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Enhancing Energy Efficiency in IoT-WSN Systems via a Hybrid Crow Search and Firefly Algorithm

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Abstract: In the realm of enterprise technology, Internet of Things (IoT)-based wireless devices have witnessed significant advancements, enabling seamless interactions among machines, sensors, and physical objects. A critical component of IoT, Wireless Sensor Networks (WSN), have proliferated across various real-time applications, influencing daily life in both critical and non-critical domains. These WSN nodes, typically small and battery-operated, necessitate efficient energy management. This study focuses on the integration of crow search optimization and firefly algorithms to optimize energy efficiency in IoT-WSN systems. It has been observed that the energy reserve (RE) of a node and its communication costs with the base station are pivotal in determining its likelihood of becoming a Cluster Head (CH). Consequently, energy-saving data aggregation techniques are paramount to prolonging network longevity. To this end, a hybrid approach combining crow search and firefly optimization has been proposed. The crow search algorithm plays a significant role in enhancing data transfer efficiency, while the firefly algorithm is instrumental in selecting optimal cluster heads. This integrated methodology not only promises to extend the network's lifespan but also ensures a balance between energy conservation and data transmission efficacy.

Keywords: Internet of Things (IoT); Wireless Sensor Networks (WSN); Clustering; Energy efficiency clustering protocols; Sensor Nodes (SN); Base Station (BS); Cluster Head (CH); Mobile agent; Crow search optimization; Firefly algorithm

1 Introduction

WSN and IoT are closely related and frequently used in tandem to enable a variety of applications. As a part of the IoT, WSN offers the infrastructure needed to gather data from sensors and send it wirelessly. The term IoT describes how commonplace physical things and gadgets are connected to the internet so they may send and receive data. It is a huge network of networked devices that gather and share data in order to communicate and interact with humans and other gadgets. WSNs are a particular kind of IoT deployment. A WSN is made up of interconnected sensor nodes that communicate wirelessly. Numerous sensors are installed on these sensor nodes in order to monitor and gather information from the surrounding environment. WSN is essential to the IoT because it provides the connectivity and infrastructure needed to gather and send data from sensor nodes to the larger network. WSN serves as the basis for gathering data in real-time from the physical environment, which may subsequently be incorporated into more extensive IoT systems and applications. In conclusion, the IoT is a more general term that refers to the networking of different things and devices, whereas WSN are a particular IoT implementation that concentrates on gathering and sending data wirelessly utilizing sensor nodes.

The units in the WSN are distributed at random, and those closest to the region where energy is dissipated use more energy than any of those farther away. These nodes, which fail soon, have caused an energy hole issue that surrounds the SN. The life of the network will terminate as a result of the data analysis transmitted to the sink being fully lost. At the beginning of the millennium, Kevin Ashton from MIT invented the phrase IoT. It refers to a "global range of interconnected items that depend on standard communication systems but are uniquely accessible" [1]. IoT is a word that is frequently used, although its meaning is still unclear. The IoT is a technological advance that will shape how we communicate and compute in the future [2]. Through combining every item for communication via embedded devices, it intends to extend the Internet's accessibility and create a highly decentralized system of gadgets that could interface with both people and other things [3]. The IoT has three original objectives when compared to typical information networks: wide-ranging connection, additional efficient information perception, and further complete intelligence service. A large variety of connected devices are included in the many application areas for developing IoT [4]. WSN serves as a gateway to the IoT, as depicted in Figure 1. A WSN is made up of a number of SN with limited processing and transmission power as well as limited power sources. The primary duty of the SN in a system is to transmit the data stored from the source to the sink for further operations, but due to resource constraints, undependable links among SNs, and the multiple application requirements of distinct apps, it is challenging to create an effective routing scheme in wireless sensing systems. Developing appropriate routing methods for various applications has been regarded as a crucial problem in WSN. Detection of data is necessary in so many IoT systems because BS functions require it. This could be accomplished by integrating efficient routing algorithms into the WSN system to enhance data transfer, energy efficiency, and flexibility. Designing efficient communication methods is difficult because of factors like scarce resources and weak wireless access. For diverse IoT apps, it is consequently necessary to send information with a low loss rate, minimal energy usage, and minimal delay.

