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A GENETIC ALGORITHM BASED LEACH PROTOCOL FOR CLUSTER HEAD SELECTION TO ENHANCE THE NETWORK LIFETIME OF WIRELESS SENSOR NETWORK

Manisha Kumari and Gurjinder Kaur
Department of Computer Science and Engineering, Sant Longowal Institute of Engineering and Technology, India

Abstract

Increased interest in the usage and deployment of Wireless Sensor Networks (WSN) has resulted in the development of a slew of novel routing protocols, all of which place a premium on energy efficiency. The most challenging aspect of wireless sensor network is surviving for an extended period using energy efficiently. To make the network last longer, the protocols must be energy efficient. In Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, Cluster Head (CH) selection is based on a random probability equation, and has limitations such as unequal distribution of clusters and energy, and random selection of CH. In order to solve these limitations, a method is proposed for improving CH selection and reducing CH energy degradation. The proposed algorithm, LEACH-CHGA protocol strengthens CH selection compared to the existing protocol while simultaneously lowering network energy usage. The optimal CH selection based on a genetic algorithm enhances network lifetime and energy consumption as compare to LEACH.

Keywords:

LEACH, Genetic Algorithm, Cluster Head Selection, Network Lifetime, Blend-Crossover

1. INTRODUCTION

In recent years, wireless sensor networks (WSNs) have received growing interest from each the research field and real users due to its applications of intelligent monitoring of the hazardous environment where continuous human intervention is risky, inefficient and infeasible [1]. The WSN consists of a large number of the sensor node, densely deployed over an area. Sensor nodes are equipped for working together with each other and estimating the state of their surroundings environments (i.e. light, temperature, sound, and vibration) [2] [3]. Some applications of WSN are healthcare monitoring, forest fire monitoring, transportation system [4], industrial monitoring, flood detection, disaster management, and environmental monitoring, [2] [3] etc. The architecture of WSN [3] is shown in Fig.1.

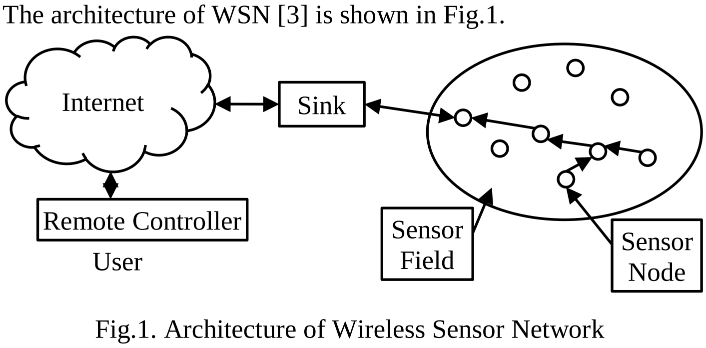

Fig.1. Architecture of Wireless Sensor Network

The major components of a WSN include sensors units, transceiver unit, processing unit, and a power supply unit [2] [3]. Because the sensor node is small, it has some constraints, including restricted memory, data sources, energy sources, bandwidth, and data rates [2]. After some interval of time, the battery in the sensor node has discharged, and it must be replaced or recharged. However, because the sensor nodes are installed in a hostile environment, it is difficult to replace or recharge them. Such an environment requires energy-aware routing protocols that provide high scalability in order to maximize the network lifetime [5]. Routing is a process to determine an efficient route between source and destination for data transmission to increase the network lifetime of WSN [6]. The design of routing protocols is quite challenging task because it is affected by the various factors such as energy, scalability, fault tolerance, security [7], etc.

The routing protocols for WSN can be classified into Network Structure Scheme, Path Establishment, and Protocol Operation [6]-[8]. According to the network structure, the routing protocols can be categorized into three types: flat, hierarchical, and location-based. Among all, hierarchical routing is an effective strategy to decrease energy consumption inside a cluster while also able to perform data aggregation to reduce the number of messages transmitted to the base station. In Hierarchical Routing [9] [10], sensor nodes are grouped into non-overlapping clusters called the clustering process. The main components of clustering are cluster head (CH), cluster member and sink. Clustering helps to improve routing at the network layer by reducing the size of the routing tables, and it also reduces transmission overhead.

The Low Energy Adaptive Clustering Hierarchy (LEACH) [11] routing protocol is the most energy-efficient but has some limitations, such as unequal distribution of clusters and energy, single hop, cluster head selected randomly, and long-distance communication. The CH is selected randomly without considering the residual energy and distance of the node from CH and base station.

So, the low-energy node can be selected as a cluster head. Therefore, the major challenge in designing a routing protocol is to select the best cluster head to minimize the energy dissipation and to increase the lifetime of the network. The proposed work improves the LEACH protocol cluster head selection, cluster formation, and CH communication with base station. To extend network lifetime and reduce energy consumption, the proposed algorithm uses a genetic algorithm to pick the best cluster heads. It is named as LEACH- CHGA.

The following is a breakdown of the paper structure: section 2 provides a quick overview of some of the clustering techniques, including their benefits and drawbacks. Section 3 describes CH selection using LEACH and CH selection using genetic algorithm along with the details of the algorithm. Section 4 deals with the simulation setup environment, energy model, and section 5 deals with the results and discussion of the experiment.

