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Genetic Algorithm Based Energy Efficient Cluster Head Selection and Cluster Formation and Establishment for Hierarchical Wireless Sensor Networks

Y.P.Makimaa[1*], Dr. R. Sundarmani[2]

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Abstract: Wireless Sensor Networks (WSN) emerged due to advancements of wireless communication, Micro Electro Mechanical Systems (MEMS) etc. which plays a vital role in certain critical real world applications. In WSN, energy consumption is an important issue that is to be addressed to improve network life time and stability. Rather than other medium, sensor nodes are utilized for data transmission in WSN. Sensor nodes form ad hoc network to gather and transmit information to sink (or) to the destination node. Clustering plays vital role in the energy consumption of the sensor network, where the clustering technique improves the energy efficiency of the network compared to flat architecture. But the balanced load over the each cluster is not considered in many algorithms. In this paper, a novel hybrid technique is proposed to form clustering based on Genetic Algorithm (GE) and a hierarchical technique Algorithm for Cluster Establishment (ACE), where the establishment of optimal clustering is carried out based on selection of Cluster Head (CH) node. The CH selection is carried out based on the computation of novel fitness value of each node based on energy, distance and number of alive nodes. The CH selection is implemented by considering only the number of alive nodes in each round with their residual energy as a parameter with feedback mechanism. NS2 simulator is used to evaluate the performance of this method in terms of residual energy, energy dissipation, number of an alive nodes and number of packets delivered to CH and to Base Station (BS). Simulation results reveal that our proposed hybrid technique outperforms LEACH in terms of energy conservation and network lifetime.

Keywords: Wireless Sensor Network, Genetic Algorithm, Clustering

1. Introduction

Wireless Sensor Networks (WSN) are made up of variety of small electro mechanical terminals called sensor nodes those are capable of detecting, computing and transmitting various data parameters such as temperature, pressure, humidity, image and other parameters from the environment such as agricultural field, war zone, disaster prone area, etc [1]. The small sensor nodes consist of sensing, communication and computing facility that collect data and perform data aggregation. The sensor nodes sensing the environment where it is deployed and the aggregated data is sent to sink, which is then transfer to the end user via internet [1]. Normally sensor nodes would transmit the aggregated data directly to the base station or through intermediate nodes. In recent years many real time applications are developed based on WSN. Generally, sensor nodes are battery operated device with limited capacity and is difficult to replace battery in harsh unattended environment. One of the most crucial challenges in WSN is determining the best approach for optimizing the energy consumption of sensor nodes. The direct transmission or multidop transmission consumes more energy of the battery powered network. To reduce the overall energy consumption of the network by grouping of nearby nodes is carried out as clusters which reduce the transmission distance between the nodes. The sensing of sensor nodes are carried out over a smaller geographical distance and the sensed data is transmitted to the CH of each cluster where the clustering is a conventional medium that ensures stable and energy-efficient data transfer between the cluster head and sensor node [2]. In clustering, entire area is divided into smaller segments and for each segment a powerful node is allotted as cluster head to optimize energy usage. After certain period cluster head would be changed periodically and also the selection process of CH is crucial in terms of energy efficient data transfer and it must be accomplished after each round to guarantee the network efficiency [2]. The clustered WSN architecture is shown in figure 1. [1]. Many researchers proposed different techniques for the selection of cluster head for the load balanced energy consumption of the network where it is a hard problem to solve and many clustering algorithms are proposed in research literature [3]. Some clustering algorithms have unbalanced energy consumption too. Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO) and other bio-inspired optimization algorithms focus on exploration and exploitation while selecting a cluster head and there is always tradeoff between the optimization parameters. To overcome this genetic algorithm based clustering is proposed in this paper.

