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Energy Aware Fine Cluster Head based Routing for Heterogeneous Wireless Sensor Networks using Particle Swarm Optimization and Ant Colony Optimization Algorithms

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Abstract

Reducing a node's power consumption is a difficult task for extending the network's lifetime because the nodes are resource-constrained (i.e., limited battery power, processing capacity, storage, and non-rechargeable). Many of the existing cluster-based strategies and algorithms for heterogeneous wireless sensor networks (HWSNs) are failing to adapt to the dynamic nature of the network and energy conservation of the nodes. Recharging or replacing the deployed device drained batteries can be challenging, especially in complex situations. For the network to have a longer lifespan, power preservation is very necessary. The sensor nodes must identify the most effective clustering-based routing method to minimize energy consumption. In this, we propose an improved effective fine cluster head-based routing algorithm for HWSNs, specifically designed for cluster head (CH) and fine cluster head (FCH) selection and re-selection. Compared to ECEEC, EECABCO, LEACH, and EECRP-BOACOA, the proposed technique exhibited a longer network lifespan. The suggested technique was compared against current routing methods as, EECABCO, LEACH, ECEEC, and EECRP-BOACOA. The technique demonstrated superior network performance compared to traditional WSN clustering methods. The proposed approach had 55% living nodes after 2000 rounds, which was far better than the existing methods. The purpose of this algorithm is to minimize network energy usage, overcome sensor node power consumption, and extend the network's lifespan.

Keywords: Cluster Head, Ant Colony Optimization, Particle Swarm Optimization, Energy Efficiency, Wireless Sensor Network, Internet of Things.

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1. Introduction

A Wireless Sensor Network (WSN) consists of large number of resources constrained tiny sensor nodes that are strategically deployed across the monitoring area to detect, analyze, and collect information. These tiny devices are cost-effective and provide more capabilities in detecting, analyzing, and forwarding information. Weather forecasting, the military sector, the medical industry, and other commercial and industrial applications are just a few of the uses for WSN. WSN sensors are small in size and rely on a limited battery to power them [1-4]. The sensor uses an Analog to Digital Converter (ADC) to gather data, which it then analyzes before forwarding to the Base Station (BS), the primary location. The data that is received is processed at BS in order to make decisions for different applications. Furthermore, it is important to use the WSN's power source responsibly, since sensor nodes cannot be replaced or recharged because the sensor is located in a hostile and uninhabited area. Numerous factors, like energy-efficiency, scalability, throughput, and packet delivery ratio etc., have an impact on the WSN design. The sensor nodes in a Wireless Sensor Network (WSN) deplete their energy via two processes: 1) Sensing / monitoring area factors and 2) Transmitting information to the Base Station (BS) via the nodes. Data communication in Wireless Sensor Networks (WSN) consumes more energy compared to environmental monitoring and sensing, aggregation of data from the environment.

Sensor node limited battery power is a major WSN concern. Node failure causes network failure. Thus, WSNs are energy-sensitive, distinguishing them from conventional wireless networks. Direct data transfer from sensors to BS drains sensor nodes rapidly. Additionally, WSN energy usage must be optimized to enhance lifespan and performance. Thus, clustering sensors reduces energy usage and increases network scalability. The Cluster Head (CH) of each network cluster communicates with other CHs. As directly transferring sensed data to the BS requires more energy, clustered WSNs employ a routing protocol to find the optimum path between CHs and BS to save energy [5].

The primary goal of this paper was to increase the network's lifetime by reducing nodes' energy consumption and using accurate clustering. The paper's major contributions are as follows:

- Create an energy aware routing based on Fine Cluster Head (FCH) for HWSNs to ensure efficient network management.
- Provide an energy-aware scheme for cluster building, cluster head (CH), and fine cluster head (FCH) election, as well as later FCH and CH selection.

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- Provide a scheme for Cluster Head and Fine Cluster Head rotation and data forwarding with low network energy usage.
- Using rounds and other performance criteria, compare the proposed EAFCHR algorithm against state-of-the-art alternatives.

2. Related Work

In recent years, cluster-based routing protocols have been classified into two types: homogeneous (all deployed sensor nodes (SNs) with the same resources) and heterogeneous (SNs with different resources). For homogeneous WSNs, traditional and energy-efficient clustering-based routing protocols such as LEACH, CBRP, ACE, PEGASIS, and HEED are used, where cluster heads (CH) are selected randomly based on some threshold value. For heterogeneous WSNs, traditional and energy-efficient clustering-based routing protocols such as SEP, DEEC, EECS, and M-LEACH are used, where cluster heads (CH) are selected not randomly based on various network real-time parameters. Cluster-based routing algorithms and techniques in WSNs have gained attention and presented unique challenges in comparison to other traditional cluster-based techniques. Optimizing the battery power of nodes for energy conservation is a major issue to be considered in many WSNs. Cluster heads engage in energy-intensive processes such as data processing, transmission, data aggregation, data reception, etc [6-7]. Therefore, selecting cluster heads requires extensive supervision. To expand WSNs performance, especially the lifespan, extensive supervision is necessary. Battery power, remaining energy, node degree, density and distance of nodes are the important factors that are essentially considered for the election and re-election of cluster heads in various stages of network. In various ways, many researchers have used these important parameters in cluster head selection and reselection to enhance network lifetime and throughput. In this article, we have analyzed a variety of traditional cluster-based and meta-heuristic cluster-based algorithms [8-9]. The conditions and election probabilities are criteria for selecting the cluster head. Improvement techniques are based on round time, remaining energy, and cluster size [10-11]. Using all the techniques described in this paper, we assume that authors have focused more on threshold condition improvement techniques than election techniques.

For WSNs [12], the authors implemented an energy-efficient clustering algorithm using improved artificial bee colony optimization (ABCO) based on fuzzy C-means and economic principles to optimize the selection process of cluster heads (CHs). The authors also adopted an improved ant colony optimization (ACO) for routing from CHs to BS by introducing polling control mechanisms for intra-cluster communication to decrease power utilization. The authors of [13] suggested energy-efficient cooperative routing algorithms for HWSNs (EECRA). They aim to reduce node battery power utilization and extend network lifetime by enabling cooperative packet relay and dynamically establishing routes between nodes based on transmission directions and residual energy.

The authors of [14] focus on efficient top-k data queries in cluster based wireless sensor networks (WSNs) using wake-up receivers. The authors introduce a countdown content-based wake-up (CDCoWu) techniques, selectively activating nodes with relevant data and extending this to cluster-based WSNs. The author proposes a hybrid wake-up control that combines CDCoWu and identify-based wake-up (IDWu) based on cluster size to optimize node battery power usage and data collection delay. The authors of [15] suggested an enhanced centroid-based energy efficient clustering (ECEEC) protocol aimed at optimizing energy utilization and expanding the lifespan of WSNs. The proposed ECEEC technique addresses practical routing issues to ensure accurate data transmission, and cluster head selection and re-selection. The implemented strategy is based on a serverless architecture to manage the network effectively and evaluate its performance against existing alternatives. The demonstrated results of proposed strategy minimize the energy consumption, enhance network lifespan, and better data delivery efficiency over traditional cluster-based routing protocols. However, authors fail to adopt the dynamic network conditions and mobility of nodes.

The authors of [16] proposed an energy-efficient secure routing (EESR) protocol for WSNs based on dynamic key cryptography, and weight-based AODV. The author's goal is to determine the route's weights based on factors such as node mobility, residual energy, and bandwidth while implementing a hierarchical path from SN to CH to BS. According to the findings, the EESR protocol decreases the memory utilization and communication overhead by adopting dynamic key management. The results of the proposed protocol EESR-WAODV enhance network efficiency with respect to throughput, hop-count, and battery efficiency making it suitable for environments requiring fast communication.

