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An Innovative Fuzzy-Enhanced Black Widow Spider Optimization for Energy-Efficient Cluster Communication Through the Selection of the Ideal Cluster Head

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Abstract

This paper presents a novel approach to enhance energy efficiency in cluster-based wireless sensor networks (WSNs) by integrating fuzzy logic with the black widow spider optimization (BWSO) algorithm. The focus of the suggested fuzzy-enhanced BWSO approach is on cluster head selection, which is essential for lowering energy consumption and enhancing network performance. The program uses fuzzy logic to assess a number of factors, including network density, node proximity, and energy levels, guaranteeing a more flexible and astute decision-making process. Simulation results show that in terms of energy efficiency, network longevity, and communication overhead, the suggested approach performs noticeably better than conventional clustering strategies. This creative strategy opens the door for more sustainable communication solutions in WSNs while also addressing the shortcomings of current techniques. Interest in studying WSNs has significantly increased as a result of the advancement of wireless communications. Numerous sensor nodes that are digitally attached to one another comprise a WSN. Sensor node components are responsible for observing their environment, processing the information they get, and interacting with different sensor nodes. These sensor nodes collaborate systematically to accomplish a common goal. This suggests using the fuzzy-enhanced black widow spider (FEBWS) algorithm to improve WSN energy efficiency. The effectiveness of the proposed approach is evaluated using the NS-2 simulator. The suggested strategy performs better when the ideal parameter values are predicted using the hyper-parameter tuning technique. Performance is assessed using a number of parameters, including energy efficiency, packet loss, end-to-end latency, network longevity, and energy usage. For the sake of comparative study, the ACI-GSO algorithm, MWCSGA, RNN-LSTM approach, and Particle Swarm Optimization (PSO) algorithm are the other approaches that are contrasted with the recommended FEBWS algorithm.

Keywords: Wireless sensor network, clustering, cluster head, energy efficiency

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INTRODUCTION

Global technological improvements have led to the expansion of wireless sensor networks (WSNs), which are used in tracking systems, environmental conditions, and disaster management. An enhanced sharing technique reduces energy usage and increases network longevity. The clustering technique lowers the energy required to convey the data. WSN collects real-time data through a combined network via the Internet of Things (IoT). WSN collaboration in networks is enhanced, and energy consumption is reduced in the World Wide Web of Things [1]. Data propagation is halted within a specific network to safeguard user information. There are a few low-cost nodes with batteries and communication capabilities, including sensing frameworks in wireless sensor networks (WSN) [2]. The sensor nodes were unique and distinct from each other. Because they cannot replace the battery, they are given, and the nodes can transmit data for as long as they have received energy. Prior to making the choice, the primary device collects information from each node and analyzes it to yield the intended result.

To prolong the network life, power reduction leads to improved network performance. The sensor nodes can act as an intermediary between the Base Station (BS) and WSN, or they can transfer directly to the BS. The gateway method prolongs battery life, lowers the excessive consumption of energy, and regulates the flow of information. Gray wolf optimization (GWO) monitors sensor nodes and minimizes energy cracking to increase efficiency [3, 4].

WSNs are suitable for the agricultural industry owing to their energy efficiency. Precision agriculture (PA) is used in the agriculture sector to process and regulate crops under particular environmental conditions. Large-scale agricultural WSN acquisition impedes network traffic flow. However, this method can be decreased [5].

Appliances utilized in homes also have the advantages of WSNs. The network lifetime may be shortened because of the severe workload of the nodes. Thus, the cluster head (CH) assigns each node to the network on an individual basis. The sensor nodes can monitor key events by sounding an alarm, prompting the user to take action. By analyzing the latency that happens during data transmission, the DDC (dynamic duty cycle) approach more effectively controls the network lifetime.

The crucial and basic sensor nodes are connected to WSN and are utilized and processed in numerous applications. Furthermore, WSN may connect with several networks, which decreases the requirement for sensor nodes and increases the network longevity. The indoor localization strategy introduces the IoT. Indoor accuracy was measured using a camera, VLC, and infrared bases [6–8].