[1]*Research Scholar, Departrment of ECE, School of Engineering Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, India.makimaa261994@gmail.com*

[2]*Associate Professor, School of Engineering, Avinashilingam Institute for Home Science and higher Education for Women Coimbatore, Tamil Nadu, India, sudarmani_ece@avinuty.ac.in*

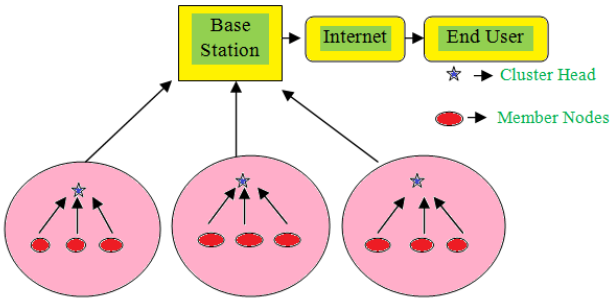

Fig.1. Overview of WSN

This paper presents a hybrid of bio-inspired optimization and hierarchical clustering for selecting proper cluster head based on the novel fitness function. Hybrid optimization technique enhances the performance of WSN by reducing additional overheads. The paper is organized as section 2 with related works and section 3 with problem formulation continued with the GA approach. The results and discussion is carried out next to GA and finally with conclusion and future work.

2. Literature Review

LEACH is the basic clustering protocol where it consists of setup phase and steady state phase. LEACH [4] was the pioneer clustering protocol in WSN. The formation of clusters is carried out in a distributed manner with setup phase, in which each node would be decided as CH or not based on the parameters such as number of times the node holding the position as CH, and the percentage of allowed CHs in the network. The periodic changing of CH will lead to more over head and in turn energy consumption of the network. Some of the other essential cluster head selection strategies are discussed in this section with their merits and demerits. Tree based clustering and routing is proposed for long life of sensor networks in heterogeneous in nature [5]. Different clustering techniques based on bio inspired are presented here. M.Sudha and J.Sundararajan (2017) have carried out a survey on various biological inspired clustering algorithms for mobile WSN [5]. This paper discussed the way in which several optimization technique were implemented in clustering process, the need of clustering and various attributes of clustering. T.Ganesan ,PothurajuRajarajeswari (2019), have proposed a Genetic Algorithm (GA) based technique to improve the lifetime of clusters [6]. Base station selects less number of CH by levering all other member nodes in a cluster using GA. Initially all sensor nodes are deployed randomly and fitness is calculated based on node residual energy and the distance between nodes. In GA, crossover and mutation are very important operators. In crossover; two nodes are crossed to provide a new solution. Mutation is the process which selects the node with best fitness. In this paper, the CH is selected based on binary value assigned to it. According to the binary value of the node, it may act as CH (binary value=1) or member node (binary value=0). This paper have discussed about the optimal position for sensor placement using GA.

VenkatRaoPasupuleti, Ch.Balaswamy (2019), have proposed efficient CH selection and optimization of routing in WSN using Earthworm Optimization Algorithm (EOA) [7]. This algorithm is inspired from reproductive behavior of earthworm (i.e) it may reproduce one – offspring or more than one - offspring. Sensor nodes are deployed and CH is selected using EOA by considering fitness with respect to distance between the nodes. Data communication is from node to CH and finally next hop is to the base station. Next hop node is selected by considering the node that has high fit factor which is to be energy, distance and delay are considered while selecting optimal path. Praveen Lalwani, Sagnik Das, Haider Banka, Chiranjeev Kumar (2016), explained the way in which Harmony Search Algorithm (HSA) is utilized for clustering and routing in WSN [8]. HSA is based on harmony memory, pitch adjustment, randomization, and CH can be selected randomly by using node – id (or) by considering harmony memory by pitch adjustment and memory update. In pitch adjustment, coordinates of CH is updated and if any node is present in that location. Node near to it is selected as CH, where the cluster is formed with less member nodes and less distance between member node and CH and high energy of CH. In routing, shortest path can be found by using fitness value. Residual energy, inter and intra cluster distance and mode degree are used to access the fitness.