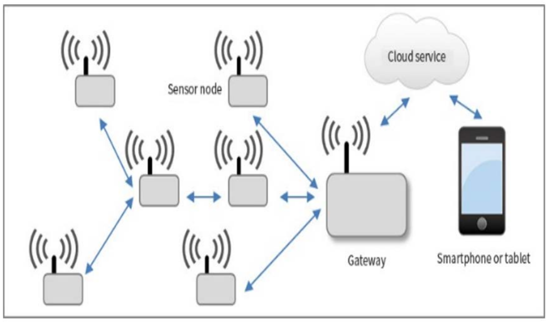

Figure 1. WSN as a gateway for IoT [5]

The organization of the article is as follows: Section 2 summarizes the literature review conducted for the study, Section 3 explains a clustering approach, and Section 4 gives an introduction to the crow search approach. The paper's related work and the difficulties with the current body of work are displayed in Section 5. The outcomes of the suggested work are shown in Sections 5 and 6, which illustrate the suggested approach. The paper comes to a conclusion in Section 7.

2 Literature Survey

In order to maximize the functionality and lifespan of IoT-WSN systems, energy efficiency is a critical component. To address the issues of energy efficiency in this environment, a combined solution combining the Firefly Algorithm (FA) and Crow Search Algorithm (CSA) has been developed. This section shows various existing works:

Alabdali et al. [6] suggested a paradigm for energy-efficient clustering using a wireless energy balancer to solve the aforementioned restrictions. To begin, an n-level clustering is provided, which results in CHs being completely leveraged and their energy usage being reduced. Secondly, by zeroing the variance among the remaining energy of CHs, an energy balancer is employed to recover as much lost energy as possible. The suggested scheme's conductance has been contrasted with the CMS2TO and DGOB methods. In comparison to previous schemes, simulation results reveal that the suggested system increased network lifespan by 20%, overall energy usage by 52%, system overhead by 20%, calculation time by 46%, and wasted energy by 86%. Finally, the suggested framework demonstrates that it is a feasible approach for extending network lifetime and improving energy efficiency.

According to the research conducted by Abushiba et al. [7], the proposed CH-leach utilizes less energy than LEACH and DEEC, according to an evaluation of current systems. Researchers studying WSNs have concentrated on wide-range integration and energy efficiency. Energy-efficient technologies can be used to absorb energy from sensor nodes. Despite the fact that numerous WSN protocols exist, clustering-based hierarchal forwarding approaches gain more attention owing to their higher scalability. Sensors are battery-operated, limiting the amount of energy available in most cases. In this investigation, scholars recommend CH-leach. It includes frameworks, techniques, and assessments. Its performance was evaluated using analytical and simulation techniques. The assessment considered the most important WSN components, including energy and longevity. Compared to LEACH or DEEC, the suggested CH-leach uses less energy. CH-leach extends the longevity of the network as a whole by 91% or 43%, respectively, as compared to LEACH or DEEC procedures.

Cao uses mobile agent techniques for data fusion. First, the WSN model as well as mobile agent structure are characterized, and afterwards, the data fusion routing method is suggested, which employs the enhanced ACO method to identify a better approach [8]. In the migration flows of a mobile user, not just the separation of two endpoints is considered, but also average energy, which might protect the operator from moving to an incorrect node. Lastly, computation results demonstrate that the proposed approach minimizes network latency while also boosting system reliability.

Sasirekha and Swamynathan Cluster-chain mobile agent routing is a multiple tunneling protocol that splits the smart sensors into a few subgroups. In step one, only those devices in every cluster act as the backbone to gather knowledge inside concentric circles. MA is sent out from the sink node to analyze information across all CH nodes in step 2. Energy demand, transmission time, and system longevity are all simulated. In areas such as energy utilization, packet delay, and connectivity endurance, the recommended CCMAR outshines LEACH, PEGASIS, and ECCP, according to the numerical simulations [9].