For WSNs, the authors of [17] suggested metaheuristic algorithms like butterfly optimization and ant colony optimization-based energy-efficient routing protocol for WSNs. The authors proposed the Butterfly Optimization Algorithm (BOA) to select effective cluster heads (CHs) and Ant Colony Optimization (ACO) uses the shortest path from CHs to BS. The network model assumes identical sensor nodes with fixed positions, while the energy model uses a first-order radio model. According to the finding, the EECRP strategy optimizes energy utilization, enhancing the network's lifetime by balancing battery power conservation among nodes. However, the author was unable to address the network dynamics and mobility of nodes.

For WSNs, the authors of [18] suggested metaheuristic based "Self-Adapting Differential Search Strategies Improved Artificial Bee Colony Algorithm (SADSS-IABCA)-Based Cluster Head Selection Scheme for WSNs," a novel strategy is implemented to enhance wireless sensor network lifetime and performance. Proposed SADSS-IABCA balances exploration and exploitation during cluster head (CH) election based on ABCA optimization and DE strategies. Three alternative self-adaptive DE algorithms increase local search, prevent poor sensor nodes from becoming cluster leaders, and improve global optimization to extend network lifespan. According to the findings, the SADSS-IABCA strategy improves WSN QoS by increasing node throughput, and energy efficiency. However, the authors were failing to adopt major parameters like node degree, node mobility, and efficient re-selection of cluster heads.

The authors of [19] aim to decrease node battery-power usage and expand network lifespan. They propose an energy-efficient routing protocol for WSNs by adopting metaheuristic algorithms such as butterfly optimization algorithm (BOA) and ant colony optimization algorithm (ACOA). The BOA is used to select optimal cluster heads

(CHs) based on battery capacity and node degree, whereas the ACOA is used to find the efficient routes from SNs to BS by considering key parameters such as node degree, selection and re-selection, and distance to BS. Compared to traditional cluster-based routing protocols, they show improvements in energy consumption, and throughput. Further enhancements in cluster heads (CHs) selection, energy efficiency, and fault tolerance.

Our basic idea is to use metaheuristic and traditional cluster-based routing protocols for WSNs to deal with all the important issues, such as node degree, choosing and re-selecting cluster heads (CHs), energy use, and node mobility. We then suggest fine cluster heads (FCHs) to enhance network lifetime in WSNs.

3. Proposed Fine Cluster Head based Architecture

3.1 Problem Statement

In this part, WSN difficulties are examined and the recommended technique is explained. Modern Heterogeneous Wireless Sensor Networks (HWSNs) issues: HWSNs require the right goal techniques to save energy. For clustering-based routing algorithms prioritized node residual energy. This only decreases network energy usage when the method prioritizes battery power and distance equally. Small and large-scale HWSNs should use energy-efficient WSNs. NON-CH members of CH's cluster influenced WSN performance in clustering-based routing. Direct packet transfer from cluster head (CH) to base station (BS) uses high network energy. It causes network packet loss due to hot spots. Ant Colony Optimization-based routing's proactive and reactive algorithms cause packet loss between networks. Due to severe and unsupervised conditions, sensor nodes become unreliable and defective. During data packet transmission, node energy consumption is also a major concern. Nodes with insufficient energy discard packets during data transmission.

Solution Statement

To construct energy-efficient WSN, this research considers both energy and distance since each node's energy consumption is directly related to its distance. Consideration of WSN node energy prevents packet loss. Multi hop network routing solves routing issues. Routes from source to BS are created using Ant Colony Optimization. The routing goal functions are node residual energy, distance, and hops per cluster. Consider these settings to decrease network packet loss. An energy-efficient WSN works well in simple and complex monitoring areas. This part presents details on the network architecture, energy model, and a comprehensive explanation of the Particle Swarm Optimization and Ant Colony Optimization Algorithms. We propose an FCH-based clustering algorithm specifically designed for HWSNs. We implement the model in two phases: network setup and network management. The network setup phase discusses the energy management of nodes, clustering of nodes, cluster head election, and fine cluster head election based on the distance to the base station. The network management phase covers the transmission and re-election of cluster heads and fine cluster heads.

3.2 Network Model

Figure 1, illustrates the configuration of the clustering based heterogeneous wireless sensor network. The network model is created by taking into account the following factors: In a Heterogeneous Wireless Sensor Network (HWSN), all the tiny devices (SNs) possess different beginning energy levels and processing times. The Euclidean Distance used to determine the distance between SNs. The tiny devices (SNs) are deployed randomly in the sensing region and their positions will change after deployment due to mobility of nodes. The base station (BS) obtains data on the remaining energy and distance from the sensor nodes. Using an efficient CH selection technique and fine cluster head (FCH), CHs and FCHs are chosen for all the deployed devices as per the provided information. Next, the routing technique is used to acquire the pathway connecting the FCHs to the BS.

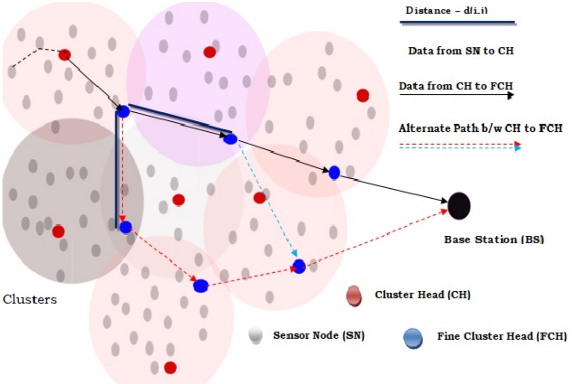

Fig. 1. Clustering based Wireless Sensor Network Architecture

3.2.1 Network Setup Phase

One base station (BS) and tiny resource-constrained devices, randomly deployed around the interested area, comprise the HWSNs. Once the sensors have been deployed, the system will divide these nodes into clusters by identifying their neighboring nodes. After forming the clusters and identifying cluster heads (CHs) based on node performance metrics, all CHs communicate requests to the BS directly or through the CH node, depending on the distance between the CHs and the BS. During this process, some of the CHs will announce themselves as fine cluster heads (FCH) to forward information to the BS.

Fine Cluster Head

The entire network will be divided into clusters, each with a cluster head (CH). The primary goal of the CH is to collect data from neighboring or cluster nodes, then forward to the sink node through other CHs called fine cluster heads (FCH). Fine Cluster Head (FCH) is also called as Gateway Node (GN). Since the Cluster Head (CH) bears numerous responsibilities in managing the data from the cluster member nodes, it requires more energy to forward data directly to the BS, a task that other CHs assist with. As a result, CHs can use uneven energy during the transmission process. As a result, CHs designate a node as an FCH that forwards information to the sink node. FCH nodes are sensor nodes they are common neighbors of CHs. Each FCH determines the distance between itself and the CHs. The network management will select the new FCHs as per the distance and residual battery power of the CHs and FCHs. The cluster's residual energy and the distance to the closest neighboring cluster head (CHs) and fine cluster head (FCH) nodes in the network determine the selection and re-selection of FCH nodes. The cluster selects the node with the highest residual energy and proximity to the other CHs as the fine cluster head node. Following node deployment in this phase, the nodes will wake up and broadcast hello messages to identify their neighboring nodes, forming clusters, these hello-messages will include node_id, message_type, node_id, node_mobility, node_loc, cluster_status, and cluster_id.