Waild Osamy, Ahmed A.AEl – Samy, and Ahmed Salim (2016), have discussed about Chicken Swarm Optimization (CSO) to optimize CH selection and to decrease energy consumption [9]. Chicken Swarm Optimization based Clustering Algorithm (CSOCA), aims to increase network lifetime and minimize energy consumption in network. CSOCA works in three phases. Initially in CH selection phase, CH is selected based on energy consumption for each iteration. Next, cluster is formed with predefined nodes and CH and finally based on TDMA, after sensing of data by each member node the data is forwarded to CH. This paper also explained about a hybrid technique which combines CSOCA and GA to increase network life, reduce energy consumption and also to balance the available energy where CH is selected based on GA. P.K.Poonguzhali, N.P.Ananthamoorthy (2019), have implemented a hybrid technique which combines ACO and HSA in which ACO implements path based clustering and HSA selects low density node [10]. In this technique two CHs are selected where one CH is utilized to gather data from member nodes in cluster and another CH transfer data from CH to base station. ACO finds shortest path and HSA is utilized to maintain route by adjusting mode location based on its density. The uneven energy distribution is taking place in the clusters and the nodes, to overcome this new CH selection and cluster establishment based on GA is proposed in this paper.

3. Problem Formulations

Data transmission in WSN consumes more energy compared to processing, and nodes which have long distance communication consumes more energy compared to short distance communication, hence the limited energy resources making it difficult to maintain energy throughout the network [11]-[15]. For energy efficient transmission, an absolute route and nodes with sufficient amount of energy is needed along with the shortest path transmission. Clustering provides short range communication between cluster members and CH, along with few long distance communications. Rotation of the cluster head always leads to energy consumption of the network. Hence, in this paper a GA based energy optimization algorithm that overcomes the drawback of above and also finds proper cluster head which leads to a cluster establishment [16]-[18].

3.1. Network Model

Initially, sensor nodes are placed randomly in particular area of interest over which has to acquire the data and the sensor nodes possesses the following characteristics:

1. All nodes are stationary.
2. Base station can be located either outside or inside the field.
3. Power can be tuned according to distance of transmissioRadio Model

Radio model used in WSN is represented in figure 2. The radio model used is free space model [12, 13] described below given E_{ele}=60nJ/bits is energy dissipated to run the circuitry and φ_{amp} =10PJ/(bit*m^2) is energy dissipated by transmission amplifier.

Transmitter and receiver energy is calculated using following equations [1,2]:

$$E_{Tr}(m,d)=E_{ele} * m +\varphi_{amp}* m * d^{2} \quad (1)$$

$$E_{Re} =E_{ele}* m \quad (2)$$

$$E_{ACK} =\tau_{ACK} (E_{Tre}(m,d) + E_{Re}) \quad (3)$$

where $\tau_{ACK}= \eta_{ACK} / n$ is ratio between length of packet to acknowledgement of packet.

$$\text{Total energy} = E_{total}= E_{Te}(m,d) + E_{Re}+E_{ACK} \quad (4)$$

where E_{ele} and φ_{amp} are constants and m represents number of bits transmitted or received. d represents distance between transmitting and receiving antenna and E_{ACK} is energy consumption for acknowledgement packet exchange.

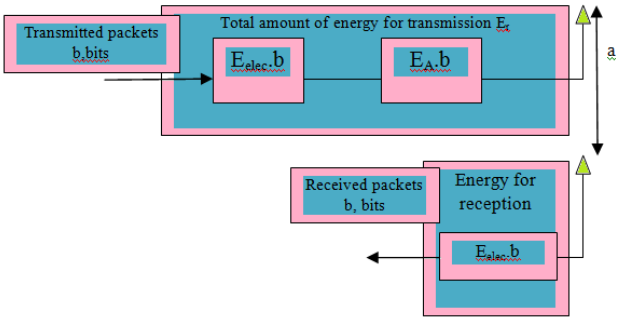

Fig.2. Radio model for WSN transmission

4. Overview of Genetic Algorithm

A heuristic search algorithm is the Genetic Algorithm which follows Darwin's theory of natural evolution. In Genetic Algorithm parents are selected based on fitness value to produce new off spring. Then the new off spring replaces the one with least fitness in the population. Genetic Algorithm follows 3 operators namely selection, cross over and mutation.