An enhanced Cuckoo Search-based Clustering is suggested. The aforementioned protocol establishes a fitness function depending on the cluster size, the residual energy of the nodes, and the separation between the CH and the member node. The cost for every eligible node is determined, and contenders for CH are nodes with the greatest fitness values. The node designated as a CH has the lowest expenditure based on Euclidian distance and the ratio of the sum of all nodes' energies to the sum of all CHs' energies. This approach considerably extends network lifetime [10] as compared to LEACH, PSO-ECHS, and E-OEERP. Istwal and Verma suggested a dual CH Routing Algorithm (DCHRP) that uses dual cluster heads with three heterogeneity levels to extend longevity [11]. In their study the major goal is to lower energy waste by reducing the number of cluster head selections. The retained customers of DCHRP increased by 9.99 percent and 47.18 percent when contrasted to ETSSEP and TSEP, respectively, and by far more than twice when contrasted to SEP, according to a MATLAB simulation. DCHRP's overall lifespan rises by 3.28 percent and 42.31 percent when contrasted to ETSSEP and TSEP, respectively, or around three times when contrasted to SEP.

Mahesh and Vijayachitra focused on using a hybrid optimization technique to pick the CH in WSNs in the best possible way, ensuring good communication and energy-conscious routing [12], which is known as dolphin echolocation-based crow search algorithm, also called the hybrid optimization technique, merges the crow approach and the dolphin echolocation method to efficiently and rapidly select CH, depending on several restrictions. With the help of the proposed methodology, WSN begins the energy-aware routing. The proposed algorithm presented a superior lifetime of the network, with energy left in the node being 0.0476 with 33 alive nodes at the conclusion of 200 rounds when modeling is performed in the WSN environment deploying 50, 75, and 100 nodes.

3 Clustering

In WSN, clustering helps ensure energy efficiency as well as network consistency. Clustering in WSN is a well-known and long-used method. Methods for clustering over spread are actively being researched to handle problems like the lifetime of networks or energy. For several sensor network issues, including virtualization, energy, and longevity, clustering sensor nodes is essential. Using clustering optimization methods, communication is restricted to a limited area, while only relevant data is sent via forwarding nodes (gateway nodes) to the rest of the system. As demonstrated in Figure 2, a cluster is made up of a collection of nodes, and a CH oversees the local interactions between cluster members. Successful interaction between cluster members and the CH occurs in addition to the CH's energy-saving grouping and combining of the acquired data. The CH may additionally produce an additional layer of clusters before they reach the sink.

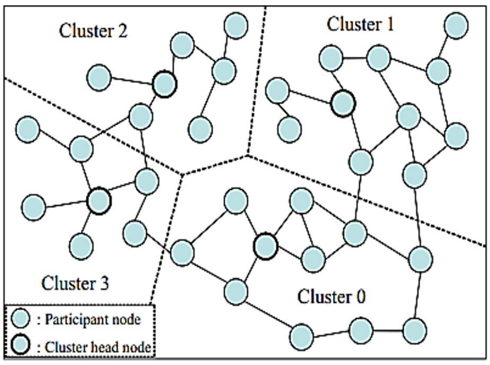

Figure 2. Cluster in WSN [13]

Virtualization and clustering in WSNs improve resource utilization, scalability, fault management, energy efficiency, dynamic reconfiguration, and security, which in turn improve wireless sensor network administration and overall performance.

Depending on the particular protocol or method utilized, different standards or algorithms may be used to choose or assign CHs in WSNs or other distributed systems. These are a few popular methods:

Algorithms based on proximity:

Distance-based: CHs are nodes that are selected based on their center location within a cluster or their minimum distance from other nodes in the cluster.

Signal strength: CHs are nodes that have higher connections or stronger communication signals.

Energy-oriented algorithms:

Lowest energy consumption: The nodes chosen to function as CHs are those with the highest residual energy or the least energy usage.

Energy balance: allocating the CHs' responsibilities so that each network node's energy usage is balanced.

Degree-based methods for nodes:

Connectivity: CHs are nodes in the network that have a higher number of links or connections.

Degree centrality: In the network structure, nodes with a greater degree of centrality are chosen.

Hybrid approaches:

Putting several measures together: Certain algorithms elect CHs based on a combination of node degree, energy, and distance.

Machine learning or fuzzy logic: applying machine learning or fuzzy logic methods to choose CHs in an adaptable manner according to different parameters.