3.2.2 Network Processing

The proposed mechanism consists of two distinct approaches: one algorithm is adapted to select the Cluster Head (CH) and Fine Cluster Head (FCH), while the second algorithm is responsible for routing data throughout the network. The PSO algorithm is used for the purpose of selecting the most efficient sensors, while the CH and FCH, and ACO algorithms are utilized to determine the shortest transitory route among the FCH and BS. Subsequently, the Cluster Heads (CHs) transfer the gathered information to FCH, then FCH forward to another FCH or directly to the Base Station (BS) via the route defined by Ant Colony Optimization (ACO). The approach being presented is extensively outlined in the following section.

3.3 Cluster Head (CH) and Fine Cluster Head (FCH) Selection Using PSOA

Nature-inspired metaheuristic algorithm Particle Swarm Optimization Algorithm (PSOA) was invented by. This PSOA mimics swarm behavior, including food hunting and mating. Swarm behavior is defined in terms of the search strategy. Usually, the released scent of other butterflies attracts the butterflies to one another. Then the migration of swarm is either random or in the direction of the swarm with stronger scent. Moreover, the stimulus intensity of the swarm is found by means of the objective functioning. Using node degree, node centrality, distance to its neighbors, distance to the BS and residual energy, the PSOA selects the best CHs and FCHs from all the sensors. The swarm identifies a set of sensor nodes from a network to choose as CHs and FCHs in the CH and FCH selection phase of PSOA. Every dimension of a swarm corresponds to the network's CH and FCH count. Every swarm starts with a random node_id among and where is the total number of network nodes. Assume, $S_j = (S_{j,1}(k), S_{j,2}(k), ..., S_{j,n}(k))$ be the jth swarm and where every swarm location $S_j,d(k)$, $1 \leq d \leq n$ that determines the node_id among 1- n in the network and m define the CHs and FCHs in the network. For instance, suppose the network consists of 100 sensor nodes, CH will be 10% and FCH will be 5 – 10 % of the overall node count. Every PSOA swarm has a dimension according to the 10 CH and 5 to 10 FCH count. Each swarm then positions $S_i,d(k)$, $1 \leq d \leq 10$ itself between the random numbers ranging from 1 to 100, hence determining the overall count of sensor nodes. Every swarm location is mapped together with sensor node coordinates.

A. Swarm Location Improvisation

The location improvisation of the swarms is adapted for the selection of CHs and FCHs. The mechanism of relocating the swarm's locations defined as follows:

IN PSOA, swarm positions are improved in global or local search phases. The random number in [0, 1] determines global or local search phase. From all network nodes, new swarms are randomly invented with node_id. Remaining swarm's smell enhances their position. Based on swarm scent, positions are updated. In addition, the PSOA initiates local search when the swarm cannot locate any aroma.

B. Fitness Function of PSOA

PSOA fitness function chooses the network's ideal CH and FCH between sensors. Dead nodes are avoided as CHs and FCHs during clustering using the fitness function's residual energy. The ideal CH and FCH is chosen based on the distance between the nodes and the candidate FCH to the BS to reduce node energy usage. The node degree determines the FCH with less normal nodes to preserve it for further rounds. Additionally, its cluster members' and cluster heads enhanced centrality reduces their transmission distance to FCH.

C. Residual Energy of CH and FCH

CH gathers data from standard sensor nodes, FCH collect data from CH and sends it to BS in a HWSN. CHs and FCHs need a lot of energy to do their jobs, thus the node with the most remaining energy is chosen.

D. Distance between the SNs within Cluster

It determines its CH's distance from typical sensor nodes (SNs). Energy loss at the node is mostly determined by the transmission line distance. Low transmission distance to CHs results in low energy usage for the chosen node. The distance between SNs and CHs is denoted as $dis(SN_i, CH_m)$ and CH has the number of sensor nodes described as X_j.

E. Distance between the FCHs

It determines its FCH's distance from typical sensor nodes (SNs). Energy loss at the node is mostly determined by the transmission line distance. Low transmission distance to FCHs results in low energy usage for the chosen FCH. The distance between FCHs and FCHs is denoted as $dis(FH_i, FH_m)$ and network has the number of FCH nodes described as H_j.

F. Distance between the FCHs and BS

Distance from FCH to BS. Distance via the transmission route determines the node's energy usage. If BS is physically far from FCH, it requires more energy for data transmission. Energy usage may cause FCH to drop suddenly. For data transmission, the node closer to the base station is favored. The distance between FCHs and BS is denoted as $dis(FH_i, BS)$.

3.4 ACO based Routing in WSN

Based on ant behavior, Ant Colony Optimization (ACO) is a metaheuristic method. Ants find food and the shortest path in their nest. Using ACO, discrete issues are modeled as a graph with nodes and linkages. In this setup, each node contains ants and each connection is weight-related. To compute link cost, a random number, distance, or a mathematical formula are used. Distance from FCH to BS and remaining energy of FCHs is optimized using ACO. This section fully explains the route generating method using ACO [15 - 19].

1. An ant generates route FCH to BS via other FCHs. Source CH generates Forward Ant Packets for route configuration.
2. Packets are sent randomly as per the probability matrix to the next FCH node. Continue transmission until the BS receives forward ant packets.
3. Packet transmission, beach packet builds a local database with information on the visited FCH, including node_id, remaining energy, and distance to the BS, and node degree. Mostly, the residual

energy of the FCH relies on the number of packets transferred across the network.

4. The forward ant provides the database for the backward ant packet, which is extended to reach BS. The backward ant then communicates along the same route as the forward ant packet transfer.
5. Pheromone values at each route are updated depending on node_degre, residual energy, and BS distance.
6. The ant chooses the next hop using the node transition method in equation to determine the probability of selecting the next node.

This research highlights cluster maintenance as a crucial step for balancing load amongst clusters. Energy drains faster in clusters near the BS owing to inter-cluster traffic. To prevent node failure, cluster maintenance is needed. This increases data transmission lifespan from source node to BS. If the remaining energy of the CH and FCH exceeds the threshold, the PSOA algorithm is re-initialized to select cluster heads (CHs) and fine cluster heads (FCHs) in the network. After selecting CHs and FCHs using the clustering approach, the ACO is utilized to determine the routing route to BS.

This approach uses PSOA algorithm to pick CH and FCH effectively. Seven factors are used to choose CHs and FCHs: mobility of node, centrality, distance to neighbors, and distance to the BS, distance from CH to FCH, distance from FCH to FCH, node degree, and residual energy. These factors determine the FCH from the node set. FCH and BS are regularly monitors node residual energy to prevent data transmission failures. The ACO algorithm determines the best transmission route from the source node to BS via CHs and FCHs. Detects the fastest route to minimize node energy, PSOA and ACO are used for optimal CH and FCH selection and route generation, resulting in an energy-efficient HWSN design. Using an energy-efficient clustering-based routing may enhance network lifespan and packet transfer to the BS.

In the algorithm, we describe the process for data transmission between nodes and the selection of CHs and FCHs. We demonstrate that after the network setup, a set of new CHs and FCHs from the clusters is created, and a hello_message is progressed. Initial neighbor discovery, cluster formation, CH selection, FCH selection, and hello_message transmission to BS all consume energy. For simplicity, we have partitioned the entire process into three phases, or modules. The simulation executes the modules in sequential order.

