5)

The successful connection is denoted by 1 and unsuccessful connection is represented by 0. pis the node‘s probabilistic value, p0 is the node‘s threshold probability. Optimization technique is included in the approach of multi-path optimization to evaluate the communication between end-to-end users for maximizing the performance of the channel. WSN‘s average path $f(v_i)$ is expressed below in the Equation 6.

$f(v_i) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(p_i - p_{avg})^2/2\sigma^2}$------------------------(6)

Communication path of the node present in WSN is indicated by variance $2\sigma^2$ and mean value of data transmitted in WSN is provided by p_{avg}. Efficient path for communication in microgrid integrated with WSN can be identified using the energy of the node E(N) as expressed in the Equation 7.

$E(N) = \rho d\lambda$------------------------(7)

Where ρ is transmitted data packets, d is number of nodes and λ denotes other factors like weather, temperature and humidity. Communication distance, CH energy level and number of transmitted data packets are optimized.

Algorithm 1. Improved Whale Optimization Algorithm (IWOA) for WSN with MG

```
Initialize:
    Initialize WSN nodes and Microgrid components
    Initialize parameters for IWOA (population size, maximum iterations, etc.)
Main Loop:
    for each generation G from 1 to MaxGenerations do
        Evaluate Fitness of WSN nodes and Microgrid components using appropriate fitness function
        Update Positions of Whales (Microgrid Components) in the Search Space:
        for each whale in population do
            Update whale's position based on its current position and other parameters
        end for
        Evaluate Fitness of Updated Microgrid components
        Update Microgrid Configuration:
        for each microgrid component in population do
            if Fitness(microgrid component) < Fitness(WSN nodes) then
                Replace corresponding WSN node with the microgrid component
            end if
        end for
    end for
Select Final Solutions:
    Apply non-dominated sorting to obtain Pareto fronts (if using multi-objective optimization)
    Choose solutions from Pareto fronts based on desired trade-offs
Output the selected solutions as the final optimized configurations
Perform Post-Optimization Energy Management (if applicable):
Adjust microgrid component operation based on optimization results
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Route Construction

Data transmission is performed by establishing communication with CH and Sensor Nodes (SN). To establish the communication proper routing between CH and SN is required. The data transmission includes ID and calculates the maximum energy level of nodes as E_{max} inside the link of wireless communication. CH and sink nodes are built on the foundation ofenergy estimated and the CH receives the broadcasted information. The flow chart representation of the IWOA model proposed is represented in Figure 3.2.

In the IWOA model Sink node, Hop, particle size, iteration i and equivalent number of CHs are initialized before starting the search. Sink node is assigned with the random number in range of 0 and 1 with initial routing value RR_i. Whales will start to search for prey and calculate their fitness and best fitness value is updated. Evaluating the function of fitness is based on the structure of the inter-cluster network quality. When the level of energy of the CH becomes lower than the level of energy of the remaining sensor nodes, a new CH is formed. The residual lifetime (Resi_Life Time) of the old CH in the network is calculated.