4 Crow Search Approach

CSA is a meta-heuristic approach that depends on the behavior of the crow, an intelligent bird that lives in flocks. The crows use probability to secure the caches and their memory to recall where the food was in prior iterations [14]. Crows have a thieving habit when it comes to finding food. CSA is user-friendly and easy to apply. The method strives for a global optimal outcome while also ensuring greater diversity. The CSA position alert is as follows:

$$\mathrm{Xi(t)} = \begin{cases} \mathrm{Xi(t) + Ri \times dit \times (Mj(t) - Xi(t)); Rj \geq Aj(r)} \\ Random\ Position \qquad\qquad\qquad otherwise \end{cases} \tag{1}$$

If the random likelihood surpasses the awareness possibility, the role is updated using Eq. (1). Otherwise, the position is updated using the random search. The following is an update on the position:

$$\mathrm{Xi(t) = Xi(t) + Ri \times dit \times Mj}(t) - \mathrm{Ri \times dit \times Xi(t)} \tag{2}$$

$$\mathrm{Xi(t) = Xi(t)[1 - Ri \times dit] + Ri \times dit \times Mj}(t) \tag{3}$$

$$\mathrm{Xi(t)} = \frac{1}{[1 - \ \mathrm{Ri} \ \times \mathrm{dit}]}[\mathrm{Xi(t+1) - Ri \times dit \times Mj(t)}] \tag{4}$$

The goal of the Clustering Search Algorithm (CSA) is to improve search process variety. The CSA uses clustering techniques to avoid premature convergence to unsatisfactory solutions and to explore various sections of the search space. By organizing related solutions into clusters and encouraging inquiry both within and across these groups, this variety is attained.

By preserving diversity, the CSA can more successfully investigate a greater variety of options and might even find superior options that other search algorithms might have missed. This can be very helpful in complicated optimization issues where there are several local optima and a large search space.

4.1 Pseudocode of CSA

The pseudo-step-by-step method for implementing CSA as an optimization approach.

(1). Establishing this same issue and its variables. The issue, decision parameters, and constraints have all been defined. To follow that, the customizable CSA variables flock size, highest set of iterations, flight length of time, and recognition likelihood are assessed.

(2). The location as well as the memory of the crows should be reset. As flock members, particular numbers of crows are distributed at random within a d-dimensional search window. Every crow represents a workable solution to the issue, and d stands for the total set of options. Every crow has its memory cleared to zero. It is hypothesized that the crows hid their meals at their original location as they lacked experience in the initial version.

(3). Examine the objective equation: By inserting the values for the choice variables into the function with objectives, the level of quality of each crow's location is determined.

(4). Put the crow in a new location: Do the following to build new roles in the search space: Let's imagine that the first crow desires to develop a new job. This crow picks a random member of the flock, then follows that bird to the location of the meals it has hidden. This process is repeated for each crow.

(5). Ask about whether a novel viewpoint is viable. The practicality of each crow's new position is assessed. A crow will change positions if the new location is viable. Otherwise, the crow doesn't have to shift into the newly created role; it just stays where it is.

(6). Ascertain the objective function of new locations. The fitness feature value is calculated for every crow's new place.

(7). The objective is used to update the crows' recollections. A crow refreshes its memory with the new place if the new role has a greater feature value than the previously remembered position.

(8). Repeat steps 4 through 7 until the maximum threshold is reached. When the termination criteria are met, the global optimization approach is available as the optimal storage position in terms of objective function value.

In wireless sensor networks, the CSA (Clustering-based Stable Election Protocol) clustering method is used to increase energy efficiency and extend network lifetime. Forming clusters and choosing cluster leaders is a multi-step process. Let's go over the steps of the algorithm and define some important terms:

(1). Initialization: A random energy level and a unique ID are assigned to each sensor node in the network at this point.

(2). Cluster Formation: Based on their energy levels, a selection of nodes are chosen as cluster heads at the start of the procedure. It is more likely for the nodes with higher energy levels to lead a cluster. The other nodes in the network are then informed about the cluster heads' candidacy by broadcast.

(3). Awareness Possibility: The likelihood that a non-cluster head node may learn about a cluster head's candidacy message is referred to as the "awareness possibility". A number of variables, including the nodes' transmission range and the candidacy message's signal strength, can affect this likelihood.

(4). CH Selection: A number of cluster heads send candidacy notifications to each non-cluster head node. Based on variables such as the cluster head's energy level, distance from the receiver, and communication link quality, it assesses the signals it receives. Next, the node decides which cluster head is the best fit to join.

(5). Completion of Cluster Formation: The clusters are formed once the nodes that are not cluster heads have chosen their corresponding cluster heads. A cluster head and the nodes that have made the decision to join that cluster make up each cluster.