2. RELATED WORK

WSNs comprises of base stations (BS), radio communication channels, and sensor nodes with low power supply [2]. As a result, developing a new routing protocol with optimal CH probability selection is critical. Data transmission and reception account for the majority of energy consumption. Many researchers are still working on developing an energy-efficient routing protocol with the correct selection of CHs and clusters. Several hierarchical routing protocols for sensor networks are proposed in the literature [5] [9] [10] [12], the main aim of which is to select the cluster head and create stable clusters in a network environment. Many researchers are still working on improving network lifetime and designing an energy-efficient routing algorithm.

Heinzelman et al. [11] presented a LEACH approach for clustering that was proven to be more effective as compare to MTE (Minimum Transmission Energy) and direct transmission techniques. LEACH divides its operation for every round into a two-phase; set-up phase for cluster head selection and cluster formation and a steady-state phase for communication between nodes and cluster head. LEACH select CH randomly which results in unequal distribution of clusters and low-energy node can be selected as a CH. As a result, the rough distribution has a bigger impact on network performance.

Hong et al. [13] presented T-LEACH, a threshold-based cluster head replacement scheme for WSNs, focused on the cluster head replacement by using the threshold of residual energy to improve both energy efficiency and balance of energy consumption. It extends the lifetime of the entire network by reducing the amount of head selection and replacement cost, when compared with the existing clustering protocols such as LEACH, LEACH-C, etc. Salim et al. [14] proposed intra-balanced LEACH (IBLEACH), a clustered routing algorithm that improves the LEACH protocol performance by balancing energy usage in the network. It divides each round of process into three phases: Setup, Pre-steady, and the Steady phase. In the steady-state phase, the cluster workload is divided between the cluster head and cluster members to reduce the workload of the CH.

Abushiba [15] introduced CH-Leach Protocol, to improve the network lifetime, novel topology and routing algorithms are proposed in this paper. Implanting Centralized k-Means algorithm for selecting a CH and cluster formation added high stability in the setup phase which gives longer network lifetime. Annushakumar and Padmathilagam [16] introduced a modified hybrid fusion routing algorithm combination of Q-LEACH and QDIR (Quadrant based directional routing protocol) which maximize the lifetime of network by using Genetic Algorithm (GA). The network is divided into four quadrants and CH is selected based on threshold value in each division and data transmission from sensor node to CH of different regions occurs by using a genetic algorithm. The genetic algorithm used FND (first node dead) and HND (half node dead) to calculate the weight value in the fitness function.

Miao [17] proposed an improved LEACH Protocol (LEACH-H) based on a Genetic Algorithm. In this paper, the threshold value is corrected by using three parameters that contain residual energy, the distance between node and base station, and the node number of neighbours. The weight values are calculated using GA and results show that the lifetime of LEACH-H is increased when compared with LEACH. Peiravi et al. [18] presented an optimal method of clustering homogeneous WSNs using a multi-objective two-nested genetic algorithm or M2NGA, a centralized algorithm that is carried out by the base station to optimize the network lifetime and delay. To maximize network lifetime, the top-level GA uses energy consumption for transferring one bit to CH and delay in terms of hop count as fitness functions. Within the cluster, the lower level GA is utilized to optimize communication from sensor nodes to the CH.

Pachlor and Shrimankar [19] presented a Vice-Cluster-Head-Enabled Centralized Cluster-based routing protocol (VCH-ECCR), which optimally uses the energy of the sensor by using the vice cluster head two-level hierarchy and reduce clustering frequency. Liu and Ravishankar [20] introduced LEACH-GA, in which the preparation phase is utilized to pick out the optimal probability for selecting a cluster head by using a genetic algorithm at once followed by the set-up and steady-state phase. Sivakumar and Radhika [21] explored the stability period of LEACH-C, LEACH, and LEACH-GA by altering its probability and initial energy.

Abo-Zahhad et al. [22] presented GAEEP clustering protocol based on Genetic Algorithm to effectively enhance stability period. GAEEP determines the optimal cluster head number and their positions in order to improve network life by reducing the energy consumption of sensor nodes involved in the communication process. The GAEEP protocol further improves the clustering process reliability by extending the stability phase and reducing the instability period. Bhatia et al. [23] proposed a scheme, termed GADA-LEACH, which improves CH selection by using a genetic algorithm in LEACH protocol. This paper proposed a relay node between the sink and the CH to achieve the objective of distance-aware routing. The fitness function includes energy parameters, a distance of CH with associated nodes, and a distance of BS from CH.

Khunteta and Bajpai [24] introduced a method to select cluster heads in LEACH protocol using a genetic algorithm to improve the lifetime of the WSN by dividing the whole network into certain classes. A genetic algorithm is used to establish the best route between cluster head and base station in the network and the performance is compared with the LEACH protocol. Bari et al. [25] proposed an energy-efficient routing approach, based on a genetic algorithm (GA), for scheduling the data gathering of relay nodes, which can significantly extend the lifetime of a relay node network. This approach is used to determine a suitable routing strategy for upper-tier relay node networks. The author considered a two-tiered sensor network architecture, where higher-powered relay nodes act as cluster heads and sensor nodes transmit their collected data directly to their respective cluster heads. For smaller networks, this GA-based technique is always able to locate the best solution.