Sensor nodes use radio signals to correlate their signals and determine their positions. This study developed a clustering technique for energy-efficient optimum communication. WSNs have become a crucial technology for a range of applications such as environmental monitoring, smart cities, healthcare, and industrial automation. These networks comprise multiple sensor nodes that work together to gather, process, and transmit data. However, one of the primary challenges facing WSNs is energy efficiency, as sensor nodes are typically battery-powered and must operate for extended periods without human intervention. Therefore, optimizing energy consumption is crucial for prolonging network lifespan and ensuring reliable communication [9–11].

Clustering is a widely adopted technique in WSNs that enhances energy efficiency by organizing sensor nodes into groups, each managed by a designated cluster head. The cluster head is responsible for aggregating data from its members and transmitting them to the sink or base station. Choosing an optimal cluster head is crucial because it significantly affects energy consumption and overall network performance. Conventional approaches to cluster head selection typically depend on static criteria or straightforward decision-making processes, which may struggle to adapt to changing network conditions and differing energy levels of nodes [12–15].

To address these limitations, this study proposes an innovative approach that combines the black widow spider optimization (BWSO) algorithm with fuzzy logic. The BWSO algorithm, inspired by the hunting behavior of black widow spiders, provides a robust optimization mechanism that can effectively navigate the solution space to identify optimal cluster heads. By incorporating fuzzy logic, our method enhances decision-making through the evaluation of multiple, often uncertain, criteria, such as node energy levels, distance to the base station, and node density. This leads to a selection process that is more flexible and adaptive [16–18].

In this paper, we outline the design and implementation of the fuzzy-enhanced BWSO algorithm, evaluate its performance through simulations, and compare it with traditional clustering methods. The findings demonstrate that our approach significantly improves energy efficiency and network longevity, contributing to the advancement of sustainable communication solutions in WSNs [19–20].

PROPOSED METHODOLOGY

The fuzzy-enhanced black widow spider (FEBWS) method, an energy-efficient clustering technique, is discussed in this section to provide the best possible data packet transmission between the sender and recipient. Initially, the network is set up with n sensor nodes, which are then joined together with their neighbors to form method clusters. Increasing the network lifetime is necessary for sending data over energy-efficient and optimal node paths.

The proposed FEBWS algorithm selects the best CH among the cluster nodes and sends data to the BS via the CHs. Choosing an energy-efficient approach to the BS improves the communication inside and between clusters. Figures 1 and 2 show the energy efficiency of the clustering approach.

RESULTS AND DISCUSSION

This section suggests a Fuzzy-Enhanced Balanced Weight Scheduling (FEBWS) algorithm for increasing energy efficiency in WSNs. Performance, delivery of packet ratio, network lifetime, and energy efficiency are among the performance metrics used to evaluate the performance of the proposed FEBWS algorithm using the NS-2 simulator. Table 1 contains information on the simulation parameters, and the following subsections offer concise justifications for the results.

Numerous methods, such as the suggested "FEBWS method," MWCSGA, ACI-GSO algorithm, RNN-LSTM model, and PSO algorithm, are used to investigate the energy efficiency of the nodes in Figure 3. In the experiment, 100 nodes were used to achieve 92 percent efficiency. The proposed FEBWS algorithm demonstrated greater efficiency than the other existing methods, with energy efficiency rates of 77%, 86%, 70%, and 62% when utilizing the ACI-GSO, MWCSGA, RNN-LSTM, and PSO algorithms, respectively.

The ACI-GSO, MWCSGA, RNN-LSTM, PSO, and suggested FEBWS strategies are used in the end-to-end delay study, as shown in Figure 4. The end-to-end latency of the FEBWS algorithm was extremely low. WSN energy efficiency increased as a result of the suggested FEBWS algorithm, reducing the end-to-end latency to 88 ms.