(6). Data Aggregation and Transmission: The cluster head gathers and aggregates data from each member node inside the cluster. The combined data is subsequently sent by the cluster head to the base station or another node that has been assigned.

(7). Eq. (Equation): An equation that the CSA algorithm uses to determine the likelihood that a node will become a cluster head is referred to as 'Eq'. Typically, the calculation considers variables including the node's remaining energy, the distance to the base station, and the total number of rounds the node has previously served as a cluster head.

These phrases and actions are unique to the CSA algorithm and are intended to maximize network performance and energy consumption in wireless sensor networks.

An issue's restrictions, nature, and the properties of the optimization algorithms themselves all play a role in the decision of which of the Crow Search Algorithm (CSA) and Firefly Algorithm (FA) to use for a given problem.

Finally, choosing the Firefly and Crow Search algorithms is based on their own strengths, such as their ability to handle multimodality, find a good balance between exploration and exploitation, adapt to different types of problems, and be good at global optimization. It is crucial to take into account the particulars of the optimization issue at hand and how well these methods fit its specifications. The choice to employ these algorithms might also be reinforced by empirical research or benchmarking outcomes in related issue domains.

5 Proposed Methodology

In the existing work, the authors have considered the RE of the node and the cost of interaction with the base station to compute the probability of the node becoming the cluster head. The second parameter in this approach essentially relates to the distance between the head and BS since the energy usage cost depends on the distance itself. Apart from this, the energy consumed within the cluster in data aggregation also plays an important role in the optimal cluster head election process. For instance, if the average distance among the head and neighbors is pretty high, then it will expend more energy in data aggregation itself. Therefore, this parameter needs to be considered as well when selecting the best cluster heads. Furthermore, the use of a mobile agent to collect data has some other issues, like that the itinerary of the mobile agent must be planned to save energy and that clocks among the nodes must be synchronized with the mobile agent, so this causes extra burden on the nodes. It can be replaced with some other data-forwarding approach.

5.1 Objectives

Following are the comparison parameters that are used to compare the existing and proposed techniques.

- To study various existing techniques that focus on augmenting network lifetime.
- To make use of firefly optimization to select optimal cluster heads and crow search optimization to optimize the data transmission.
- To implement the bio-inspired proposed protocol in MATLAB.
- To evaluate the effectiveness of the current or suggested protocols based on the amount of AN, the amount of DN, the amount of energy left in the system, or the network's overall throughput.

5.2 Research Methodology

The network lifetime is one of the prime concerns when designing protocols for sensor systems. This issue of lesser network lifetime will be solved using the clustering protocol in this work. It will concentrate on the optimal selection of CH in the network. This will be done using firefly optimization, in which the attractiveness value of the nodes is computed. The attractiveness value in this work will depend on the remaining energy of the nodes and the interaction cost with the base station and with the members as well. The most attractive node will be elected as CH in the system. The heads will form the cluster with the nearest nodes.

After cluster creation, the nodes aggregate data at the cluster head. At this phase, the information transmission to the base station will be optimized using a multi-hop routing process. In this, every CH will forward the information to BS using some relay node. The optimal relay node will be selected using crow search optimization, in which the fitness function of the node will be computed based on its remaining energy and distance from the base station.

It is noteworthy that the particular limits or thresholds for selecting between direct transmission and multi-hop routing may differ based on the needs, network architecture, and application. These standards are usually established in accordance with the features and objectives of the network deployment.

5.3 Comparison Parameters

Following are the comparison parameters that are used to compare the existing and proposed techniques.

- Number of Alive Nodes: It can be calculated by counting the number of nodes in the system that are active. The network's energy effectiveness is calculated after every round.
- Number of Dead Nodes: It can be calculated by counting the number of dead nodes in the system. This is calculated for each cycle to determine the network's energy efficiency.
- Remaining Energy: When each node contributes its remaining energy to CH, average energy values are determined and sent to other nodes. The lifespan of a network and average energy use are directly related.
- Throughput: Throughput at BS is the rate at which data packets are successfully delivered. It doesn't account for lost packets. Throughput primarily deviates from PDR during times of high traffic. There's less traffic in our study. As a result, throughput and the ratio of packets delivered are almost always equal.