3. METHODOLOGY

This section includes energy-efficient CH selection using LEACH protocol and selection of CH using LEACH-CHGA algorithm:

3.1 SELECTION OF CLUSTER HEAD USING LEACH PROTOCOL

In LEACH protocol [11], a node decides to become a CH with a likelihood *p* and advertises its decision. After the CH election, each CH broadcasts an advertisement message to the other nodes and each one of the other (non-CH) nodes determines a cluster to which it belongs, by picking the CH that requires the least amount of communication energy. To adjust the load, the role of CH is pivoted intermittently among the nodes in a cluster. The turn is performed by getting every node to pick an arbitrary number *T* somewhere in the range of 0 and 1. A node turns into a CH for the current revolution round if the generated number is smaller than the threshold value in Eq.(1).

$$T(n) = \begin{cases} \dfrac{p}{1-p\left(r \bmod \dfrac{1}{p}\right)} & \forall n \in G \\ 0 & Otherwise \end{cases} \quad (1)$$

where *p* is the probability of CH node election, the value of *r* represents the current round; *G* is the collection of nodes that were not been CHs in the previous 1/*p* rounds.

3.2 SELECTION OF CLUSTER HEAD USING LEACH-CHGA PROTOCOL

Genetic Algorithm (GA) [26] is an evolutionary algorithm based on natural selection. Each generation contains an encoded representation of a potential solution for the population. This is referred to as the chromosome. Genes are the building blocks of a chromosome. Fitness function is used for the evaluation of various chromosomes. The general flowchart of the genetic algorithm is given in Fig.2. By adding network factors such as energy, the distance between nodes and cluster heads, and the distance between cluster heads for CH selection, the overall performance of the network can be improved. The objective of the proposed algorithm is to select the best CH position to improve the network lifetime. Previously, cluster heads were chosen at random using a probability equation, but in this proposed approach, cluster heads are chosen using a GA.

The distance between the node and the cluster head, the node energy, and the distance between the sink and cluster head affect the network overall performance. These factors work together to improve the network efficiency. The LEACH-CHGA protocol details, as well as how GA was utilized to find the best CHs, are as follows:

3.2.1 Problem Representation:

Finding correct CHs is critically essential to minimizing energy consumption. In the LEACH-CHGA algorithm, the BS form a chromosome binary stream *X* with length n. Here n is the number of nodes in the network. If the value of *X* is 1, then the corresponding node is cluster head, otherwise normal node.

3.2.2 Objective Fitness Evaluation:

Because CHs drain more power than non-cluster heads, so, higher number of CHs waste more energy and fewer number of CHs result in greater energy efficiency. The fitness function includes energy parameters, a distance of CH with associated nodes, and a distance of BS from CH. By minimizing the following objective function *F* [23] in Eq.(2), GA is used to identify the optimal positions of CHs.

Fitness Function (F): $F = [(0.3*F_1)+(0.35*F_2)+(0.35*F_3)]$ (2)

where F_1 shows the ratio of all node energy to cluster head energy, F_2 shows the ratio between the Euclidean distance of CH and its associated node to the nodes number in the cluster, and F_3 shows the ratio of Euclidean distance between BS to all CH to the number of CH formed.

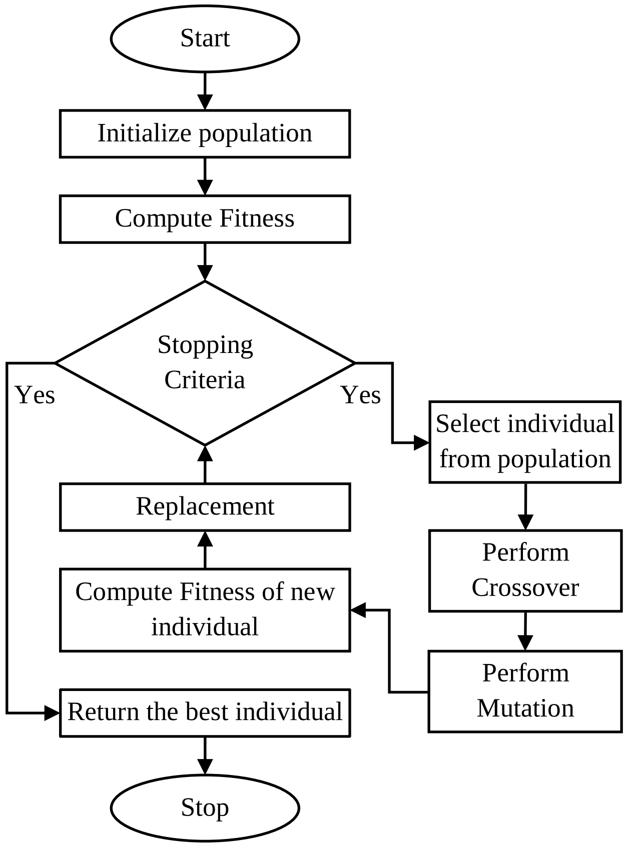

Fig.2. Flowchart of Genetic Algorithm

3.2.3 GA Operator:

The three operators of genetic algorithm are selection, crossover, and mutation. In the proposed algorithm, the parent node is selected using the Tournament Selection method. After it, blend-crossover and the mutation operator is applied to the chromosomes with the crossover probability pc and mutation probability pm and then, elitism is applied.