Selection: Chromosomes are classified based on the fitness function and the one with best fitness function is selected.

Cross-over: Provides a new off spring by combining genetic qualities of two parents.

Mutation: Search space is diversified by randomly modifying new individuals.

Once the new generation is created, the algorithm must search for termination state. When the termination condition is fulfilled, the algorithm comes to a halt. Otherwise, the cycle continues until the termination condition is achieved. Working of Genetic Algorithm is illustrated in figure 3. In many applications, Genetic Algorithm is one of the accepted algorithms to solve the optimization issues. Other operators are not considered in the proposed one which would increase the complexity of the working process of the algorithm. In WSN, cluster formation and cluster head selection plays a critical role in minimizing the energy consumption of the network.

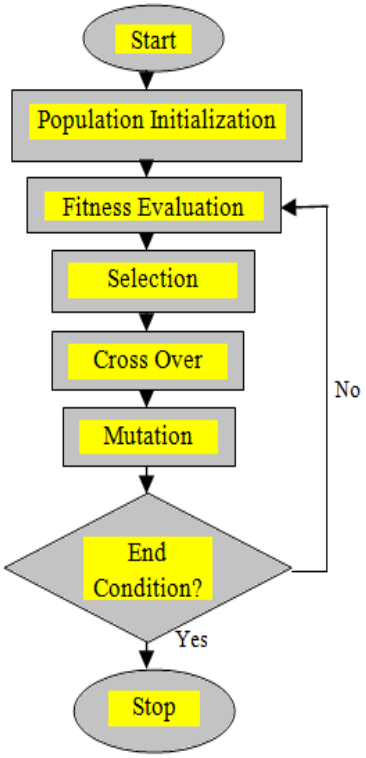

Fig.3. Flow chart of Genetic Algorithm

5. Proposed Methodology

In WSN, energy consumption is considered as an important issue that is to be addressed which otherwise results in energy loss of sensor node which would lead to life time reduction of the WSN. To overcome this problem, this paper proposes a GA based CH Selection and algorithm for cluster establishment (ACE) for improvement of life time of WSN and also the performance is evaluated against LEACH. The results reveal that the suggested hybrid algorithm outperforms LEACH. The results reveal that the suggested hybrid algorithm outperforms LEACH. The process flow of the proposed method is shown in figure 4.

The overall flow of algorithm is given as,

Step 1: Initial population is generated randomly.

Step 2: Fitness function is calculated based on energy, distance and number of alive nodes.

(i). Selection of parent nodes using probabilistic method.

(ii). Apply single point crossover over it.

(iii). Apply mutation operator if it is necessary.

Step 3: The new offspring is to be generated according to that new population is updated.

Step 4: End

Step 5: Cluster head selection and cluster formation to be carried out based on the best fit chromosomes.

5.1. Population Initialization

The total number of nodes is considered as an initial population which is generated using random number algorithm

[14]. Where 1 represents the CH chromosome and 0 represents member node in the population.

5.2. Fitness Calculation

Fitness is calculated based on energy, distance and number of alive nodes. Fitness function for evaluation of fittest chromosome is given in equation number 5, [15]:

$F(CH) = \{E * \sin(mA)\} / \{E_n + D_n\}$ (5)

E_n = Energy of node

D_n= Distance between two nodes

mA=Number of alive nodes

E = Sum of energies of all alive nodes

Based on fitness value, fittest chromosome is used to select CH for current iteration. Optimal number of CHs is selected based on energy and once the CH is selected, member nodes join their respective CHs based on distance. Member nodes collect date from the surroundings and pass it to its respective CHs and the CHs gather information and finally transmit to the base station.

