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Energy-Efficient Cluster Head Selection via Genetic Algorithm

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ABSTRACT
Environmental monitoring and industrial automation use WSNs extensively. Since sensor nodes have limited batteries, WSNs must be energy efficient. LEACH helps WSNs capture energy-efficient data. Cluster heads affect LEACH protocol energy consumption and network lifespan. This paper improves LEACH protocol cluster head selection with the genetic algorithm Algorithm. The program chooses cluster heads that maximize network energy efficiency. Cluster heads represent solutions in the Genetic Algorithm's genetic model. Energy efficiency measures fitness, selection, crossover, and mutation boost fitness. We extensively simulated to test our proposed strategy. We compared LEACH-GA, the original LEACH protocol, and various optimization methods. This article shows 100% network lifespan improvement compared to various routing protocols including; LEACH-C, FIGWO, GA-LEACH, PSO, ABC-SD, CGTABC2& ACO, LEACH, I-LEACH, I-LEACH. Whereas it gives 54% compared to ED-LEACH, and 28% compared to GADA-LEACH. The LEACH-GA algorithm outperforms the baseline LEACH algorithm and other algorithms in energy in terms of energy efficiency, network lifetime, and data aggregation. Our paper introduces a novel cluster head selection strategy for the LEACH protocol, which advances WSNs as Genetic Algorithms are integrated. The LEACH-GA algorithm increases energy efficiency and network longevity. Thus, it offers a feasible solution for energy-constrained WSN applications to help build and deploy effective WSN protocols, improving sensor network sustainability and dependability.

Keywords:

Cluster head selection; Energy efficiency; Fitness evaluation; Genetic Algorithm; LEACH; Wireless Sensor Networks.

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1. INTRODUCTION

The broad implementation of Wireless Sensor Networks(WSNs) in recent years has fueled substantial advances in various sectors, including environmental monitoring, healthcare systems, and industrial automation. WSNs are networks of low-power, resource-constrained sensor nodes that gather and send data to a central base station or sink node. Due to the limited power resources of these sensor nodes, which directly influence network lifetime and performance, optimizing energy efficiency in WSNs is critical [1]. The selection of cluster heads, which operate as mediators between sensor nodes and sink nodes, is essential in determining the energy efficiency of WSNs. The goal of cluster head selection algorithms is to distribute energy consumption fairly among sensor nodes, reduce communication overhead, and increase network lifetime.

Traditional methods, such as the Low-Energy Adaptive Clustering Hierarchy (LEACH) algorithm, frequently rely on randomized or probabilistic procedures, resulting in inefficient cluster head selection and untapped energy savings potential [2]. To solve these constraints, this work proposes using Genetic Algorithms (GAs) to optimize cluster head selection in WSNs. GAs, based on natural evolution concepts, have proven to help tackle complex optimization problems in various disciplines. A GA-based approach is used in this study to discover an ideal selection of cluster heads that maximize energy efficiency and improve network performance [2]. The proposed GA-based cluster head selection algorithm works in stages: first, sensor nodes are randomly assigned to clusters, and a fitness function is created considering parameters such as energy usage, network connectivity, and load balancing. The GA creates a population of potential solutions through repeated generations using genetic operators such as selection, crossover, and mutation. Individual cluster head configurations are evaluated for fitness throughout each generation, with only the fittest solutions advancing to the next generation [3].

Recent advances in WSN research have seen significant gains in using evolutionary algorithms, especially genetic algorithms, to optimize various network characteristics. For example, [1] proposes a modified evolutionary algorithm to improve cluster head selection in WSNs, exceeding existing algorithms regarding energy efficiency and network lifetime. Genetic algorithms have gained popularity because of their capacity to solve complex optimization issues and find near-optimal solutions. Using evolutionary algorithms, researchers investigated several aspects of cluster head selection and energy efficiency in WSNs [4]. One study [5], in particular, presents an improved evolutionary algorithm combined with fuzzy logic to improve cluster head selection. The fuzzy logic system modifies the importance of fitness function characteristics such as residual energy, distance to the base station, and sensor node density. Compared to previous ways, this strategy improves energy efficiency and network lifetime. Furthermore, multi-objective optimization for cluster head selection is introduced in [6] allowing the evolutionary algorithm to address numerous objectives simultaneously, such as energy consumption, network coverage, and communication overhead. A Pareto-based genetic algorithm creates non-dominated solutions that represent trade-offs between multiple objectives, allowing network designers to select a cluster head configuration that meets their individual needs [7]. Furthermore, advances in machine learning approaches have substantially impacted cluster head selection in WSNs. A hybrid technique is used in [8], which combines genetic algorithms and machine learning, with the genetic algorithm exploring alternative cluster head configurations and a machine learning classifier evaluating fitness based on previous data. This method improves cluster head selection accuracy by utilizing previous network activity. The primary contributions of this research are enumerated as follows: The application of the Genetic Algorithm for the selection of cluster heads in the LEACH protocol in wireless sensor networks offers several significant advantages, as observed in the outcomes of our proposed protocol, namely GCH-LEACH. The aforementioned benefits can be succinctly outlined as follows:

- Improved Energy Efficiency: The GA provides energy-efficient cluster head selection. The GA selects candidates with greater energy resources and communication capabilities based on energy levels and base station proximity, lowering energy usage and enhancing network lifespan.
- Adaptability and Flexibility: The GA-based solution adapts to various network settings and environmental variables. Tuning the algorithm's parameters to account for node density, communication range, energy models, and quality of service needs ensures optimal performance in varied scenarios.
- Dynamic and Adaptive Cluster Head Selection: The GA allows dynamic and adaptive cluster head selection, favoring nodes with higher energy and communication capabilities. This adaptability prevents network partitions and optimizes data aggregation, reducing premature energy depletion.
- Optimization Potential: The GA's iterative nature allows for continuous optimization and refinement of cluster head selection. By evaluating and evolving potential solutions through selection, crossover, and mutation Operations. The GA converges toward optimal or near-optimal cluster head choices, further enhancing energy efficiency in the network. The primary concern addressed in this research study pertains to the energy efficiency challenges encountered by WSNs, which can impose constraints on their operational effectiveness and longevity. The careful selection of cluster heads is a crucial determinant of the energy efficiency of WSNs since these specific nodes assume a pivotal function in the aggregation and transmission of data. Nevertheless, the current cluster head selection algorithms may not be adequately optimized in terms of energy economy, resulting in inferior performance and a diminished lifespan of the network. The objective of this study is to bridge this existing research gap by presenting a novel approach for the selection of cluster heads through the deployment of the genetic algorithm. This algorithm is specifically developed to optimize energy consumption and extend the overall operational lifespan of the network. The suggested technique aims to enhance energy efficiency in the network by iteratively assessing and

refining viable solutions using selection, crossover, and mutation operations. This iterative process facilitates the convergence towards optimal or near-optimal cluster head selections. This study addresses a research gap by presenting a thorough and efficient method for selecting cluster heads in WSNs with a specific focus on enhancing energy efficiency.