From the figure 3.2. explains the flowchart of IWOA which evaluates the fitness of the nodes and selects the best nodes for hop of the transmission. After updating the best value, iteration limit l is set, again the search continues and updates the fitness. If the set limit is greater than iteration i, the best routing probability is updated, else the limit value is incremented. The data transmitted count (hop m) is calculated for every iterations and the search stops. Residual life period of the network is estimated on the foundation of fitness function and it is expressed in Equation 8.

$$F_X = Net_{LT}\text{------------------------}(8)$$

Net_{LT} is the average residual lifetime of all the CH in the network. The lifetime of the network is achieved by maximizing the fitness function F_X.

The significant solution is provided by the particle having the largest F_X. Search agent vector position, probability node and best probability node (X_i, P_i and $P_{i\text{-best}}$) were updated for various time instances of particle size in the iteration process as follows.

$$X_{ki} = \begin{cases} 0 \ to \ 0.01 & if X_{ki} \le 0 \\ 1 & if X_{ki} \le 0 \end{cases}\text{------------------------}(9)$$

$$P_i = \begin{cases} F_i, Fitness(F_i) > FitnessX(F_{i-best}) \\ F_{i-best}, FitnessX(F_i) \le FitnessX(F_{i-best}) \end{cases}\text{------------------------}(10)$$

$$P_{i-best} = \begin{cases} F_i, Fitness(F_i) > FitnessX(G_{best}) \\ G_{best}, FitnessX(F_i) \ge FitnessX(G_{best}) \end{cases}\text{------------------------}(11)$$

Where F_i is the fitness of a particle, $F_{i\text{-best}}$ is the particle's best fitness, G_{best} is the best solution identified by continuing this process till reaching the maximum iteration. The routing information forms the basis for the CH and CH's next hopping, represented as CH_NextHop(CH_i). In each CH_i the value of i lies between 1 and m. Position of the elements chosen in CH_Next(CH_i) is denoted by $X_{i,d}$ position. The CH_NextHop(CH_i) and CH_Next(CH_i) values are obtained. Integer calculation among CH_NextHop(CH_i) and CH_Next(CH_i) is denoted by L and is expressed in Equation 12.

$$L = ceil(X_{i,d}, CH\_NEXT(CH_i)\text{------------------------}(12)$$

Entire routing in the inter cluster network is processed between CH and sensor node depending on radii of CH in the network. Using Equations (13) and (14) the minimum lifetime and maximum lifetime are estimated.

$$\min_{lifetime}(N) = \min\{Resi\_lifetime(CH_i) | \forall CH_i \in CH\}\text{------------------------}(13)$$

$$\max_{lifetime}(N) = \max\{Resi\_lifetime(CH_i) | \forall CH_i \in CH\}\text{------------------------}(14)$$

The actual energy level of the node is obtained by the Equation 15

$$E_{actual}(CH_i) = E_{max}\left(1 - \frac{\max_{lifetime}(N) - Resi\_lifetime(CH_i)}{\max_{lifetime}(N) - \min_{lifetime}(N)}\right)\text{------------------------}(15)$$

E_{max} is necessary for the improvement of stability of the network and dynamic adjustment in the network. The calculated actual energy level of the node is utilized for repeating the iteration process to identify the next CH.

IV. RESULT AND DISCUSSION

In this section, parameters used for analysis are presented. The data transmission parameters of the sender and receiver in the IWOA network are considered for optimization. The values used for simulation are expressed in Table 4.1. The performance is compared with the existing algorithms namely JFSO, HABCFA, and LORA. The performance metric namely packet delivery ratio and network lifetime.

Table 4.1 Settings for Simulation

Simulation Parameter	Value
Tool	Network Simulator 2

Data Size	250KB
Maximum Coverage Area of CH	200sqm
Initial Energy	4J
Initial CH Energy	15J
Sensor Node	1000
CH	100
Coverage Area of SN	25sqm
Area Size	500*500 m

From the above table 4.1 explains the simulation parameter for the transmission, the sensor nodes energy should be minimum 4 joule, cluster heads minimum energy should be 15 Joule, sensor nodes of coverage area is 25sq.m and area size of 500*500m.

Packet Delivery Ratio