Figure 5 shows the packet drop for several algorithms, such as the ACI-GSO methodology, PSO, RNN-LSTM model, MWCSGA method, and FEBWS strategy. The proposed FEBWS algorithm achieved a low packet drop rate of 130 packets, which significantly enhanced performance. In comparison, the ACI-GSO, MWCSGA, RNN-LSTM, and PSO algorithms resulted in packet drops of 350, 160, 540, and 630, respectively.

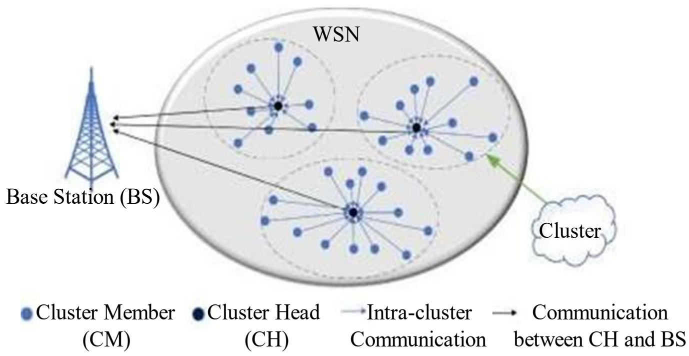

Figure 1. The structure of the suggested energy-efficient clustering method.