Algorithm: ***Energy-Efficient Fine Cluster Head based Routing Algorithm for WSN using PSO and ACO.***
Input: ***Sensor Nodes (SN) with similar capabilities.***
Output: ***Energy-Efficient WSN.***
Initialization Step: *Initialization of 'n' SNs with similar resources.*

```
for node 1 to n
    Initialize $SN_k$ energy $E_{initial}$
    Set minimum energy for Sensing $E_{minS}$
    Set minimum energy for Transmission $E_{minT.}$
    Set mobility of node $SN_{kMOB}$
    Set threshold energy $E_{th}$ for participation in selection of CH and FCH.
Deployment of n SNs in monitoring area.
```

Clustering Step (Module 1): *Creation of n Clusters (with n-CHs and < n-FCHs).*

```
Particle Swarm Optimization ($SN_n$, i, j, l, BS)
```

Routing Step (Module 2): *Efficient Routes from CHs to BS via the FCHs.*

```
Ant Colony Optimization ($CH_m$, $FCH_n$, BS, l)
Energy – Efficient Routing for WSN.
```

Module 1: ***Creation of n Clusters (with n-CHs and < n-FCHs) using Particle Swarm Optimization***
Input: ***SN_n****: 'n' number of Sensor Nodes,* ***l:*** *Longest distance from SN to BS,* ***i and j:*** *monitoring area,* ***BS:*** *Base Station of the network.*
Output: ***n-Clusters (with n-CHs and < n-FCHs).***

```
Repeat

    for i to n do
        for j to m do
            find_Neighbor($SN_i$, $SN_j$) and find_distance($SN_i$,$CH_k$)
            if(($CH(E_k)$ > $SN(E_j)$) and ($CH(E_k)$ >= $SN(E_i)$))
                append($SN_i$, $SN_j$) then declare $CH_k$ as Cluster Head.
            else if($SN(E_i)$ > $SN(E_j)$)
                append($SN_i$, $SN_j$) then declare $SN_i$ as Cluster Head.
            else
                append($SN_i$, $SN_j$) then declare $SN_j$ as Cluster Head.
        append(CH)
    for i to n do
        for j to m do
            find_Neighbor($CH_i$, $CH_j$) and find_distance($CH_i$,$CH_j$)
            $SN_k$=find_CommonNode()
                append($SN_k$) then declare $SN_k$ as Fine Cluster Head.
            if($SN(E_i)$ > $SN(E_j)$)
                append($SN_i$) then declare $SN_i$ as Fine Cluster Head.
            else
                append($SN_j$) then declare $SN_j$ as Fine Cluster Head.
until $CH_{count}$ ==10 % of n and $FCH_{count}$ <= 10% of n.
```

Module 1: ***Finding Route using Ant Colony Optimization (ACO)***
Input: ***SN_n****: 'n' number of Sensor Nodes,* ***l:*** *Longest distance from SN to BS,* ***i and j:*** *monitoring area, BS****:*** *Base Station of the network,* ***CH****: Cluster Head,* ***FCH****: Fine Cluster Head.*
Output: ***Energy Efficient Cluster based Routing(Shortest Route from CHs to BS via FCH).***

```
for i to n do /* n: number of Fine Cluster Heads (FCHs) */
    while FCH not found BS
        repeat
            process(dis($FCH_i$, $FCH_j$)< (dis($FCH_i$, $FCH_k$))
                update route
            until BS.
    if($FCH(E_i)$< $FCH(E_{th})$) || $CH(E_i)$ < $CH(E_{th})$) then
        call module1
    else
        call module2.
```

4. Network Simulation Setup

NS-3, an open-source event-driven simulator, was used to test network performance. Using OTcl and C++, this simulator lets researchers describe backend mechanisms. Object-oriented tool command language enables manipulation of stimulation scripts and object configurations [20][21]. The simulated monitoring area is 200x200 m with 100, 150 and 250 SNs. Figure 2, shows that network test environment with base station coordinates is (100, 100) in three scenarios. Node GPS is used for obtain the location of all nodes and dynamic. The numbers of rounds to evaluate the network performance and simulator settings are in Table 1. The proposed algorithm setups were executed on a system having the Windows 11OS, configured with an 13th Gen Intel(R) Core (TM) i5-1340P 1.90 GHz, 16GB and 500 GB of RAM and SSD. The NS-3 simulator is used to execute and analyze the performance of the proposed Energy Efficient Fine Cluster Head based Routing (EEFCHR). We carried out the experiments more than 50 times in order to guarantee the reliability of the findings, and then we determined the average value in order to arrive at the desired conclusions.

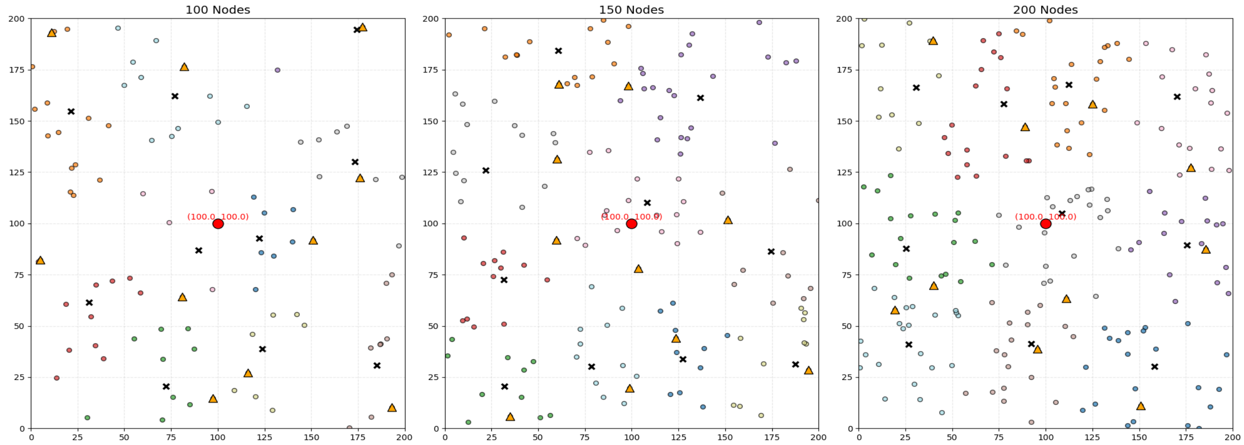

Fig. 2. Network monitoring area with Base Station (BS) coordinates is (100, 100), (a) 100 nodes, (b) 150 nodes, and (c) 200 nodes.

Table 1. Simulation Setup Proposed System Parameters.

Parameters		**Values**
Monitoring Area		200 * 200 m
Number of Sensor Nodes		100, 150, and 200
Energy	Initial Energy of Sensor Nodes (SNs)	2J - 5J
	Threshold for CH	0.5J
	Threshold for FCH	1.0J
Energy Consumption	Data Aggregation at Node	5nj/b
	Data Aggregation at FCH	0
	Data Aggregation at CH	5nj/b
	Data Transmission SN to CH	50 nj/b
	Data Transmission CH to FCH	50 nj/b - 100 nj/b
	Data Receiving from Node	10 nj/b
	Data Receiving from CH	10 nj/b
Round Time		10 Sec
Packet Size		200 bits
Distance	Threshold distance node to CH	10 m
	Threshold distance CH to FCH	20m
Mobility	Sensor Node	2 m/s
	CH	2 m/s
	FCH	.5 m/s

This section discusses the simulation setup and proposed methods performance. The fine cluster head-based routing performance is evaluated using metrics such as energy conservation, latency, packet transmitted, throughput, alive and dead nodes, first node to dead (FND), half nodes to dead (HND), and last node to dead (LND).

We study the network scalability for the proposed algorithm EEFCHR along with parallel research outcomes such as LEACH, EECABCO, ECEEC, and EECRP-BOACOA. EECRP-BOACOA, by increasing the number of nodes (100, 150, and 200) in a monitoring area (200 * 200). Data throughput, Energy Consumption, Network Scalability, and Network Lifetime are utilized to assess the proposed EEFCHR algorithm. To test performance, several experiments are done. Sensor nodes (SNs) with some mobility are randomly deployed in the monitoring area and regulate transmission power using distance. ACO based reliable and error-free communication paths, and sensor nodes use localization algorithms to know their positions. Every FCH node is within range of its neighboring CHs. Our comparison included four traditional and existing clustering protocols: LEACH, EECABCO, ECEEC, and EECRP-BOACOA. EECRP-BOACOA was created for environmental monitoring without energy concern, whereas ECEEC was built for sensor based IoT networks and predated proposed protocol. For WSNs energy performance testing, the EEFCHR is updated and implemented. We employ three distinct scenarios to assess the performance of the proposed algorithms, which encompass node aliveness, average transmission, packet received ratio (PRR), and energy consumption (EC), while also taking scalability into account by expanding the number of nodes within the monitoring area.