The remainder of this paper is structured as follows;In section 2, related works, clustering, cluster-based routing, energy efficiency, and optimization techniques for cluster head selection in wireless sensor networks routing methods are studied. Section 3 discusses the model of the network and radio communication system and explains the proposed systems by highlighting the newly proposed algorithm. In Section 4, the proposed system uses optimal CH using the genetic algorithm. Section 5 discusses the modeling and observations of the obtained results for different parameters, then the overall performance is evaluated by comparing it with the existing systems based on results. Finally, section 6 provides conclusions to this work.

2. RELATED WORKS

The selection of cluster heads in WSNs plays a critical role in optimizing energy efficiency, extending network lifetime, and facilitating data aggregation. Optimization approaches such as genetic algorithms, differential evolution, bat algorithms, African vulture optimization, grey wolf optimization, and fuzzy logic have been chosen to enhance performance through the selection of suitable cluster heads. These approaches take into account several aspects such as the energy level of nodes, the distance between nodes, and the heterogeneity of the network. Nevertheless, certain methodologies may possess inherent constraints. The paper [1] proposed a differential evolution-based routing algorithm for wireless sensor networks used in environmental monitoring. The algorithm optimizes the routing paths to conserve energy and prolong the network lifetime. In [2], the authors presented an improved version of the LEACH protocol using the bat algorithm for wireless sensor networks. The authors optimize the clustering process to enhance energy efficiency and extend the network lifetime. The authors in [3] introduced a cluster head selection technique based on the African Vultures Optimization Algorithm (AVOA) for wireless sensor networks. The algorithm aims to optimize the selection of cluster heads to improve the network's overall performance.

The authors in [4] proposed an improved Grey Wolf Optimization (GWO) algorithm for energy-efficient cluster head selection in WSNs. The algorithm optimizes the selection of cluster heads to minimize energy consumption and prolong the network lifetime. The authors in [5] present a new energy-efficient clustering algorithm for wireless sensor networks using fuzzy logic and genetic algorithms. The proposed algorithm aims to minimize energy consumption by optimizing the selection of cluster heads based on network parameters. In the article [6], the researchers proposed a novel evolutionary algorithm for cluster head selection in heterogeneous wireless sensor networks. The algorithm is designed to enhance the selection process by effectively managing energy consumption and prolonging the overall lifespan of the network. A novel Multi-objective Cluster Head-based Energy-aware Optimized Routing (MCH-EOR) algorithm explicitly designed for wireless sensor networks is presented in [7]. The algorithm considers various objectives, such as enhancing energy efficiency and optimizing routing, to enhance the network's overall performance. In [8], the authors used the genetic algorithm to present an energy optimization technique for wireless sensor networks. The algorithm aims to optimize the deployment of sensor nodes to minimize energy consumption and prolong the network lifetime. Combining the multi-objective genetic algorithm and the gravitational search algorithm to optimize the selection of cluster heads in wireless sensor networks is done in [9]. The proposed approach considers multiple objectives, including energy efficiency and network stability. In [10], the authors proposed a genetic algorithm-based optimized LEACH protocol for energy-efficient wireless sensor networks. The authors optimize the selection of cluster heads and data aggregation to improve energy efficiency. The researchers in [11] suggested a new evolutionary algorithm for cluster head selection in heterogeneous WSNs. The algorithm optimises energy consumption and prolongs the network lifetime by selecting appropriate cluster heads. The authors in [12] introduced LEACH-GA, a novel adaptive clustering protocol for wireless sensor networks to achieve energy efficiency. This protocol incorporates the principles of LEACH, a popular clustering algorithm, and the genetic algorithm. The objective is to optimize the selection process of cluster heads by considering their energy levels as a crucial criterion. In [13], the authors proposed optimizing the network topology and deployment to improve network performance. The paper focuses on the adaptive design optimization of wireless sensor networks using genetic algorithms. The researchers in [14] presented an optimized cluster head selection method for heterogeneous wireless sensor networks using the genetic algorithm. The proposed algorithm focuses on improving network performance by optimizing the selection of cluster heads, whether it involves a single data sink or multiple data sinks. The goal is to enhance the overall efficiency and effectiveness of the network. The authors proposed an enhanced approach in their paper [15] and introduced a genetic algorithm-driven optimization method for selecting cluster heads in wireless sensor networks. The algorithm aims to extend the network's lifespan by identifying cluster heads with optimal energy levels. The proposed approach aims to enhance the network's overall energy efficiency and prolong its operational duration. The paper's authors proposed an enhanced approach in their study referenced as [16] and discussed a genetic algorithm-based optimization method for cluster head selection in wireless sensor networks, focusing on prolonging the network lifetime through optimal cluster head selection. The research [17] presented an extensive review encompassing diverse clustering strategies in wireless sensor networks, covering classical optimization and machine learning approaches. It offers a comprehensive field examination, highlighting key findings, addressing challenges, and providing insights into future directions. The paper is a valuable resource for understanding the current state of clustering techniques and paving the way for further advancements in the field. The authors offered in [18] to examine the efficacy of a hybrid optimization algorithm in virtual head selection within wireless sensor networks. The efficiency of the algorithm is assessed by the authors with energy consumption and network lifetime. The research team proposed a new technique for their research in [19]. They introduced a novel clustering protocol for wireless sensor networks that leverages the genetic algorithm approach. The proposed algorithm focuses on optimizing the selection of cluster heads to enhance network performance. The protocol aims to improve the overall efficiency and effectiveness of the network's cluster head selection process by employing the genetic algorithm. The researchers in the prior research [20] introduced a cluster head selection technique for wireless sensor networks based on a genetic algorithm approach and aimed to optimize the process. The proposed approach aims to improve network performance by selecting cluster heads with optimal energy levels. In [21], the authors present a genetic algorithm for energy harvesting in wireless sensor networks. The algorithm's primary objective is optimizing the energy harvesting process and enhancing the network's overall energy efficiency. The literature reviewed in this research examines several elements of cluster head selection, routing, and energy optimization in WSNs. The papers put forth a range of algorithms and techniques aimed at enhancing network performance, optimizing energy usage, and prolonging the lifespan of the network. One scholarly article presents a routing method for environmental monitoring that utilizes differential evolution. This algorithm aims to optimize routing paths and extend the lifespan of the network. The literature review showcases the significance of energy economy in WSNs and emphasizes the necessity of efficient cluster head selection algorithms for optimizing network performance and longevity.