- **Blend-Crossover:** The operator is started by selecting a uniformly random real value drawn from a range <min($Z_{1i}^{(m)}$, $Z_{2i}^{(m)}$)-($a*d_i$), max($Z_{1i}^{(m)}$, $Z_{2i}^{(m)}$)+($a*d_i$)>, where a = real integer as shown in Algorithm 1. In order to establish the balance between exploration and exploitation of the search space, where the value of a is selected as 0.5 [27].

3.2.4 Selection of Best Solution:

In this step, the fitness of the initial population and generated offspring are compared. The population is updated with the individuals that have minimum fitness value.

3.2.5 Stopping Criteria:

The stopping criterion achieves when the number of iterations surpasses the maximum allowed.

Algorithm 1: Algorithm for Blend Crossover

Two parents $Z_1^{(m)}$ and $Z_2^{(m)}$ are selected from a pool of parents.

Generate $Z_1^{(m+1)}$ and $Z_2^{(m+1)}$ offspring as follows:

For i=1:n

$d_i = |Z_{1i}^{(m)} - Z_{2i}^{(m)}|$

Select a uniformly random real value u_1 drawn from range: <min($Z_{1i}^{(m)}$, $Z_{2i}^{(m)}$)-(a*d_i), max($Z_{1i}^{(m)}$, $Z_{2i}^{(m)}$)+(a*d_i)>

$Z_{1i}^{(m+1)} = u_1$

Select a uniformly random real value u_2 drawn from a range: <min(Z_{1i}(m), Z_{2i}(m))-(a*d_i), max(Z_{1i}(m), Z_{2i}(m))+(a*d_i)>

$Z_{2i}(m+1) = u_2$

End

The steps of LEACH-CHGA algorithm are described as below and the flowchart is shown in Fig.4:

Step 1: Initialize network parameter on which network depends: initial energy (E_0), number of nodes (n), packet size (k), transmitter (ETx) and receiver energy (ERx), amplifier energy.

Step 2: Initialize GA parameters: population size ($nPop$), crossover rate (pc), mutation rate (pm), maximum iteration.

Step 3: Deploy nodes randomly on the simulation area (n×n) square units.

Step 4: Initialize population for cluster head selection. Select the CH from the nodes present in the network.

Step 5: Calculate fitness function for node in the population, so that best individual is selected as CH. Fitness function include energy parameters, distance of CH with its associate nodes, distance of base station from CH.

Step 6: From the fitness evaluated, the best individuals are selected using tournament selection.

Step 7: Apply blend-crossover and perform mutation operation for selecting efficient CHs.

Step 8: After it fitness of each individual is evaluated again and compared with initial one. If evaluated fitness is less than initial population, the current population is updated by the corresponding new generation. Otherwise, the initial population is passed to the next generation that means elitism is performed, and then next iteration takes place.

Step 9: After selecting the cluster heads, cluster is formed and communication is initiated between cluster head and nodes. Final communication between cluster head and base station or sink is accomplished and the network lifetime is determined as long as first node died.

Step 10: After this the calculation of parameters such as energy consumption, number of alive nodes, throughput etc. is done.

4. SIMULATION ENVIRONMENT

In the LEACH-CHGA algorithm, the Matlab R2016a tool is used for simulation. The nodes (n=100) are deployed randomly in the simulation area (n×n) m^2 i.e. (100×100) m^2. The base station is deployed outside the network area (x=50, y=130) as shown in Fig.5. In this proposed algorithm, first order model is used for calculating the consumption of energy. It is a simple model for the energy dissipated by radio hardware [11]. The transmitter disperses energy to operate the radio electronics and the power amplifier, whereas the receiver disperses energy to operate the radio electronics, as shown in Fig.3. Free space (when power loss is d^2) and the multipath fading (when power loss is d^4) are two channel models. The distance between the transmitter and receiver is taken into account in these models. By properly adjusting the power amplifier, power control can be used to invert this loss. When the computed distance (d) is smaller than the threshold distance (d_0), the model utilized is the free space (f_s); otherwise, the model utilized is multipath (m_p). As a result, the total energy spent in Fig.3 can be estimated using the formula:

For transmitting k-bit message a radio expends:

$$E_{Tx}(k,d) = \begin{cases} E_{Tx-elec}(k) + E_{Tx-amp}(k,d) & if\ d = d_0 \\ E_{elec} * k + \varepsilon_{fs} * k * \sqrt{d} & if\ d < d_0 \\ E_{elec} * k + \varepsilon_{mp} * k * \sqrt[4]{d} & if\ d \geq d_0 \end{cases} \quad (3)$$

where threshold $d_0 = \frac{\sqrt{\varepsilon_{fs}}}{\sqrt{\varepsilon_{mp}}}$

Receiving this message radio expends:

$$E_{Rx}(k)=E_{Rx\text{-}elec}(k)=E_{elec}*(k) \quad (4)$$

where E_{elec} is the energy consumed to transmit or receive 1-bit message; ε_{fs} is the amplification coefficient of free-space signal and ε_{mp} is the multi-path fading signal amplification coefficient, d represents the distance between transmitter and receiver; k is the number of bits for sending information and do is the threshold distance.