A. Alive Node Analysis with 2% and 5% of FCHs and CHs

Network lifetime depends on active nodes. First experiment evaluates number of living nodes with various rounds. LEACH, EECABCO, ECEEC, and EECRP-BOACOA outperform parallel research routing protocols. Table 2 and 3 shows that, a network test environment, the number of alive nodes in a 100-, 150-, and 200-node network is examined. The base station (BS) is located at (100, 100), and there are 5% and 2% of CHs and FCHs. Around 5% CHs, the first node fails around 900 - 1200 rounds. LEACH, EECABCO, and EECRP-BOACOA have a fast first node death rate, whereas ECEEC indicates a failure between 700 and 800 cycles. Our proposed approach outperforms the others. The first node in LEACH, EECABCO, ECEEC, and EECRP-BOACOA fails at 600 - 700 rounds, whereas the proposed algorithm EEFCHR fails around 900 - 1200 rounds (Figure 3 with 5% CHs and FCHs). The last node in LEACH, EECABCO, ECEEC, and EECRP-BOACOA fails at 1600 - 2000 rounds, whereas the proposed algorithm EEFCHR fails around 2800 - 3000 rounds (Figure 3 with 5% CHs). Around 2% CHs, the first node fails around 900 - 1200 rounds. LEACH, ECEEC, EECABCO, and EECRP-BOACOA have a fast first node death rate. Our proposed approach outperforms the others. The first node in LEACH, EECABCO, ECEEC, and EECRP-BOACOA fails at 300 - 400 rounds, whereas the proposed algorithm EEFCHR fails around 500 - 600 rounds (Figure 4 with 2% CHs and FCHs). The last node in LEACH, EECABCO, ECEEC, and EECRP-BOACOA fails at 700 - 800 rounds, whereas the proposed algorithm EEFCHR fails around 1200 - 1600 rounds (Figure 4 with 2% CHs and FCHs). After 700 - 800 rounds number of alive nodes zero, whereas proposed model has around 55% node are alive and functioning network operations. Our proposed EEFCHR algorithm potential to increase the number of active nodes and extend the lifespan of Heterogeneous Wireless Sensor Networks is significant. Optimized CH and FCH selection and route creation in WSNs conserve sensor node energy, enhancing network lifespan during data transmission. The number of alive nodes for each algorithm is compared in Figure 3 and 4, as well as in Table 2 and 3, with regard to the number of rounds and by making use of the 5% and 2% of CHs and FCHs, respectively. The data and results from the simulation demonstrate that the number of alive nodes that were carried out by EFFCHR is greater than that of any other parallel research protocols (LEACH, EECABCO, ECEEC, and EECRP-BOACOA) in terms of increasing the number of nodes (100, 150, and 200) being monitored in the area.

Table 2. Using 5% CHs and FCHs, Number of Alive Nodes in a 100, 150, and 200 Nodes Network.

No of Rounds	No of alive nodes														
	EAFCHR			EECABCO			ECEEC			EECRP-BOACOA			LEACH		
	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N
100	100	150	200	100	150	200	100	150	200	100	150	200	100	150	200
200	100	150	200	100	140	200	100	140	180	100	136	188	100	138	182
300	100	150	200	100	132	193	100	138	171	100	124	174	100	135	163
400	100	150	200	100	118	183	100	132	164	100	110	152	100	124	139
500	100	150	200	100	112	167	100	124	146	100	99	133	100	111	118
600	100	146	200	98	105	145	100	104	122	98	88	119	92	91	100
700	100	143	197	83	91	125	96	94	101	88	81	94	80	79	70
800	100	134	194	70	85	104	82	78	77	74	70	72	72	65	51
900	100	130	190	55	69	88	69	61	52	64	61	48	48	49	33
1200	92	128	184	38	60	69	47	59	39	44	49	32	24	35	19
1600	78	121	162	19	48	42	23	33	22	23	36	15	8	21	10
2000	53	91	154	4	22	22	7	19	11	3	11	7	0	8	3
2500	31	78	128	0	3	11	0	8	4	0	0	0	0	0	0
2800	13	65	82	0	0	4	0	0	0	0	0	0	0	0	0
3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

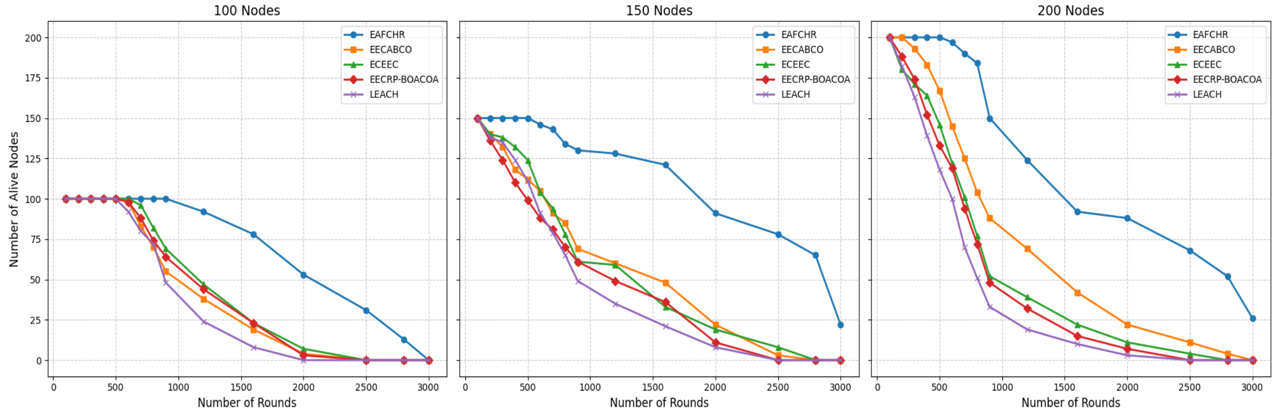

Fig. 3. Number of alive nodes anlysis with 5% CH's and FCH's

Table 3. Using 2% CHs and FCHs, Number of Alive Nodes in a 100, 150, and 200 Nodes Network.