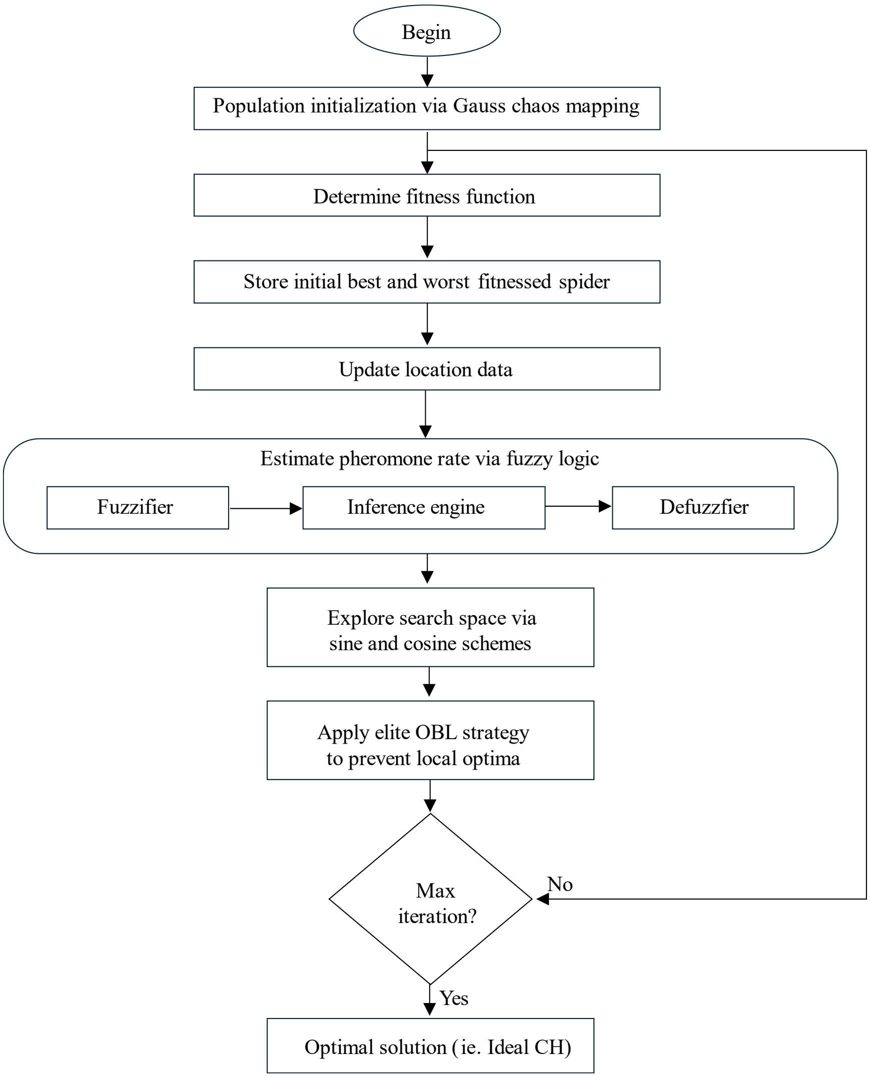

Figure 2. Flow diagram of FEBWS algorithm.

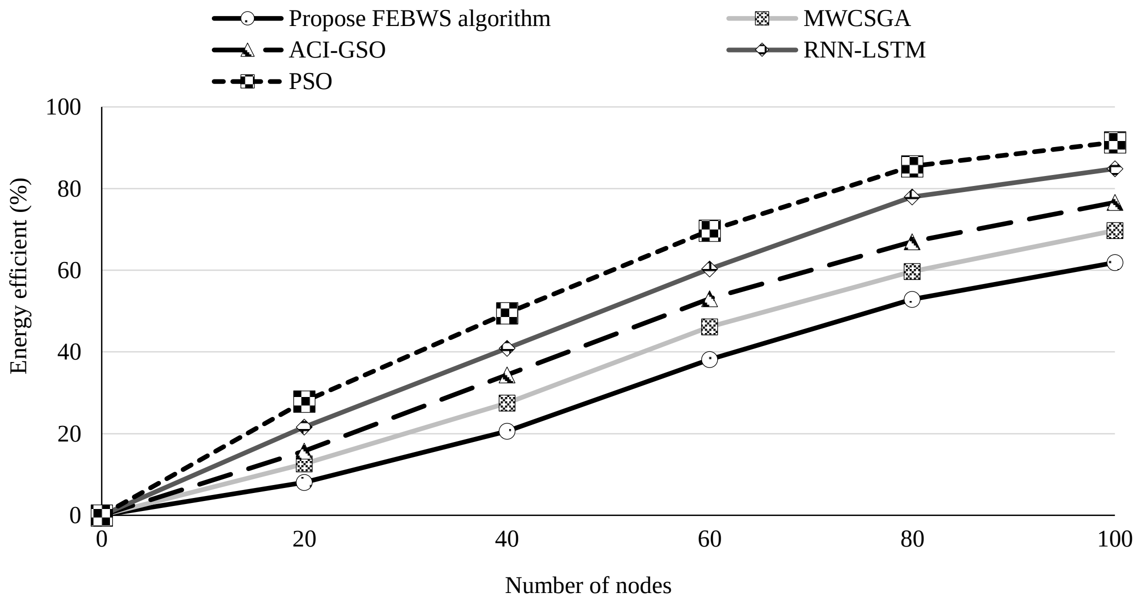

Figure 3. Comparative evaluation based on energy efficiency.