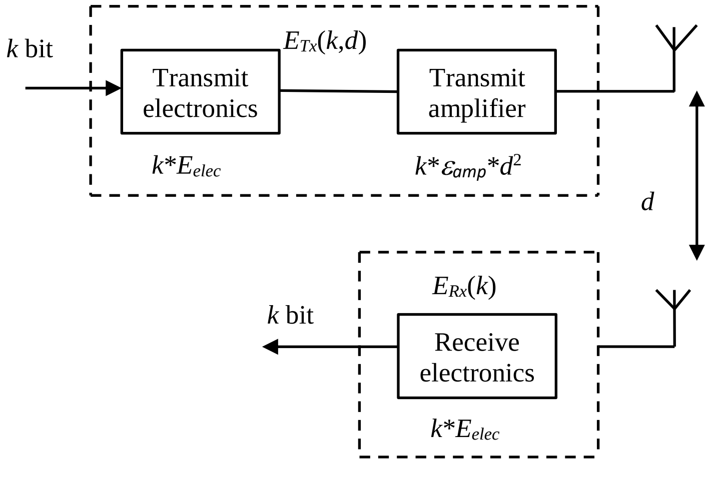

Fig.3. First Order Radio Model

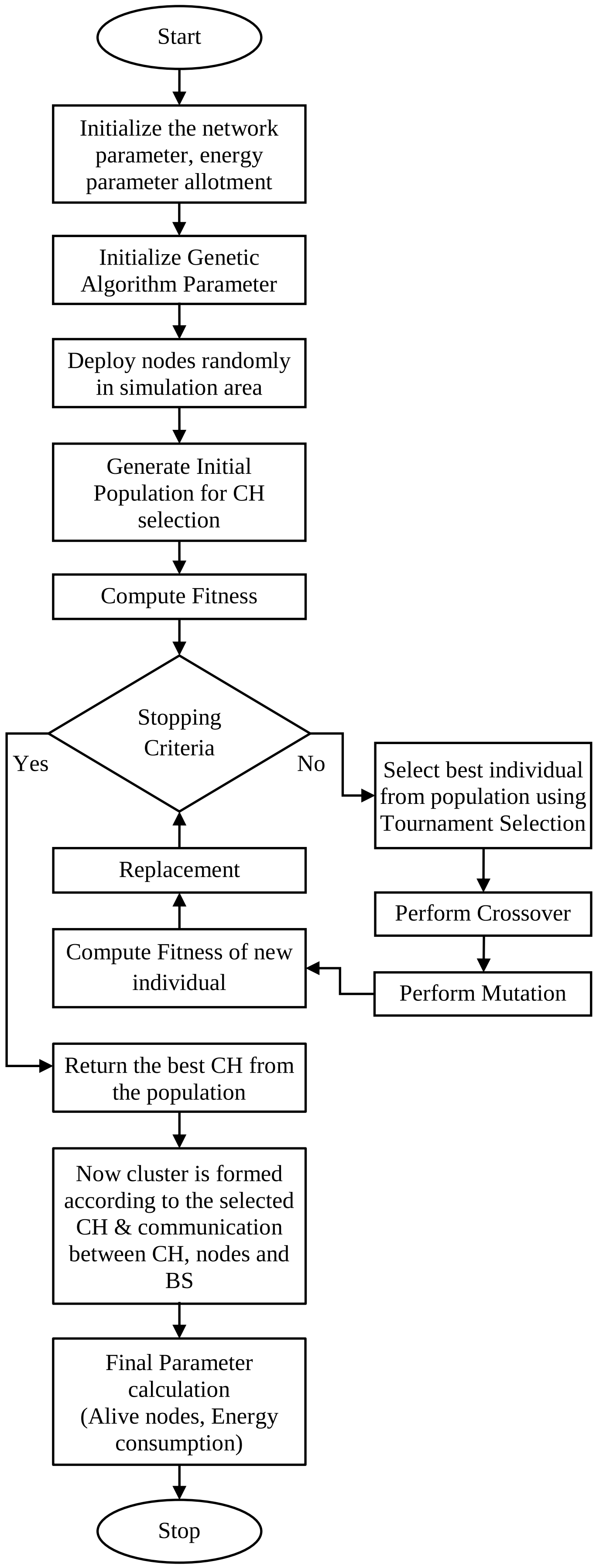

Fig.4. Flowchart of LEACH-CHGA algorithm

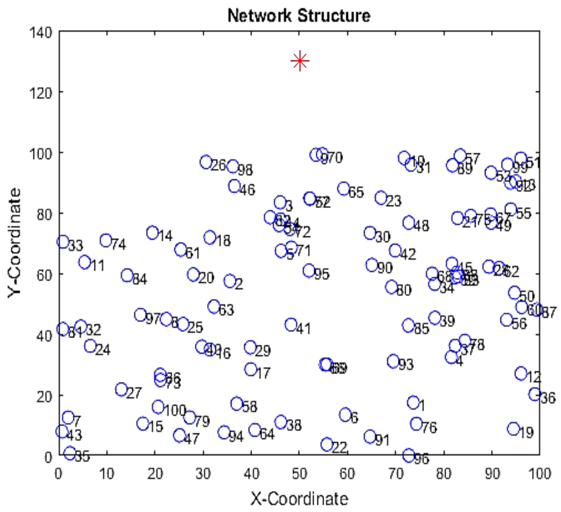

Fig.5. Network Structure of LEACH-CHGA

5. RESULTS AND DISCUSSION

The Table.1 lists the various simulation parameters as well as the genetic algorithm parameters for simulating the environment. The following metrics were used to compare the performance of clustering procedures in this paper: network lifetime, throughput and remaining energy.