No of Rounds	No of alive nodes														
	EAFCHR			EECABCO			ECEEC			EECRP-BOACOA			LEACH		
	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N
100	100	150	200	100	150	200	100	150	200	100	150	200	100	150	200
200	100	150	200	100	141	170	100	133	161	100	129	154	100	122	141
300	100	150	197	100	128	152	100	121	141	98	120	123	96	104	97
400	100	142	182	95	120	127	91	110	107	85	98	102	71	90	72
500	100	123	160	82	100	100	72	92	83	70	80	71	45	65	41
600	98	105	141	62	82	69	46	69	51	58	54	43	18	37	9
700	79	84	108	40	57	38	19	45	20	40	35	21	0	18	3
800	59	66	84	25	31	15	0	22	0	24	12	7	0	3	0
900	32	36	51	8	12	4	0	0	0	9	8	0	0	0	0
1200	4	10	23	0	4	0	0	0	0	0	0	0	0	0	0
1600	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

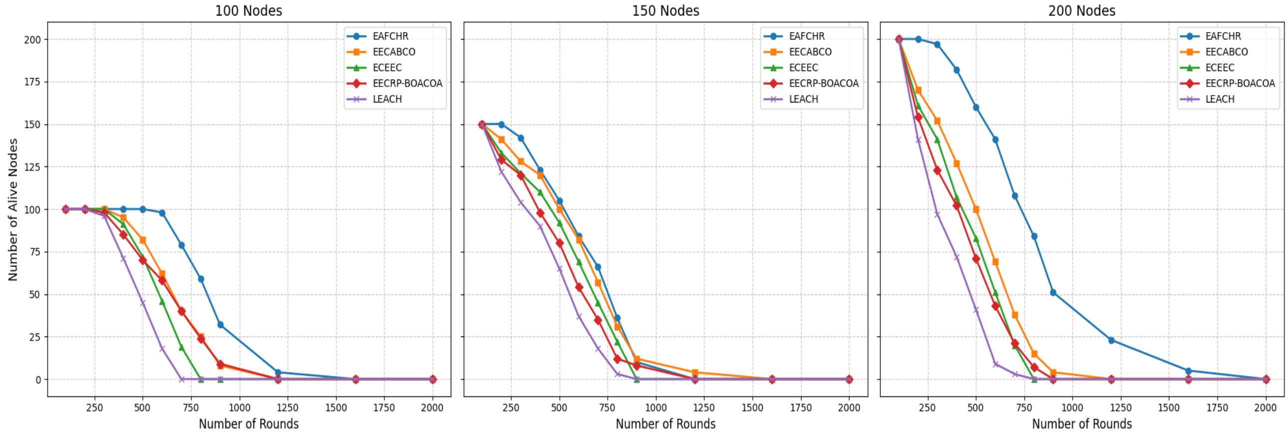

Fig. 4. Number of alive nodes analysis with 2% CHs and FCHs

B. Energy Consumption Analysis with 2% and 5% of FCHs and CHs

This section compares the recommended methodology's average energy use to existing algorithms. The recommended EECABCO, ECEEC, EECRP-BOACOA, and LEACH approaches provide average energy consumption estimates in Figures 5 and 6. In a network test environment, the energy consumption of nodes in a 100-, 150-, and 200-node network is examined. The base station (BS) is located at (100, 100), and there are 5% and 2% of CHs and FCHs. Figures 5 illustrate the average energy utilization of 100, 150, and 200 nodes respectively from the sensing zone (200, 200) for BS in the center (100, 100). Based on these data, the suggested technique is more energy efficient than EECABCO, ECEEC, EECRP-BOACOA, and LEACH. Because of random CH selection and single-hop data transport, LEACH uses more energy. EECABCO and ECEEC expend more energy because it disregards distance when picking a CH. An appropriate path from FCH to BS and FCH selection among the set of nodes contribute to the suggested methodology's energy efficiency. In this study, choose the next hop node (FCH) with the lowest distance to save energy. To minimize the energy-wasting at CHs re-selection, the traditional protocols EECABCO, ECEEC, EECRP-BOACOA, and LEACH, change the cluster head after each round without addressing energy fatigue. The proposed strategy EAFCHR transmits data to BS via multi-hop fine cluster head nodes. This method results in a decrease in both CH and FCH effort and energy use. Initial energy use is modest. The amount power utilization for each algorithm is compared in Figure 5 and 6, as well as in Table 4 and 5, with regard to the number of rounds and by making use of the 5% and 2% of CHs and FCHs, respectively. The data and results from the simulation demonstrate that the amount of energy consumption that were carried out by EFFCHR is higher than that of any other parallel research protocols (LEACH, EECABCO, ECEEC, and EECRP-BOACOA) in terms of increasing the number of nodes (100, 150, and 200) being monitored in the area.

Table 4. Using 5% CHs and FCHs, Energy Consumption in a 100, 150, and 200 Nodes Network.

No of Rounds	Energy Consumption (J)														
	EAFCHR			EECABCO			ECEEC			EECRP-BOACOA			LEACH		
	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N
100	5	5	3	13	14	13	8	8	8	10	10	11	14	14	14
200	22	16	9	31	33	21	26	27	19	35	21	23	29	29	28
300	38	24	18	48	51	33	43	48	28	68	34	31	47	44	42
400	47	37	27	62	64	46	68	66	40	92	57	42	68	63	58

500	59	50	41	73	70	58	82	89	57	121	79	61	84	84	72
600	73	66	64	98	81	77	102	107	71	143	110	79	113	112	90
700	88	85	82	120	100	95	125	123	91	159	129	98	156	143	110
800	92	102	107	148	158	114	153	148	110	185	151	105	193	168	130
900	100	120	124	160	140	134	187	167	132	211	167	125	221	190	150
1200	130	135	142	200	152	181	223	179	154	243	185	148	248	215	175
1600	170	144	164	230	159	192	238	190	181	250	199	169	250	230	199
2000	200	159	172	250	168	211	248	204	210	250	218	187	250	244	214
2500	223	172	202	250	191	232	250	224	228	250	228	205	250	250	239
2800	248	200	232	250	211	250	250	240	241	250	239	225	250	250	250
3000	250	228	241	250	250	250	250	250	250	250	250	250	250	250	250

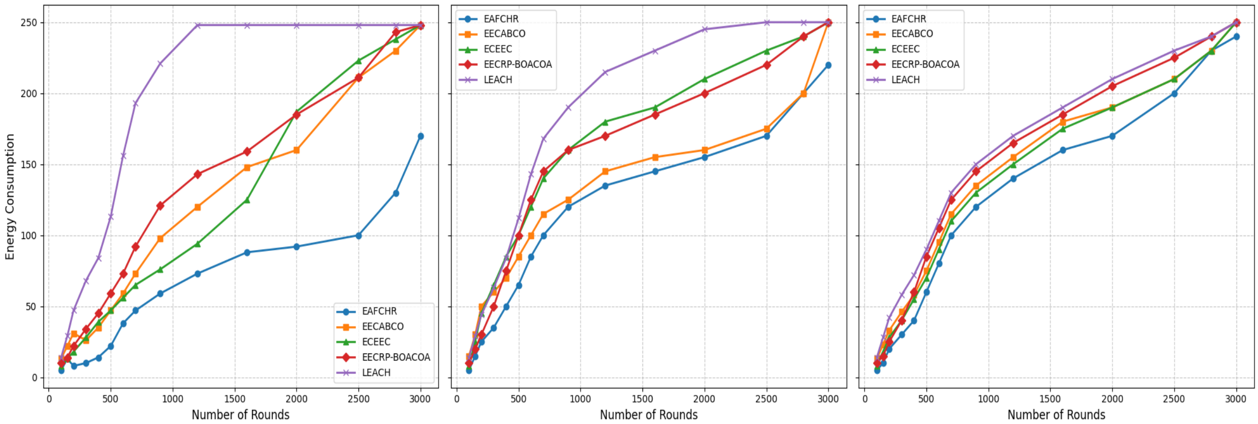

Fig. 5. Energy Consumption Analysis with 5% CHs and FCHs.

Table 5. Using 2% CHs and FCHs, Energy Consumption in a 100, 150, and 200 Nodes Network.