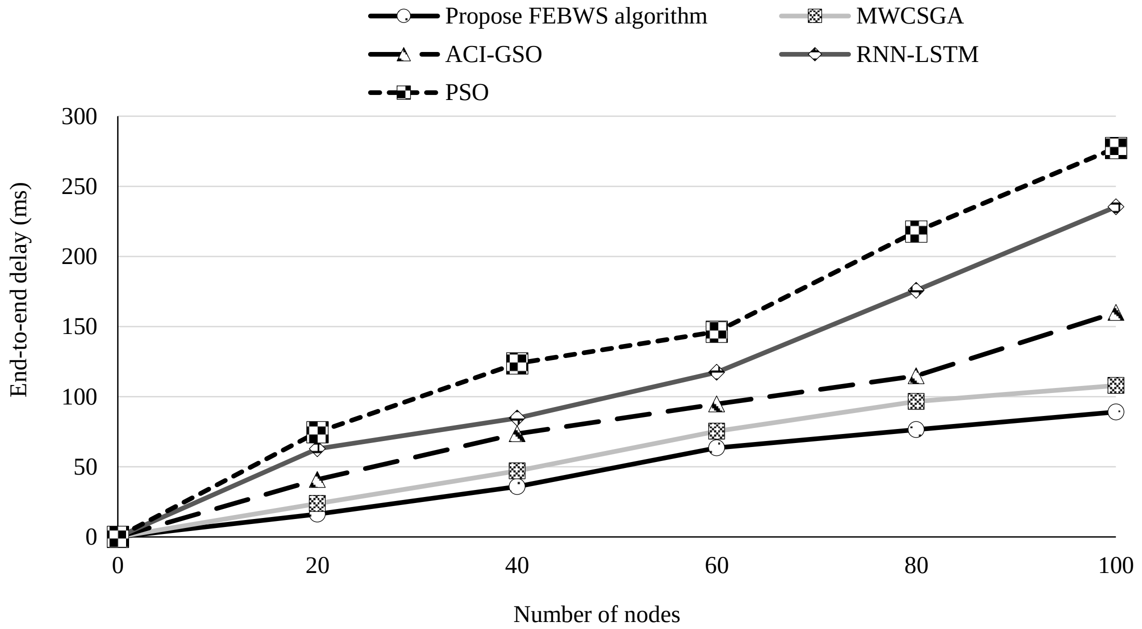

Figure 4. Comparative evaluation of end-to-end delays.

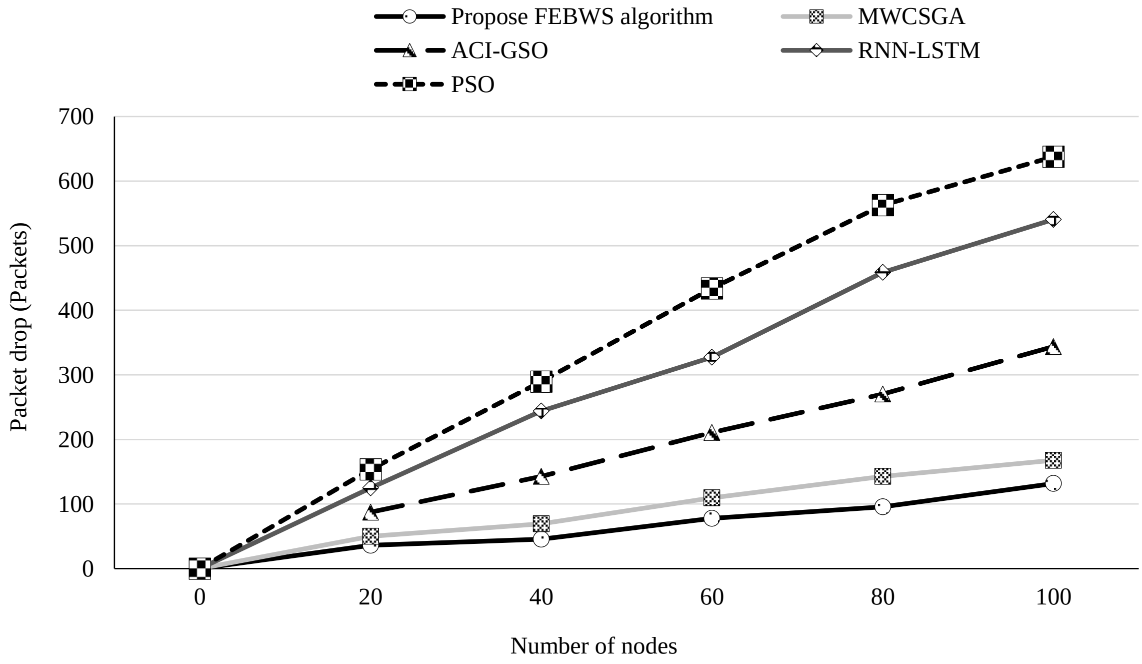

Figure 5. Comparative evaluation of packet drop.