Table.1. Simulation Parameters

Network Parameter	Value
Network size	100*100m^2
Number of nodes	100
Packet Size	3000 Bits
Initial Energy of node (E_0)	0.7,0.8,1 J/node
Energy to run transmitter and receiver (E_{elec})	50 nJ/bit
Energy for Data aggregation(E_{da})	5 nJ/bit
Energy of amplifier for short distance (E_{fs})	10 pJ/bit/m ^{2}
Energy of amplifier for long distance (E_{mp})	0.0013 pJ/bit/m^2
Threshold distance (d_0)	87.70m
Population size	Number of CH
Crossover Rate	0.4
Mutation Rate	0.006
Selection Method	Tournament Selection

5.1 NETWORK LIFETIME

The network lifespan in a WSN is the time between deployment and the point at which the network is considered non-functional [28]. For the network lifespan measurement in the proposed protocol, the time when the first sensor node (FND) dies was taken into account. The network lifetime is calculated by varying initial energy as 0.7J/node, 0.8J/node and 1 J/Node.

5.1.1 When Initial Energy=0.7 J/node:

In the LEACH and LEACH-CHGA routing protocols, the first node died at various levels of rounds (see Fig.6). The death of the first node occurred at 1228 and 1657 rounds in LEACH and LEACH-CHGA respectively. Finally, when compared to the LEACH routing protocol, LEACH-CHGA achieves a longer network lifetime by 34.93% rounds.

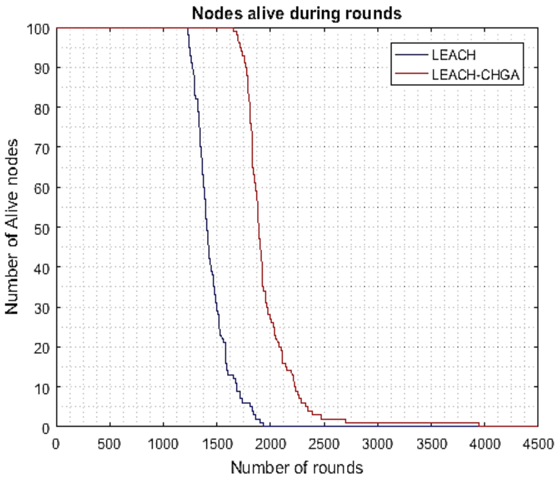

Fig.6. Network Lifetime comparison of LEACH and LEACH-CHGA (initial energy is 0.7J/node)

5.1.2 When Initial Energy=0.8 J/node:

The lifetime of network in LEACH and LEACH-CHGA is compared in Fig.7 with initial energy 0.8 J/node. The death of the first node occurred at 1305 and 1865 rounds in LEACH and LEACH-CHGA respectively. Therefore, the lifetime of LEACH-CHGA is increased by 42.91% rounds.

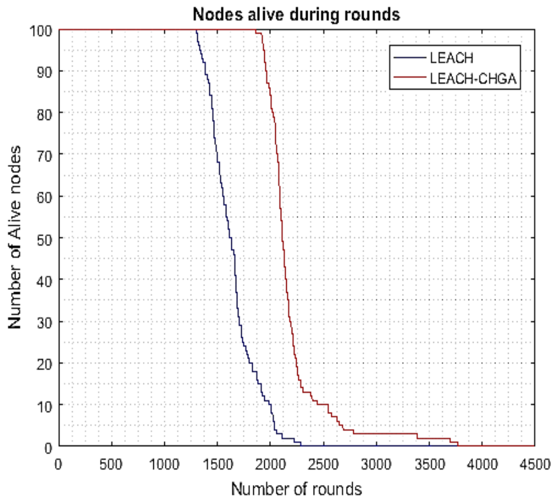

Fig.7. Network Lifetime comparison of LEACH and LEACH-CHGA (initial energy is 0.8J/node)

5.1.3 When Initial Energy=1 J/node:

The network lifespan is compared in Fig.8 with initial energy 1 J/node of LEACH and LEACH-CHGA. The death of the first node occurred at 1706 and 2438 rounds in LEACH and LEACH-CHGA respectively. Hence, the lifetime is increased by 42.90% rounds in LEACH-CHGA.

We can see from the Fig.9 that as the value of Initial Energy is increased, the FND probability decreases and the network lifetime grows.

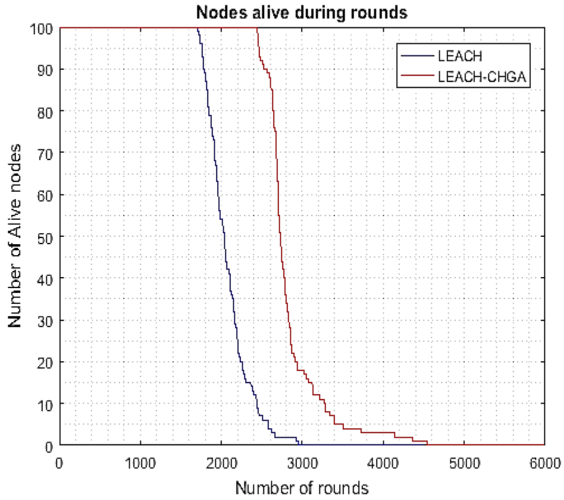

Fig.8. Network Lifetime comparison of LEACH and LEACH-CHGA (initial energy is 1J/node)