3. MODEL OF THE NETWORK AND RADIO COMMUNICATION SYSTEM

The Genetic Cluster Head LEACH (GCH-LEACH) protocol, as proposed in this study, incorporates a network model that is based on a set of predetermined assumptions; the Base Station (BS) is a device that possesses ample resources. After their deployment, all sensor nodes remain in a stationary position. Each sensor is equipped with a Global Positioning System (GPS) chip or another device for determining location. Sensor nodes that are situated nearby demonstrate a correlation in their collected data. Because of the communication channel's symmetry, the energy required to convey a message from sensor node s1 to sensor node s2 is equal to the energy needed for the opposite direction of transmission. The transmission in the opposite direction (from node s2 to node s1) is contingent upon meeting a specified signal-to-noise ratio.

We assume that the radio hardware energy dissipation follows the straightforward model depicted in Figure 1, where the transmitter emits energy to power the radio electronics and the power amplifier, and the receiver emits energy to power the radio electronics.

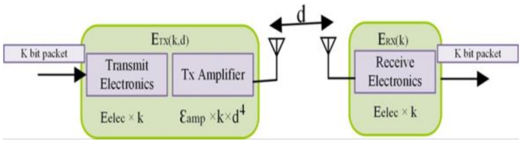


Fig. 1 The Radio Energy Dissipation Model.

Depending on the distance between the transmitter and receiver, both the free space (d^2 power loss) and the multipath fading (d^4 power loss) channel models were utilized for the experiments reported here. Thus, the radio needs to spend the following to send a k-bits message d meters away: The proposed GCH-LEACH protocol is analyzed using the radio model presented in the first reference [22], illustrated in Figure 1. Eq. (1, 2, and 3) provides the expression for the transmitted and received energy over k-bits. Where:

$$E_{TX}(k,d) = E_{TX-elec}(K) + E_{TX-amp}(k,d) \quad (1)$$

$$E_{TX}(k,d) = \begin{cases} k \times E_{elec} + k \times \varepsilon fs \times d^2 & d < d_0 \\ k \times E_{elec} + k \times E_{TX-amp} \times d^4 & d \geq d_0 \end{cases} \quad (2)$$

$$E_{RX} = K \times E_{elec} \quad (3)$$

$E_{Tx}(k,d)$: The Total transmitted energy concerning packet size and distance between the transmitter and receiver. $E_{TX-elec(K)}$: The Transmitter electron energy for packet size. $E_{Tx}(k,d)$: The Total transmitted energy concerning packet size and distance between the transmitter and receiver. $E_{TX-elec(K)}$: The Transmitter electron energy for packet size. $E_{Tx-amp}(k,d)$: The Transmitted amplification energy concerning packet size and distance between the transmitter and receiver. E_{RX}: The Transmitted received energy.

$$d_0 = \sqrt{\varepsilon fs / E_{Tx-amp}} \quad (4)$$

$$d = \sqrt{(x2 - x1)^2 + (y2 - y1)^2} \quad (5)$$

The threshold distance is an important factor in determining the electronic energy (Eelec) of a signal. This energy is influenced by various factors such as the digital coding, modulation, filtering, and spreading techniques employed. On the other hand, the energy of the amplifier ($\varepsilon fs\ d^2$ or $E_{Tx-amp}\ d^4$) is contingent upon the distance between the source and the receiver, as well as the permissible bit-error rate. Let us consider a hypothetical scenario in which a set of N nodes is uniformly distributed throughout a region with dimensions M × M. In the context of L clusters, where each cluster is composed of mi member nodes (where i = 1, 2, ..., L), the CH consumes energy through the process of receiving signals from its member nodes, aggregating these signals, and subsequently transmitting the aggregated signal to the BS. Therefore, the amount of energy dissipated by the CH node in the ith cluster during a single frame can be calculated using Eq. 6.

$$E_{CH}(i,k,d) \begin{cases} (k \times E_{elec} \times m_i + k \times E_{DA}(m_i+1) + k \times E_{elec} + k \times \varepsilon fs \times d_{i-to\ BS}^2) \\ \text{if } d_{i-to\ BS} < d_0 \\ (k \times E_{elec} \times m_i + k \times E_{DA}(m_i+1) + k \times E_{elec} + k \times E_{Tx-amp} \times d_{i-to\ BS}^4) \\ \text{if } d_{i-to\ BS} \geq d_0 \end{cases} \quad (6)$$

In the given equation, the variable k is used to symbolize the number of bits contained within each data message, $d_{i\text{-}toBS}$ denotes the distance between the i^{th} CH node and the BS, and perfect data aggregation is assumed. Every member node is required to transmit its sensed data to the respective CH once within a frame. As a result, the energy dissipated by each member node can be calculated using Eq. 7. Where $d_{l\text{-}toCH}$ represents the distance between the l^{th} member node and its corresponding CH.

$$E_{mem-i}(l,k,d) = \begin{cases} k \times E_{elec} + \varepsilon fs \times k \times d_{l-to\ CH}^2 & \text{if } d_{l-to\ CH} < d_0 \\ k \times E_{elec} + E_{Tx-amp} \times k \times d_{l-to\ CH}^4 & \text{if } d_{l-to\ CH} \geq d_0 \end{cases} \quad (7)$$

E_{DA}: The energy dissipated for aggregation data. $E_{CH}(i,k,d)$: The energy dissipated by each CH node. $E_{mem-i}(l,k,d)$: The energy dissipated by each member node.