6 Rusults

MATLAB was used to model both the planned and actual work. A 100-square-meter system with 100 randomly located nodes was used for the purpose of modeling. Table 1 below includes a list of different model variables used in simulation:

Table 1. Simulation parameters

Parameter	Value
Channel	Wireless
Set of Nodes	100
System Region	$100 * 100$ sq meters
BS Position	$(50, 50)$
$\mathrm{E}_{e\ \mathrm{lec}}$	50 nJ/bit
E_{da}	5 nJ/bit/message
$\mathrm{E}_{\mathrm{amp}}$	$0.0013\mathrm{pJ/bit/m^4}$
E_{fa}	$10\mathrm{pJ/bit/m^2}$
Packet Size	4000 bits
Initial Energy	0.5 Joules

Network efficiency is measured by the quantity of active nodes, dead nodes, residual energy, and transmission. Throughput is the number of packets sent to BS, but the lifetime of a network is influenced by the number of active nodes. A 100-by-100-yard space is unevenly covered in nodes. The BS can be found at (50, 50). In this section, the outcomes of the recommended Crow search technique are displayed. Clusters provided to BS and the effectiveness of energy conversion are used as output metrics to test the proposed strategy. All SN are evenly distributed within the previously mentioned sensor area, where BS is meant to be. Using the MATLAB application, the suggested solution was produced. The energy-saving factor is determined by the live/dead node proportion. Utilizing a system of 100 randomly distributed nodes, four different situations were tested. Utilizing average RE consumption, the number of active or dormant nodes, throughput, and the efficacy of a network were assessed.

- **Number of Alive Nodes:** The number of active nodes was utilized to calculate the energy consumption for every item. The proposed approach is 1200, 1400, 1600, 1800, and 2000 rounds in total as shown in Figure 3.

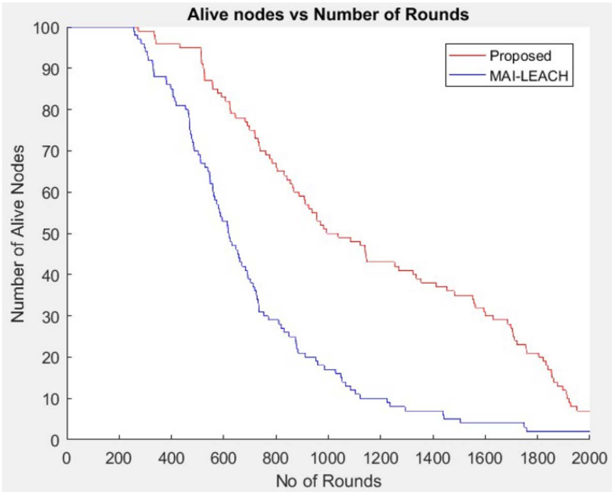

Figure 3. Comparison of alive nodes

- **Number of Dead Nodes:** The number of dead nodes was utilized to determine the energy use of the device for every run (no. of rounds) as shown in Figure 4.

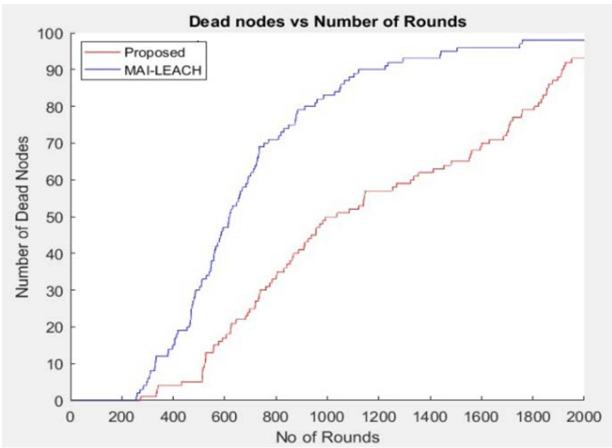

Figure 4. Dead nodes vs number of rounds

These dead nodes in the network are against rounds for both schemes. This indicates a better network lifetime in the case of the proposed technique. The new scheme's choice of CH relies on the algorithm known as crow search or the firefly method, which computes the fitness function of the node based on its energy or distance from the BS. Therefore, the performance of the proposed scheme is better than the existing scheme.