Table 1. Simulation parameters.

S.N.	Simulation parameters	Ranges
1	Simulator	NS-2.34
2	Total number of nodes	100
3	Coverage area	1000×1000
4	Initial energy	0.5 J
5	Packet size	4000 bits
6	Simulation period	100 ms
7	CH percentage	0.05

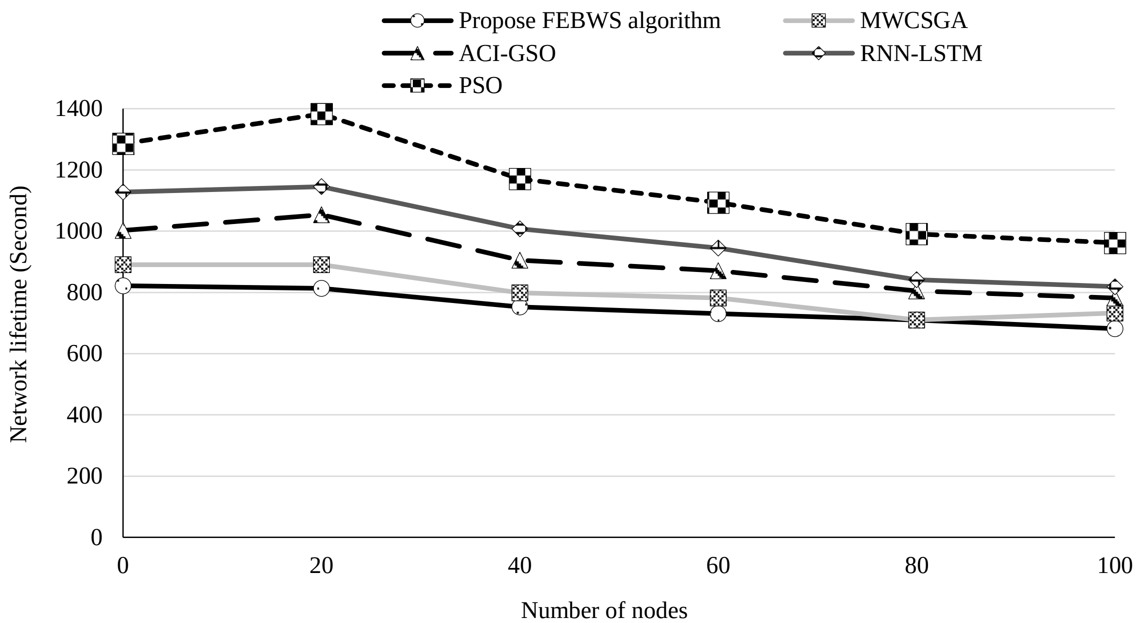

Figure 6. Comparative evaluation of network lifetime.

Figure 6 compares the network lifespan of the suggested FEBWS algorithm with those of a number of other already employed techniques, including the ACI-GSO procedure, MWCSGA, RNN-LSTM approach, and PSO algorithm. With an extended network lifetime of 1400 s, the proposed FEBWS algorithm improved WSNs energy efficiency of WSNs. According to the ACI-GSO, MWCSGA, RNN-LSTM, and PSO algorithms, the network lifespan is displayed in this graph at 1130 s, 1185 s, and 820 s, respectively.

CONCLUSION

This suggests that the FEBWS algorithm increases WSN energy efficiency. Using the hyper-parameter tuning process to predict the optimal parameter values improves the performance of the proposed strategy.

A number of metrics, such as packet loss, energy usage, end-to-end latency, network lifetime, and energy efficiency, are used to evaluate performance. To conduct a comparative study, the proposed FEBWS method was compared with the ACI-GSO, MWCSGA, RNN-LSTM, and PSO algorithms.

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