4. THE PROPOSED METHODOLOGY

The concept of organizing sensor nodes into clusters has been extensively explored by researchers aiming to enhance network scalability and prolong network lifespan. Each cluster typically includes a designated leader, commonly known as the CH, as illustrated in Figure 2.

Originally, the hierarchical protocol was initially utilized for power conservation in wired networks. However, it was later adapted for WSNs to achieve an extended network lifetime and reduced energy consumption. The LEACH protocol, introduced by Heinzelman [22] was the first adaptive protocol implemented in WSNs for CH selection. LEACH employs a random distribution, self-organization, and normal cluster selection method based on round-based techniques [23].

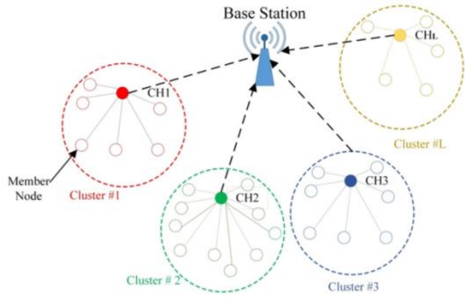


Fig.2 The Hierarchical Clustering Structure.

The primary goal of the LEACH protocol is to minimize power consumption, which is achieved through appropriate cluster selection in two Phases; the setup phase and the steady state phase. During the setup phase, the BS transmits messages to all control nodes, known as CHs. The selection of CHs is based on a threshold value T(n), which takes into account the probability of becoming a CH (p), the current round (r), and the remaining non-CHs in the last 1/p rounds, as represented by Eq. 8.

$$T(n) = \begin{cases} \dfrac{p}{1 - p\left(r \bmod \frac{1}{p}\right)} & \in G \\ 0 & \text{if } n \notin G \end{cases} \quad (8)$$

The network employs a random number generation process, generating a sequence of random numbers consisting of 0s and 1s for each node. If the generated number is lower than the threshold value T(n), the respective node is designated as a control node for its cluster, while the remaining nodes function as non-cluster heads or Cluster Members (CMs). In the steady state phase, CMs receive requests from CHs to join their clusters for data transmission. Subsequently, data is transmitted from the CHs to the sink node through the non-CH nodes. It is important to note that the node location and residual energy levels are not taken into consideration during the CH selection process. In GCH-LEACH, a preparation phase is introduced to select the optimal cluster head probability using the GA. This phase takes place in the first round, before the setup and steady-state phases. Similar to the LEACH protocol, each node in the network selects its candidate CHs following a prescribed procedure. Subsequently, the node ID, CH information, and node location are transmitted from each node to the BS. Upon receiving this information, the GA is applied by the BS to determine the optimal cluster head probability (Popt). The calculated Popt value is then broadcasted from the BS to all nodes, initiating the setup and steady-state phases. The overall process of the GCH-LEACH protocol is illustrated in Figure 3. GCH-LEACH is a means to identify the best cluster head optimal value, Popt. The energy consumption per node for the CH can be calculated using equations 1,2,3,6, and 7 as already explained. We used the genetic algorithm to determine an optimal probability for the cluster head (Popt). Following setup, the steady-state phase will begin with the broadcasting of the chosen Popt value via to BS to all nodes as shown shown in Figure 3. In our proposed approach, the selection of cluster heads is performed using the GA. The GA takes into account various factors to elect the cluster heads, such as the distance between cluster heads and the BS, the number of cluster formations in the network, the remaining energy levels of the nodes, the distances between cluster heads, and the distances between cluster heads and CMs as illustrated below. Let x be the x-coordinate of the node, y be the y-coordinate of the node, and the cluster head status (1 if a node is a cluster head, 0 otherwise).

1. Calculate the distance from the node to the base station:

Distance To Base Station $d_{i-to\ BS} = \sqrt{(x^2 + y^2)}$

2. Calculate fitness based on different factors:

a) Consumer Energy Fitness: Consumer Energy Fitness (F_{CE}) = calculate Consumer Energy Fitness (chromosome)

b) Distance to BS Fitness: Distance To BS Fitness ($F_{di\text{-}to\ BS}$) = 1 / $d_{i-to\ BS}$

c) Number of Nodes Fitness: Num Nodes Fitness (F_N) = num Nodes / (num Nodes + 1)

d) Number of Nodes in Each Cluster Fitness: Num Cluster Nodes Fitness ($F_{Cluster}$) =1/(num Nodes + 1)

e) Network Area Fitness: Network Area Fitness (F_{Area}) = (network Area / (max(x, y)^2)

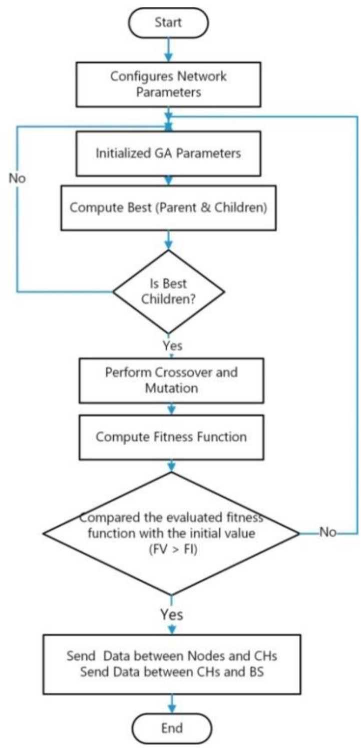


Fig. 3 The Flow Chart of the CH Selection Algorithm in the Proposed GCH-LEACH Protocol.

f) Calculate the overall chromosome fitness: Chromosome Fitness = Consumer Energy Fitness × distance To Base Station Fitness × num Nodes Fitness × num Cluster Nodes Fitness × network Area Fitness

- Fitness = $F_{CE} + F_{di\text{-}to\ BS} + F_N + F_{Cluster} + F_{Area}$

This equation represents the calculation of fitness. The fitness function evaluates the chromosome configuration by taking into account multiple factors, such as network lifetime, total energy consumption, and load balancing. It considers the number and positions of cluster heads, the distances between cluster heads and the base station, the proportions of each cluster, and the load balancing across clusters. By analyzing these parameters, the fitness function determines the system's overall efficacy.