No of Rounds	**Energy Consumption (J)**														
	EAFCHR			**EECABCO**			**ECEEC**			**EECRP-BOACOA**			**LEACH**		
	100 N	**150 N**	**200 N**	**100 N**	**150 N**	**200 N**	**100 N**	**150 N**	**200 N**	**100 N**	**150 N**	**200 N**	**100 N**	**150 N**	**200 N**
100	10	5	5	16	15	13	19	8	8	16	10	10	18	14	14
200	22	14	9	48	30	23	35	25	18	31	18	15	32	29	31
300	39	23	19	71	52	34	82	45	29	49	29	24	51	44	43
400	51	33	31	98	64	46	109	66	42	71	52	42	98	63	61
500	74	52	42	105	77	58	148	92	56	104	77	62	124	84	77
600	100	67	66	131	89	75	195	105	77	134	108	89	173	112	96
700	128	88	87	169	111	95	210	124	92	179	131	107	201	143	118
800	168	102	107	204	120	115	241	140	115	210	148	127	243	168	136
900	214	121	132	248	131	135	250	162	134	250	162	142	250	190	158
1200	245	138	146	250	149	155	250	185	152	250	172	168	250	215	176
1600	250	142	162	250	159	180	250	196	180	250	190	188	250	230	199
2000	250	156	177	250	168	190	250	215	194	250	205	208	250	245	219
2500	250	170	200	250	184	210	250	236	214	250	230	229	250	250	245
2800	250	204	225	250	220	237	250	241	234	250	250	250	250	250	250
3000	250	220	235	250	250	250	250	250	250	250	250	250	250	250	250

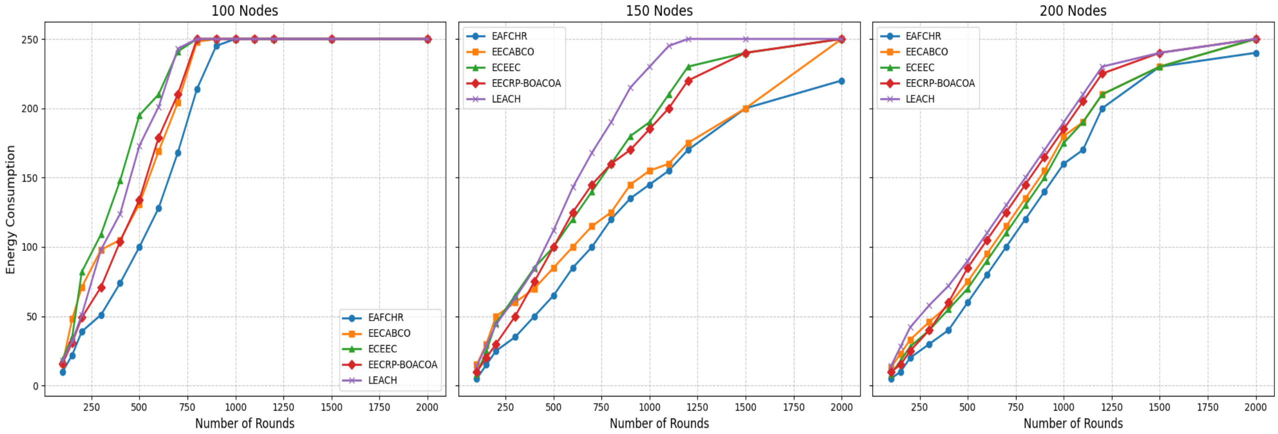

Fig. 6. Energy Consumption Analysis with 2% CHs and FCHs.

C. Packet Received Ratio with 2% and 5% of CHs and FCHs

Given varying CH and FCH percentages, average data transfer is assessed. As shown in Figure 7 for the average packet transfer when all devices (sensors) send information to the BS via CH using single or multi-hop FCHs. LEACH, EECABCO, ECEEC, and EECRP-BOACOA routing protocols have lower data transfer rates than the developed EEFCHR. The lowest data transmission rate occurs at 2% FCHs and CHs owing to increased node distance and energy consumption. The average rate increases when the number of FCHs and CHs exceeds 5%. Thus, FCH and CH percentages greatly affect HWSN data transmission. More FCHs and CHs may boost transmission rates by reducing node distances. Optimizing routing protocol and avoiding latency involves the base station. To maximize transmission efficiency and network stability, we aim to balance CHs and FCHs for optimal performance and handle energy and congestion challenges. For two situations and distinct nodes, total packets transferred to BS are analyzed. LEACH, EECABCO, ECEEC, and EECRP-BOACOA algorithms' BS packet performance assessment. The proposed technique receives more packets at the BS than LEACH, EECABCO, ECEEC, and EECRP-BOACOA in scenarios 1 and 2. The packet received ratio for each algorithm is compared in Figure 7 and 8, as well as in Table 6 and 7, with regard to the number of rounds and by making use of the 5% and 2% of CHs and FCHs, respectively. The data and results from the simulation demonstrate that the number of alive nodes that were carried out by EFFCHR is greater than that of any other parallel research protocols in terms of increasing the number of nodes (100, 150, and 200) being monitored in the area.

Table 6. Using 5% CHs and FCHs, Packet Received Ratio in a 100, 150, and 200 Nodes Network.

No of Rounds	Packet Received Ratio														
	EAFCHR			EECABCO			ECEEC			EECRP-BOACOA			LEACH		
	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N
100	4	4	4	2	3	4	1	2	3	2	2	3	1	2	3
200	7	8	9	4	5	6	3	4	5	2	3	4	4	5	6
300	8	9	11	6	7	8	3	5	7	2	4	5	6	7	8
400	10	11	13	7	9	10	5	7	9	3	6	6	7	8	9
500	12	13	15	9	11	12	5	8	10	4	7	7	8	9	11
600	14	16	18	10	12	14	7	9	11	4	9	9	8	10	12
700	16	18	21	10	12	14	7	9	13	7	10	10	10	12	14
800	18	20	23	14	16	18	9	11	14	8	10	12	12	14	16
900	20	22	25	14	16	19	10	12	15	8	12	13	14	16	18
1200	20	22	25	15	17	20	10	13	16	10	14	15	15	17	19

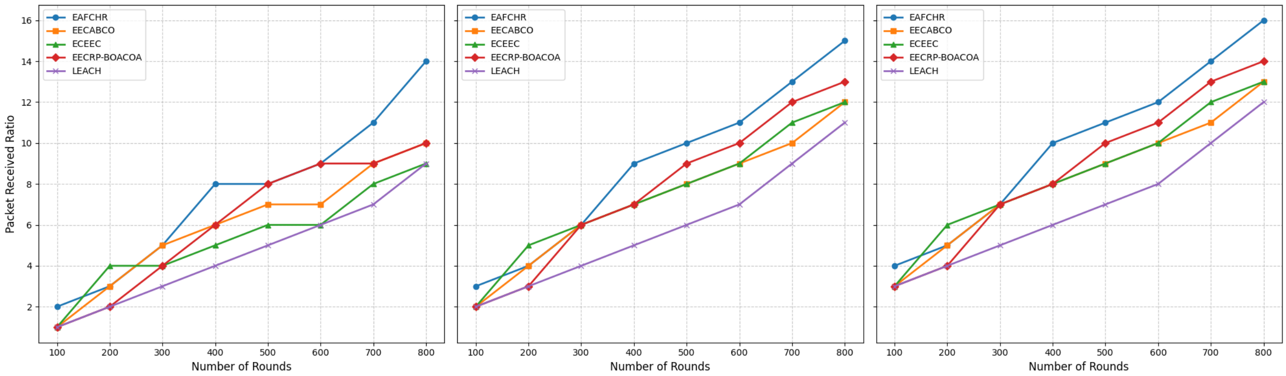

Fig. 7. Packet Received Ratio with 5% CHs and FCHs.

Table 7. Using 2% CHs and FCHs, Packet Received Ratio in a 100, 150, and 200 Nodes Network.