- **Throughput:** Throughput is the measure of how much data is successfully transferred through a system. In this case, the previously indicated equation is utilized to calculate the throughput:

$$\text{Throughput} = \frac{\text{Total No. of packets successfully transferred}}{\text{Total Number of packets transferred}} \tag{5}$$

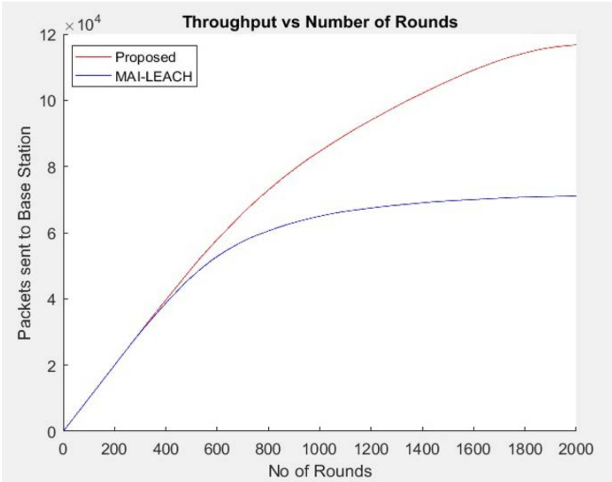

Figure 5. Comparison of throughput

Figure 5 shows the Throughput for every run (no. of rounds). The throughput of the suggested methodology enhanced packets effectively delivered, which is greater than the current method MA-I-LEACH packets sent directly because alive nodes in the network for longer periods of time give greater bandwidth.

- **Average Residual Energy:** The main resource that WSN nodes require is energy, which also influences how long the network will last. Figure 6 shows that the average Residual Energy against every run (no. of rounds) for the current MAI-LEACH method is steeper than for the suggested method. This is because steeper drops mean a faster rate of energy loss.

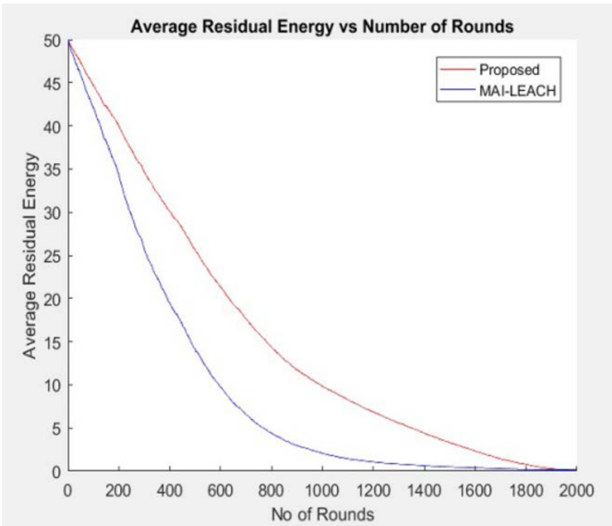

Figure 6. Average residual energy

The suggested method improves all four measures, including RE, throughput, and the number of active nodes. Because there is only one route employed, the burden on the CH building path is also enhanced. In the past, the CH would either send information directly to the BS or through a nearby CH (if the BS could be rapidly expanded).

7 Conclusion

The advancement of computing techniques has aided in the creation of WSNs, which continuously sense the required variables. In recent years, IoT-based WSN devices have received a lot of attention. While point-to-point communication is possible, these networks have limited bandwidth, power, or capacity. One proposed method for this issue is data collection. How critical information could be processed in a more energy-efficient manner is a major issue in sensing devices. As a result, different information aggregation algorithms were applied, which are discussed in this work, to reduce power usage. In this study, we will make use of firefly optimization to select optimal cluster heads and crow search optimization to optimize the data transmission. The number of active nodes, dead nodes, residual energy, and throughput are used to characterize the network's efficiency. The number of packets transferred to BS is known as throughput, while the number of active nodes affects how long the connection will last. A 100-by-100-meter region is unevenly covered in nodes. BS is situated in (50, 50). The results of the suggested Crow search technique are displayed. Clusters provided to BS and energy conversion efficiency are used as output measures to test the proposed plan. All SN are randomly located within the aforementioned sensor region, where BS is meant to be. Using the MATLAB application, the suggested solution was produced. The live/dead node proportion determines the energy-saving coefficient.

Data Availability

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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