5. RESULTS AND DISCUSSIONS

In this section, MATLAB simulations are performed to analyze and evaluate the performance of the proposed protocol. The proposed GCH-LEACH approach is assessed in this paragraph through a series of experiments conducted using MATLAB, and its efficacy is evaluated in comparison to alternative protocols. The first-order energy model that was discussed in Section 3 was used in subsequent experiments to calculate the amount of energy consumption that can be attributed to communication, to maintain a fair comparison. To minimize the impact of randomization, the experiment was repeated five times on distinct networks. The final result was determined by calculating the average of these repetitions. The simulation model's parameters were adjusted in Table 1.

Table 1: The simulation model's parameters.

Parameters	Values
Size of the network	$100 \times 100\ m^2$
Number of nodes	100,200
Packet size	2000,4000 bits
Initial energy, E_0	0.2 , 0.3, 0.5, 1 J/node
Transmitter energy, E_{TX}	50 nJ/bit
Receiver energy, E_{RX}	50 nJ/bit
Amplification energy for short distances, εfs	10 pJ/bit/m^2
Amplification energy for long distances, $\boldsymbol{Emp}$	0.0013 PJ/bit/m^2
Data aggregation energy, Eda	0.0013 pJ/bit/m^2
Maximum number of Iteration	5
Number of population	10

To facilitate a comparison between the proposed protocol and the LEACH protocol [24][25][26], A simulation was performed using a total of 100 homogeneous nodes. The nodes were initially assigned an energy level of 0.5J and distributed randomly throughout a sensor field with dimensions of 100 × 100 m², as illustrated in Figure 4. The BS was positioned in the center at coordinates (50, 50) meters, represented as a green star, normal nodes (small circles) joined to elected cluster heads (black star) are represented in blue lines, we we note that some normal node did not joint to any CH because if the distance and also the transmitted packets comprised 2000 bits, including 100 bits allocated for control packets. Figure 5 depicts the network lifetime comparison between the LEACH protocol at round 1561 and the proposed GCH-LEACH protocol at round 3000. Figure 6 illustrates that the GCH-LEACH protocol is a more energy-efficient option when compared to the LEACH protocol. The average throughput of GCH-LEACH is found to be higher than that of the LEACH protocol, with a value of 0.505, as illustrated in Figure 7. Figures 8 and 9 illustrate the network lifetime of the proposed protocol under various initial energy levels, specifically Eo = 0.2J, 0.3J, 0.5J, and 1J. The network lifetime values corresponding to these energy levels are 1721, 2582, 3000, and 6017 respectively. Additionally, the network stability was depicted, along with the occurrence of half of the network nodes becoming non-functional.

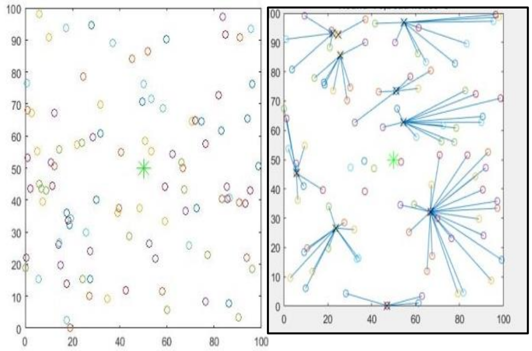


Fig. 4 Network Deployment.

The network's lifespan is 6017, 7119, and 5941, respectively. Based on the data presented in Tables 3 and 4, several conclusions can be inferred regarding the stability of the network (FND), the occurrence of half-node dead (HND), and the overall lifetime of the network (LND) across varying numbers of nodes and initial energy levels for each node. Initially, there is a decrease in the network stability when the number of nodes (N) rises from 100 to 200. Additionally, there is a decrease in the networkifetime and the occurrence of half-node failure. Also, this observation suggests that augmenting the number of nodes within the network can yield negative effects on its overall stability and performance. Furthermore, as the initial energy value (Eo) increases from 0.2J, 0.3J to 0.5J, and then to 1J. Both network stability and network lifetime experience an increase.

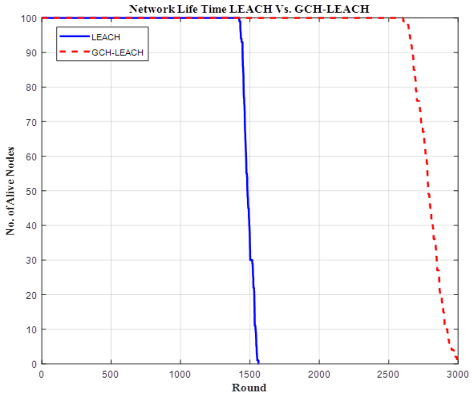


Fig. 5 Network lifetime for leach protocol vs. GCH-LEACH protocol.

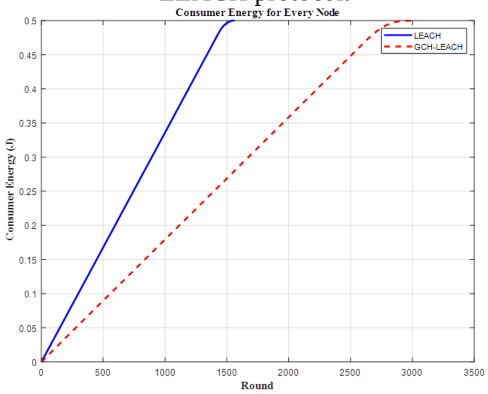


Fig. 6 Consumer energy for LEACH protocol vs. GCH-LEACH protocol.