A statistic used to assess the dependability of data transmission in a network, particularly in wireless communication systems, is the packet delivery ratio (PDR), also known as packet success rate (PSR) or packet reception rate (PRR). In relation to the total number of packets transmitted, it calculates the proportion of correctly delivered packets. A network with a higher PDR is more dependable and effective because more packets are successfully delivered to their destinations without being lost or damaged during transmission.

Table 4.2 Comparison of PDR

Node	IWOAMG	JFSO	HABCFA	LORA
50	97	92	90	86
100	91	88	85	80
150	88	83	80	75
200	86	80	78	71
250	82	77	74	68

Table 4.3. Comparison of Network Lifetime

Node	IWO AMG	JFSO	HAB CFA	LORA
50	100	100	100	97
100	99	98	95	92
150	97	93	90	87
200	96	90	88	85
250	92	87	84	79

From the above table 4.2 explains the Packet Delivery Ratio arise during the transmission. IWOAMG is comparison with existing JFSO, HABCFA and LORA, in that IWOAMG has increases the packet delivery ratio comparatively.

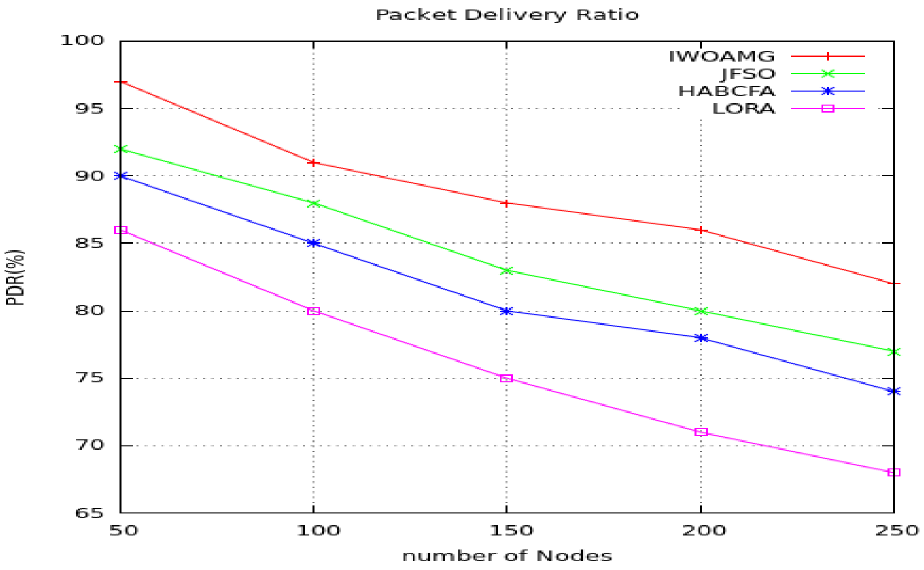

Figure 4.1. Comparison of PDR

From the figure 4.1., at the initial distance of 50 nodes, IWOAMG has the highest PDR of 97%, followed by JFSO with 92%, HABCFA with 90%, and LORA with 86%.

Network Lifetime

The network lifetime in Wireless Sensor Networks (WSNs) refers to the duration for which the network can operate effectively before the depletion of the energy resources of its individual sensor nodes. WSNs consist of a large number of small, low-power sensor nodes that collaborate to gather data from the environment and transmit it to a central location, often called the base station or sink. The network lifetime is a critical factor in the design and operation of WSNs because the energy resources of the sensor nodes are usually limited. These nodes are often battery-powered, and replacing or recharging batteries may not be practical in certain deployment scenarios, such as remote or harsh environments. Therefore, prolonging the network lifetime is crucial to maximizing the usefulness and efficiency of the WSN.

From the table 4.3 explains the Network life time arise during the transmission. IWOAMG is comparison with existing JFSO, HABCFA and LORA in that IWOAMG has increases the network life time comparatively.

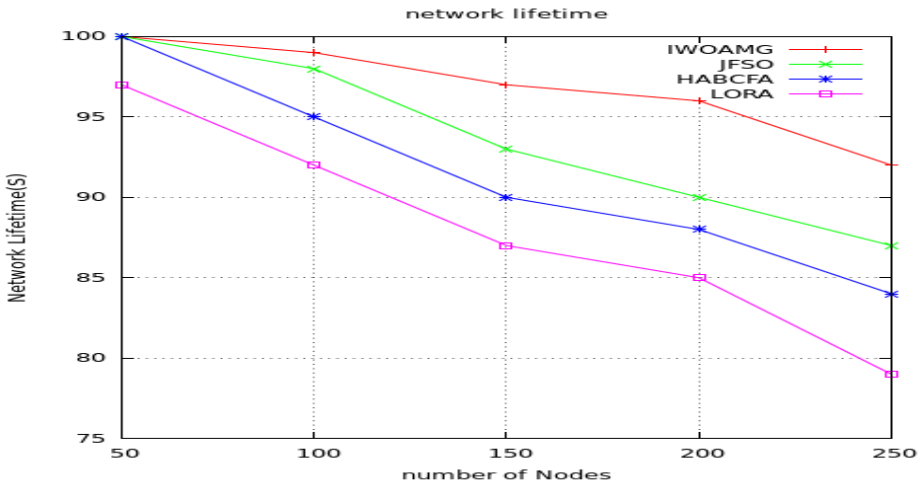

Figure 4.2. Comparison of Network Lifetime

From the figure 4.2, the network lifetime of the proposed approach is comparatively high for different node count which outperforms the existing techniques.

V. CONCLUSION

Wireless Sensor Network (WSN) integrated microgrid context, the creation and use of an effective metaheuristic approach have enormous promise for improving the effectiveness and performance of such systems. This approach may successfully handle the complicated issues related to WSN integration and microgrid management by utilising metaheuristic algorithms, which are potent optimisation approaches inspired by natural processes. For a Wireless Sensor Network (WSN) integrated microgrid environment, the use of an effective metaheuristic method utilising an upgraded Whale Optimisation Algorithm (WOA) shows promising promise in optimising the performance and efficiency of such systems. This approach provides a solid answer to the complicated problems related to WSN integration and microgrid management by combining the benefits of metaheuristic algorithms and the improvements of the upgraded WOA. In a microgrid, a WSN's lifespan is extended and efficient energy management is typically required. WOA is used to optimise energy allocation and routing in WSNs while taking into account the dynamic energy availability from renewable sources and the energy requirements of the microgrid components. Longer network lifetime and improved energy efficiency may result from this. The IWOA achieves 97.5% PDR, which is greater than current state-of-the-art methods.

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