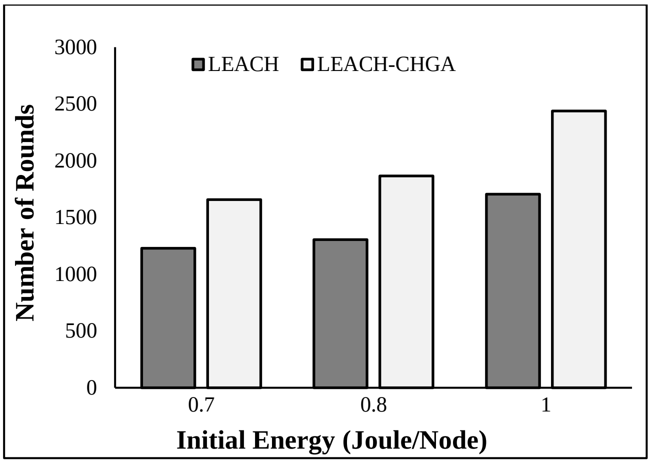

Fig.9. Routing Protocol with varying initial energy

5.2 THROUGHPUT

Throughput is defined as the total number of raw packets generated by all SNs during the system lifetime. This refers to the total amount of packets transmitted to BS. Another factor to consider when determining the high energy consumption rate is the amount of received data packets by the BS. The energy distribution in the network becomes more balanced as the BS gets more packets. The amount of received packets at the BS is shown in Fig.10-Fig.12 for LEACH, LEACH-CHGA protocols, with a packet length of 3000bits.

The Table.2-Table.4 shows the number of packets transmitted to the BS with varying initial energy. LEACH-CHGA runs for a greater number of rounds than LEACH protocol, resulting in a higher number of packets transmitted to BS. Packets to BS will be sent till the end of the round in 1934 LEACH and 3947 rounds in LEACH-CHGA, indicating that because the network is more stable, it runs for more rounds and sends more packets to BS in LEACH-CHGA, indicating a considerable improvement.

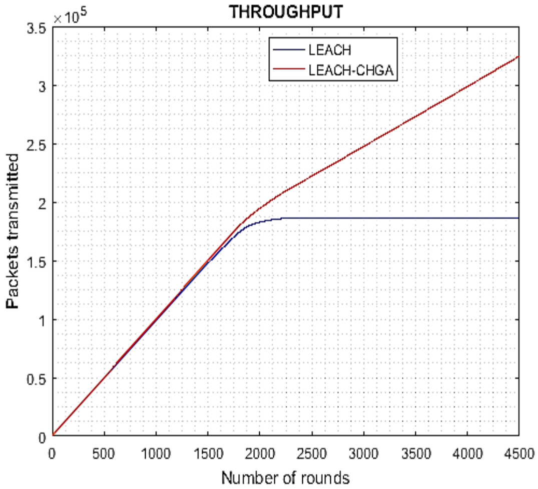

Fig.10. Number of packets transmitted with initial energy 0.7J/node

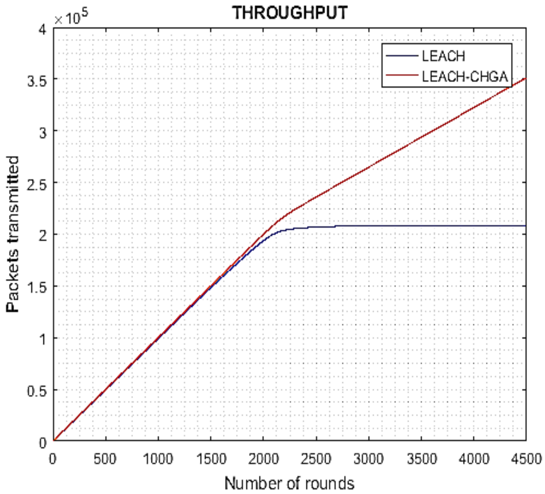

Fig.11. Number of packets transmitted with initial energy 0.8J/node

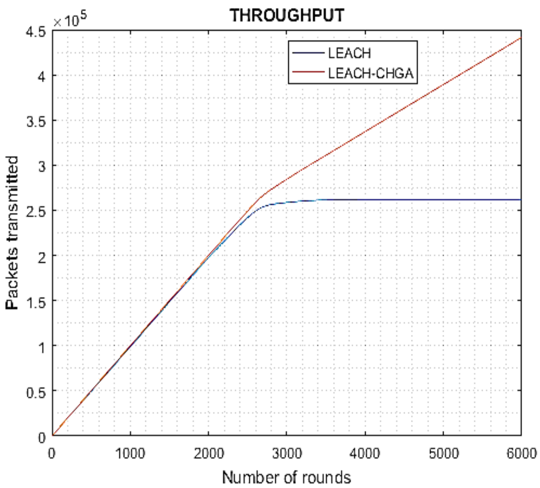

Fig.12. Number of packets transmitted with initial energy 1J/node

The Table.3-Table.5 represent the comparison LEACH, LEACH-CHGA routing algorithm of FND, LND and packet transmitted to the BS with initial energy of 0.7J/nodes, 0.8 J/nodes and 1J/nodes. We can conclude from the comparisons that the network lifetime of LEACH-CHGA is better than the LEACH protocol.