Nevertheless, there is a simultaneous increase in the count of half-node failures, suggesting that augmenting the energy allocation per node can potentially enhance the stability of the network. However, it is important to note that this augmentation may also result in a higher occurrence of node failures. Furthermore, it is noteworthy that the network performance is influenced by the placement of nodes.

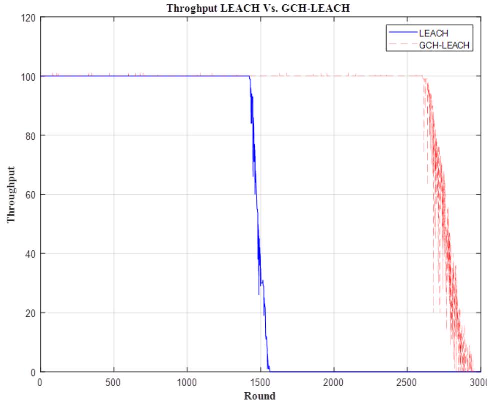


Fig. 7 Throughput for LEACH protocol vs. GCH-LEACH protocol.

For instance, the network stability and network lifetime exhibit higher values at the central location of BS (50, 50) as opposed to the peripheral location (50, 150) as shown in Figures 10 and 11. This implies that the positioning of nodes within the network can exert a substantial influence on its overall stability and performance. Additionally, the impact of packet size on network stability and lifetime is observed. Specifically, when employing a packet size of 2000, as shown in Figure 12, there is an increase in both network stability and network lifetime compared to when the packet size is set at 4000 bits. In brief, the Tables 3 and 4 illustrate that several factors, including the number of nodes, energy allocation per node, packet size, and placement of the BS, have an impact on network stability, half-node dead, and network lifetime. Furthermore, this underscores the significance of meticulous planning and customization of wireless sensor networks to maximize their overall efficiency. Figures 13, and 14, also Tables 5 and 6 illustrate that the GCH-LEACH routing protocol does exhibit superior performance compared to other routing protocols in terms of ensuring network stability across various energy levels within an IoT-based sensor network. The LEACH protocol fails to account for the energy level when determining the threshold value for CH selection. Consequently, this oversight results in the premature depletion of energy in the initial node after a few rounds, regardless of the scenario.

As shown in Table 4 and Figure 13 the performance of the network when employing the proposed protocol in comparison to other routing protocols, namely LEACH-C [27], FIGWO [28], GA-LEACH [29], PSO [30], ABC-SD [31], CGTABC2& ACO [32], LEACH [23]. I-LEACH [33], ED-LEACH [34], and GADA-LEACH [35]. The results indicate a significant improvement of 100% in network lifetime. When compared to the proposed protocol. The study examined 54% and

28% improvement in a specific context, ED-LEACH and GADA-LEACH in succession. However, it was observed that there was no improvement in network lifetime as all nodes ceased to function by round 3000. In terms of network stability, the proposed protocol demonstrated enhanced performance, with network stability achieved at round 2605 and half-node time at round 2785. In comparison, GADA-LEACH achieved network stability at round 1600 and half node time at round 2100. The CBDAS [37] and GHND [38] protocols are examples of grid-based WSNs that prioritize a limited number of parameters when selecting CHs.

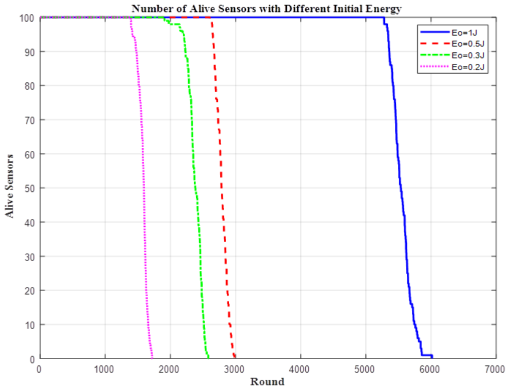
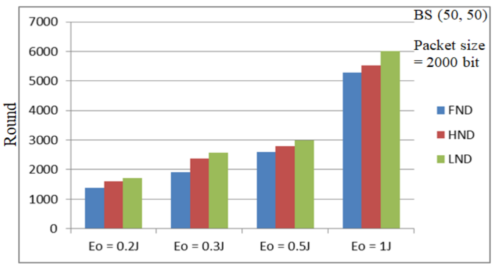


Fig. 8 The network lifetime for GCH-LEACH protocol in different initial energy.

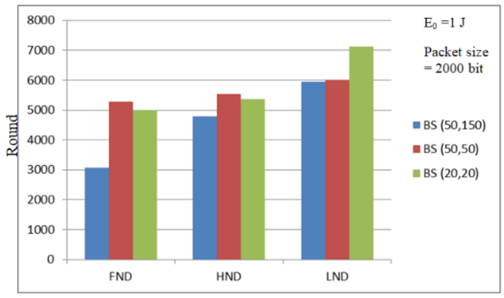


Initial Energy	FND	HND	LND
$E_0 = 0.2J$	1393	1594	1721
$E_0 = 0.3J$	1911	2382	2582
$E_0 = 0.5J$	2605	2785	3000
$E_0 = 1J$	5281	5536	6017

Fig. 9 Network performance for GCH-LEACH protocol in different initial energy

Fig. 10 Network lifetime of the GCH-LEACH protocol under varying BS positions.

These protocols have demonstrated superior performance compared to the LEACH protocol. The network is divided into zones by the IGHND [39] algorithm, which then selects a zone head based on various parameters including residual energy, average distance, and node priority. Nevertheless, the existing methods fail to take into account the optimal number of clusters in the network, leading to a suboptimal selection of cluster heads. Both GHND and IGHND take into account various parameters when selecting a zone head, however, they fail to consider the number of zones or clusters present in the network, which can significantly affect the network's longevity.