No of Rounds	Packet Received Ratio														
	EAFCHR			EECABCO			ECEEC			EECRP-BOACOA			LEACH		
	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N	100 N	150 N	200 N
100	2	3	4	1	2	3	1	2	3	1	2	3	1	2	3
200	3	4	5	3	4	5	4	5	6	2	3	4	2	3	4
300	5	6	7	5	6	7	4	6	7	4	6	7	3	4	5
400	8	9	10	6	7	8	5	7	8	6	7	8	4	5	6
500	8	10	11	7	8	9	6	8	9	8	9	10	5	6	7
600	9	11	12	7	9	10	6	9	10	9	10	11	6	7	8
700	11	13	14	9	10	11	8	11	12	9	12	13	7	9	10
800	14	15	16	10	12	13	9	12	13	10	13	14	9	11	12

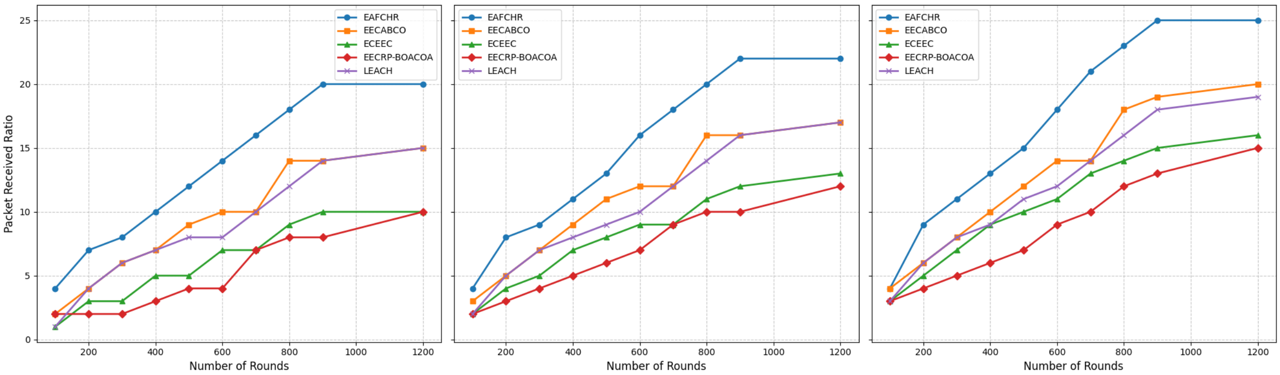

Fig. 8. Packet Received Ratio with 2% CHs and FCHs.

D. Throughput Comparison Analysis

Throughput is compared between the proposed approach and traditional clustering methods in this section. Throughput analysis for proposed, EECABCO, ECEEC, EECRP-BOACOA, and LEACH technique is shown in figures 9. The analysis evaluates by placing the BS in the middle and distance from the field. Figures 9 demonstrate the suggested approach outperforms the other four methods in throughput. First scenario sensors send approximately 1000 packets to sink node (BS), packet received ratio of proposed EAFCHR is 98.7% whereas other traditional CH based models (EECABCO, ECEEC, EECRP-BOACOA, and LEACH) PRR is 92.3%, 91.1%, 96.6%, and 89.0% respectively. In second scenario sensors send approximately 2000 packets to sink node (BS), packet received ratio of proposed EAFCHR is 98.8% whereas other traditional CH based models PRR is 91.2%, 89.9%, 95.0%, and 84.0% respectively. First scenario sensors send approximately 3000 packets to sink node (BS), packet received ratio of proposed EAFCHR is 98.9% whereas other traditional CH based models PRR is 90.3%, 88.8%, 93.3%, and 85.6% respectively. Figure 9 and table 8 shows that the network throughput of the recommended EEFCHR algorithms with increasing nodes from 100 to 200 within area 200 * 200, BS coordinates is (100, 100). Our EEFCHR algorithm, as implemented, integrates power utilization considerations in Clustering, Fine Cluster Heads Selection, and Routing phases. The FCHs select the most accurate and efficient mechanism in each level, to gain great level of scalability when compared to parallel research algorithms. Lower throughput is due to LEACH and ECEEC sensors losing energy quicker than the suggested technique. The major cause of increased energy usage is improper CH selection in EECABCO, ECEEC, EECRP-BOACOA, and LEACH. Our technology sends more data than previous methods owing to effective FCH and CH selection and optimized path design. The proposed EAFCHR approach decreases the routing overhead and PDR compared to traditional clustering algorithms. The fitness function in the proposed strategy reduces data transmission losses. The BS receives more data packets by preventing node failures during route creation. Furthermore, EECABCO, ECEEC, EECRP-BOACOA, and LEACH lead to high packet loss ratio and routing cost owing to improper CH selection and reduced network lifespan.

Table 8. Throughput in a 100, 150, and 200 Nodes Network.

Packets Delivered	**Packet Received**														
	EAFCHR			**EECABCO**			**ECEEC**			**EECRP-BOACOA**			**LEACH**		
	100 N	**150 N**	**200 N**	**100 N**	**150 N**	**200 N**	**100 N**	**150 N**	**200 N**	**100 N**	**150 N**	**200 N**	**100 N**	**150 N**	**200 N**
1000	987	991	992	923	933	939	911	925	930	966	966	980	890	890	890
2000	1976	1996	1997	1824	1864	1890	1798	1868	1698	1900	1890	1900	1680	1680	1680
3000	2967	2870	2880	2690	2716	2789	2666	2706	2356	2801	2401	2450	2569	2245	2245

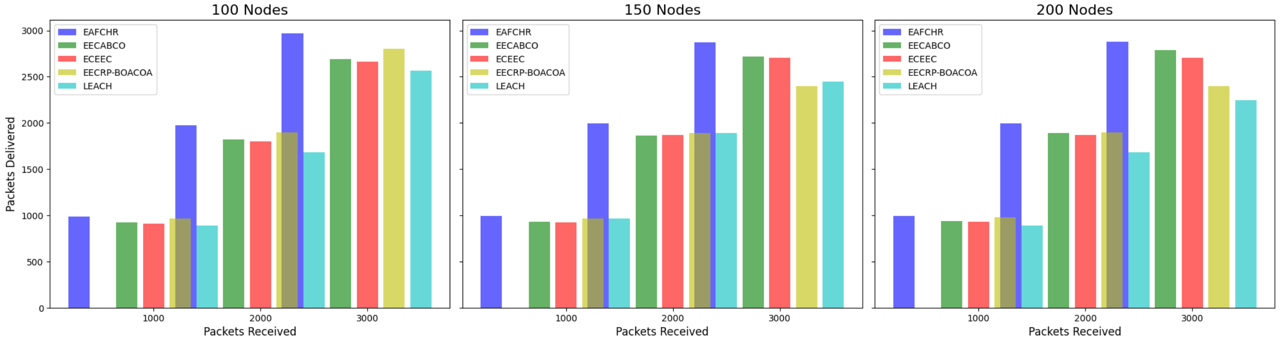

Fig. 9. Throughput comparison

5. Conclusion

In HWSN, efficient CH and FCH selection and route creation are difficult. In this paper, PSOA and ACO were adapted to decrease energy usage and enhance network lifespan. PSOA-based CH and FCH selection used seven parameters: node residual energy, fine cluster head (FCH) distance, neighbor distance, distance to BS, node mobility, node density, and centrality. The efficient CH and FCH was chosen from the nodes using this fitness function. ACO based optimization algorithm adapted to select energy-efficient route using distance to BS, average remaining energy, and node density parameters. During the proposed approach simulation, the base station went from inside to outdoors to assess performance. Compared to ECEEC, EECABCO, LEACH, and EECRP-BOACOA, the proposed technique exhibited a longer network lifespan. The suggested technique was compared against current routing methods as, EECABCO, LEACH, ECEEC, and EECRP-BOACOA. The technique demonstrated superior network performance compared to traditional WSN clustering methods. The proposed approach had 55% living nodes after 2000 rounds, which was far better than the existing methods.

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