Table.2. Routing Protocol with initial energy 0.7J/node

Protocol	FND	LND	Packet Transmitted to BS
LEACH	1228	1934	14500
LEACH-CHGA	1657	3947	152691

Table.3. Routing Protocol with initial energy 0.8 J/node

Protocol	FND	LND	Packet Transmitted to BS
LEACH	1305	2289	16458
LEACH-CHGA	1865	3767	159929

Table.4. Routing Protocol with initial energy 1J/node

Protocol	FND	LND	Packet Transmitted to BS
LEACH	1706	2949	20773
LEACH-CHGA	2438	4547	212021

5.3 RESIDUAL ENERGY

The consumption of energy of the network is determined in this paper by Eq. (3). By considering the positions and remaining energy of nodes in the cluster, we identify the best CH for each round of data transfer. The performance of the network in terms of overall remaining energy over rounds is depicted in Fig.13 - Fig.15.

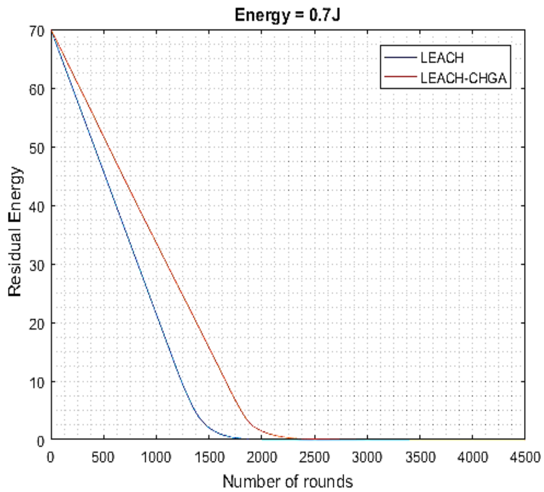

Fig.13. Remaining energy vs. rounds (initial energy = 0.7J/node)

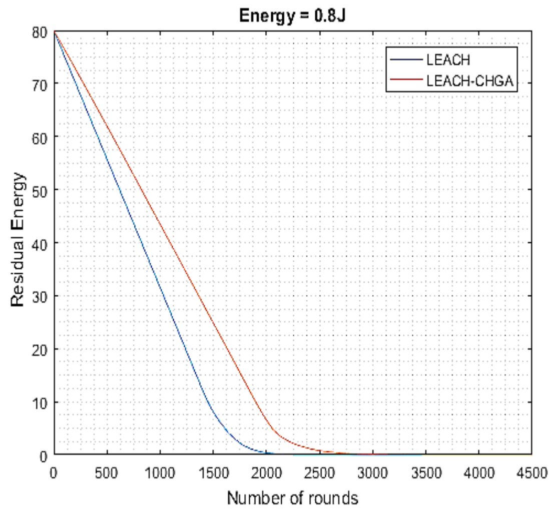

Fig.14. Remaining energy vs. rounds (initial energy = 0.8J/node)

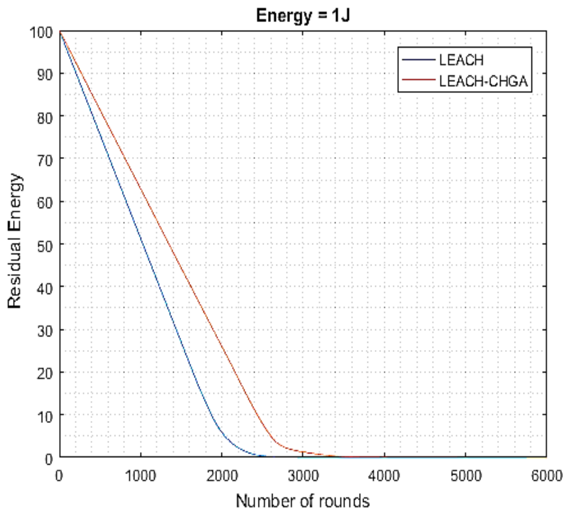

Fig.15. Remaining energy vs. rounds (initial energy=1J/node)

When compared to the LEACH protocol, the suggested LEACH-CHGA shows a slower drop as the number of rounds increases. All nodes in the LEACH protocol are dead at 1934 round, while all nodes in the proposed LEACH-CHGA protocol are dead at 3947 rounds with initial energy is 0.7J/node. As the initial energy is increased, nodes survive in the network for a long time. We can observe from the analysis that LEACH-CHGA effectively reduced the dissipated energy and increased the network lifetime.

6. CONCLUSION

In this paper, an optimized scheme with CH selection based on GA is proposed. The proposed scheme LEACH-CHGA is compared to LEACH in terms of network longevity. LEACH-CHGA proves to perform better by providing improved results in comparison. The first node died at 1657 round in LEACH-CHGA whereas first node died at 1228 round in LEACH. As network stability improves, more data is delivered to BS as a result of improved CH selection. It can be concluded that the introduced approach is better and more efficient than traditional ways since it includes a greater number of parameters in the fitness function for cluster head selection. The GA improves the cluster head selection mechanism. Other optimization approaches, such as Particle Swarm Intelligence, can be used to improve the findings even more. There are still a lot of modifications that can be made to the suggested strategy to achieve better results.

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