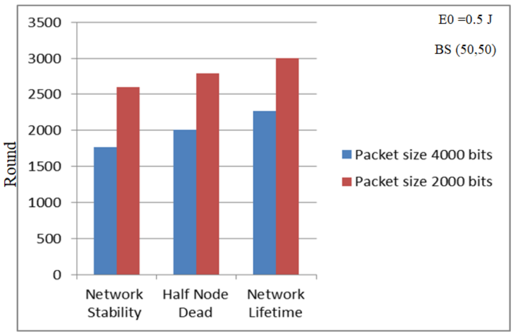
BS position	FND	HND	LND
BS (50,150)	3079	4776	5941
BS (50,50)	5280	5535	6017
BS (20,20)	5003	5358	7119

Fig. 11 Network performance of the GCH-LEACH protocol under varying BS positions.

The CBDAS protocol incurs supplementary energy consumption during the process of chain formation and data transmission from the header to the remaining nodes, thereby imposing an additional burden on the battery's longevity. This is attributed to its selection of stable nodes, such as CH.

Table 2: Comparison of network performance metrics for number of nodes =100, different initial energy, and packet size =2000 bits.

N=100, Eo =0.2J, packet size =2000			
BS Position	Network Stability	Half Node Dead	Network Lifetime
Corner (20,20)	1211	1533	1786
Center (50,50)	1393	1594	1721
Out (50,150)	517	1374	1584
N=100, Eo =0.3J, packet size =2000			
BS Position	Network Stability	Half Node Dead	Network Lifetime
Corner (20,20)	1627	2331	2655
Center (50,50)	1911	2382	2582
Out (50,150)	868	2036	2298
N=100, Eo =0.5J, packet size =2000			
BS Position	Network Stability	Half Node Dead	Network Lifetime
Corner (20,20)	2697	3835	4425
Center (50,50)	2605	2785	3000
Out (50,150)	1512	3449	3861
N=100, Eo =1 J, packet size =2000			
BS Position	Network Stability	Half Node Dead	Network Lifetime
Corner (20,20)	5003	5358	7119
Center (50,50)	5281	5536	6017
Out (50,150)	3079	4776	5941



GCH-LEACH	Network Stability	Half Node Dead	Network Lifetime
Packet size 4000 bits	1766	2013	2264
Packet size 2000 bits	2604	2785	3000

Fig. 12 Network performance of the GCH-LEACH protocol under varying packet sizes.

In an IoT context, the optimization of network stability and network lifetime is of utmost importance to maintain a consistently high level of network performance. Network Stability refers to the duration from the initiation of the network until the occurrence of the first node failure (FND), whereas Network Lifetime denotes the interval between the FND and the eventual failure of the last node (LND) within the network. To assess the effectiveness of the proposed GCH-LEACH protocol concerning the aforementioned metrics, an examination was conducted on various parameters, including HND within the network. To ensure a comprehensive evaluation in line with contemporary approaches suggested for WSN based on the IoT, such as IGHND, GHND, and CBDAS, a fair comparison was conducted. The consideration of both important parameters by GCH-LEACH contributes to an enhanced and consistent network performance. FND to gauge network stability, LND to determine network lifetime, and HND within the network. To ensure a comprehensive evaluation in line with contemporary approaches suggested for WSNs based on the IoT, such as IGHND, GHND, and CBDAS, a fair comparison is conducted. The consideration of both important parameters by GCH-LEACH contributes to an enhanced and consistent network performance.

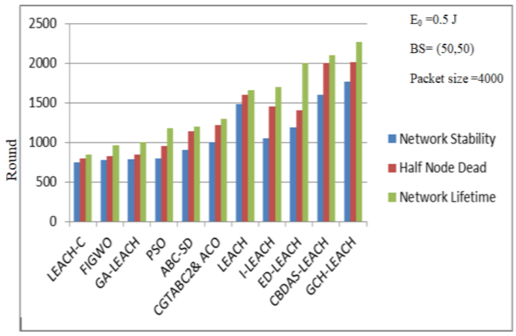


Fig. 13 The network performance of the GCH-LEACH protocol compared to other routing protocols with an initial energy of 0.5J.

The primary objective of the GCH-LEACH model is to optimize the longevity of the network by extending the duration of operational rounds and augmenting the transmission of packets to the BS in comparison to GCA [36], EAERP [36], GAECH [36], LEACH, CBDAS [37], GHND[38], and IGHND [39] as Shown in table 5 and figure 14. Demonstrates superior performance in terms of LND, HND, and FND across all energy levels. The percentage of improvement was successive 100%, 100%, 100%, 100%, 96%, 87%, 63%.

Table 3: Comparison of network performance metrics for number of nodes =200, different initial energy, and packet size =2000 bits.

N=200, Eo =0.2J, packet size =2000			
BS Position	Network Stability	Half Node Dead	Network Lifetime
Corner (20,20)	1396	1610	1829
Center (50,50)	1422	1653	1756
Out (50,150)	985	1465	1656
N=200, Eo=0.3J, packet size =2000			
BS Position	Network Stability	Half Node Dead	Network Lifetime
Corner (20,20)	1964	2428	2685
Center (50,50)	2235	2465	2627
Out (50,150)	1230	2217	2440
N=200, Eo=0.5J, packet size =2000			
BS Position	Network Stability	Half Node Dead	Network Lifetime
Corner (20,20)	2288	2633	3120
Center (50,50)	2355	2652	2935
Out (50,150)	1928	2389	2809
N=200, Eo =1 J, packet size =2000			
BS Position	Network Stability	Half Node Dead	Network Lifetime
Corner (20,20)	4717	5242	6186
Center (50,50)	4809	5337	6294
Out (50,150)	3607	4879	5874

Table 4: The network performance of the GCH-LEACH protocol compared to other routing protocols with an initial energy of 0.5J.

Routing Protocols	Network Stability (FND)	Half Node Dead (HND)	Network Lifetime (LND)	Improve %
LEACH-C[27]	750	800	850	100%
FIGWO[28]	780	830	960	100%
GA-LEACH[29]	788	850	1000	100%
PSO[30]	800	950	1180	100%
ABC-SD[31]	900	1140	1200	100%
CGTABC2& ACO[32]	1000	1222	1300	100%
LEACH[23]	1485	1600	1657	100%
I-LEACH[33]	1050	1450	1700	100%
ED-LEACH[34]	1188	1400	2000	54%
GADA-LEACH[35]	1600	2000	2100	28%

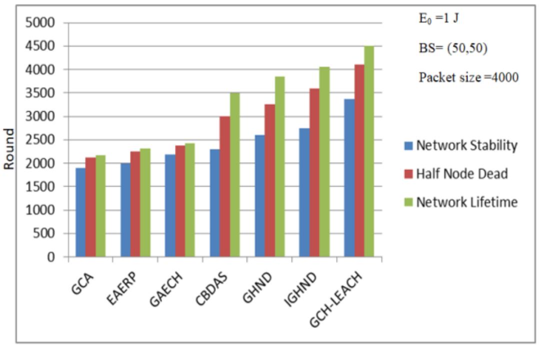


Fig. 14 The network performance of the GCH-LEACH protocol in comparison to various other routing protocols with initial energy 1J.

Table 5: The network performance of the GCH-LEACH protocol in comparison to various other routing protocols with initial energy 1J.

Routing Protocols	**Network Stability (FND)**	**Half Node Dead(HND)**	**Network Lifetime (LND)**	**Improve %**
GCA[36]	1900	2117	2165	100%
EAERP[36]	2000	2247	2309	100%
GAECH[36]	2180	2375	2430	100%
LEACH	3047	3170	3310	100%
CBDAS[37]	2300	3000	3500	96%
GHND[38]	2600	3250	3850	87%
IGHND[39]	2750	3600	4050	63%

6. CONCLUSION

In conclusion, the application of the GA for CH selection within the LEACH protocol, known as GCH-LEACH, presents notable advantages in terms of enhancing energy efficiency within wireless sensor networks. There was a range of lifespans observed across different protocols, namely; LEACH, CBDAS, GHND, IGHND, LEACH-C, FIGWO, PSO, ABC-SD, ED-LEACH, and GADA-LEACH resulting in an improvement in the network lifetime of 100%, 96%, 87%, 63%, 100%, 100%, 100%, 54%, and 28% respectively. The GCH-LEACH protocol exhibited a noteworthy enhancement in network longevity when compared to alternative routing protocols. Moreover, the GCH-LEACH algorithm demonstrates reduced energy consumption in comparison to other alternative algorithms. The proposed protocol exhibited an important enhancement in network stability and network lifetime when compared to the traditional LEACH protocol. Additionally, a substantial improvement in the best throughput has been observed. The adaptability, optimization, and dynamic selection of cluster heads by the GA, taking into account energy levels and other relevant factors, contribute to the enhancement of overall system performance, extension of network lifetime, and improvement of energy efficiency. Additional research and experimentation can be conducted to further investigate and refine the GA and its parameters to attain higher levels of energy efficiency in wireless sensor networks that utilize the GCH-LEACH protocol. Although simulations play a vital role in assessing the viability of the strategy, they do not directly tackle the actual obstacles and real-world issues that arise when implementing the solution in WSN deployments.

In the context of real-world WSN implementations, various problems and aspects must be taken into account. These include limitations imposed by the hardware used, the capacity to scale the network effectively, constraints related to the available energy sources, the influence of environmental conditions, and the necessity for reliable and resilient operation. The successful implementation of a theoretical approach in a practical context necessitates the identification and resolution of many problems, as well as the implementation of necessary modifications to enhance the solution's efficacy and dependability. Further studies and experiments are necessary for researchers and practitioners who wish to utilize the suggested approach of cluster head selection based on the GAs in real-world WSNs. These studies and experiments are required to validate the performance of the approach under different situations and restrictions. This process may entail doing hardware testing, carrying out field trials, and making necessary revisions to the algorithm to fit the complexities inherent in certain deployment settings. The careful evaluation of real-world deployment factors is paramount when transitioning theoretical research into practical implementations.

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الملخص

تستخدم المراقبة البيئية والأتمتة الصناعية شبكات WSN على نطاق واسع. وبما أن عقد الاستشعار لديها بطاريات محدودة، يجب أن تكون شبكات WSN فعالة في استخدام الطاقة. يساعد LEACH شبكات WSN على التقاط البيانات الموفرة للطاقة. تؤثر رؤوس المجموعات على استهلاك الطاقة لبروتوكول LEACH وعمر الشبكة. تعمل هذه الورقة على تحسين اختيار رأس مجموعة بروتوكول LEACH باستخدام الخوارزمية الجينية. يختار البرنامج رؤوس المجموعات التي تزيد من كفاءة استخدام الطاقة في الشبكة. تمثل رؤوس المجموعات الحلول في النموذج الجيني للخوارزمية الجينية. كفاءة الطاقة تقيس اللياقة البدنية. يعزز الاختيار والتقاطع والطفرة اللياقة البدنية. لقد قمنا بالمحاكاة على نطاق واسع لاختبار استراتيجيتنا. قمنا بمقارنة LEACH-GA وبروتوكول LEACH الأصلي وطرق التحسين المختلفة. توضح هذه المقالة تحسنًا في عمر الشبكة بنسبة 100% مقارنة ببروتوكولات التوجيه المختلفة، بما في ذلك LEACH-C وFIGWO وGA-LEACH وPSO وABC-SD وCGTABC2& ACO وLEACH وI-LEACH، بنسبة 54% مقارنة بـ ED-LEACH و28% مقارنة بـ GADA-LEACH. تتفوق خوارزمية LEACH-GA على خوارزمية LEACH الأساسية والخوارزميات الأخرى في كفاءة الطاقة وعمر الشبكة وتجميع البيانات. تقدم ورقتنا استراتيجية جديدة لاختيار رأس المجموعة لبروتوكول LEACH، الذي يعمل على تطوير شبكات WSN. الخوارزميات الجينية تفعل هذا. تعمل خوارزمية LEACH-GA على زيادة كفاءة الطاقة وطول عمر الشبكة. وبالتالي، فهو يوفر حلاً عمليًا لتطبيقات WSN ذات الطاقة المحدودة للمساعدة في بناء ونشر بروتوكولات WSN الفعالة، وتحسين استدامة شبكة الاستشعار والاعتمادية.

الكلمات الداله :

اختيار رأس المجموعة، كفاءة الطاقة، تقييم اللياقة، الخوارزمية الجينية، LEACH، التحسين، شبكات الاستشعار اللاسلكية.