5.3. Parent Selection

Two chromosomes are selected based on probabilistic method to generate next generation. Once the chromosomes are selected, Roulette Wheel method is used to perform cross over operation to generate new off spring.

5.4. Cross Over

Single cross over is done between two selected parents. Size of both parents and offspring are same.

Ex: PARENT 1: 11010 | 111
PARENT 2: 01101 | 001
Cross over point
First off-spring :11010001
Second off-spring :01101111

5.5. Mutation

Mutation is done to alter the value of gene so as to maintain genetic variation.

Ex: Off spring after cross over: 11010111
Off spring after mutation: 11110110

For each iteration, ACE is used to select new CH. ACE uses feedback information regarding number of neighboring nodes and each node can be a cluster head only one time.

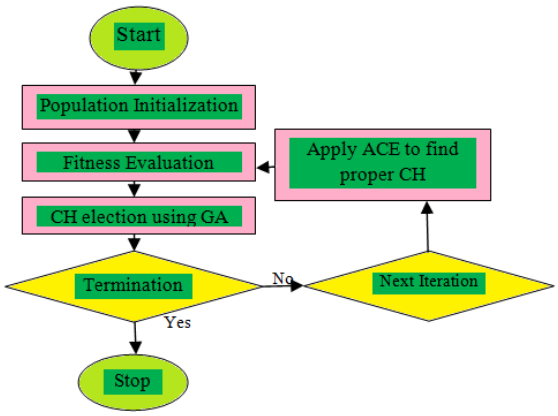

Fig.4. Flow chart of Proposed Work

6. Experimental Setup

MATLAB 2020a is used as a simulation tool to perform this work. Nodes are distributed randomly in square area N×N as shown in figure 5. Simulations are performed on 100 sensor nodes in 100×100 area. Sensor nodes are scattered and forms 10 clusters and each cluster consists of one CH and is shown in figure 6. In figure 6, different color indicates different cluster and number indicates cluster ID. After each iteration, CH is changed and new cluster is formed. Probabilistic method is used for the selection process. The percentage rate of crossover is o.5 and the mutation rate is 0.05. Simulation Parameters are given in table 1.

Table 1. Simulation Parameters

Parameters	Value
Number of nodes	100
Field Area	100*100
Optimal number of clusters	10
Number of iteration	1400
Cross over percentage	0.5
Mutation rate	0.01

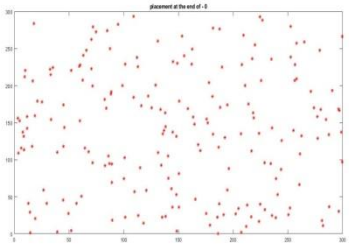

Fig.5. Random distribution of 100 sensor nodes in 100×100

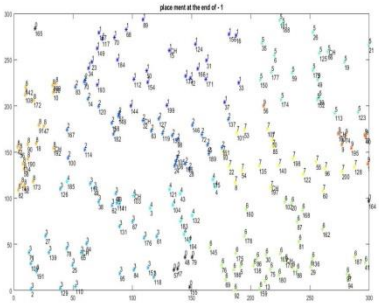

Fig.6. Cluster formation and CH selection after round 1

7. Simulation Results

The sensor nodes are randomly distributed over the square area and the sink node is located far away from the normal nodes. The clustering is formed with 10 clusters and accordingly CHs are selected based on fitness function. The GA based cluster head selection and cluster formation is compared with the LEACH protocol. It is clear from figure 7, that the proposed hybrid algorithm performs better than LEACH due to its improved CH selection algorithm, which reduces the transmission distance between cluster members and CH node and in turn better energy conservation. The better energy dissipation is performed by the proposed algorithm.

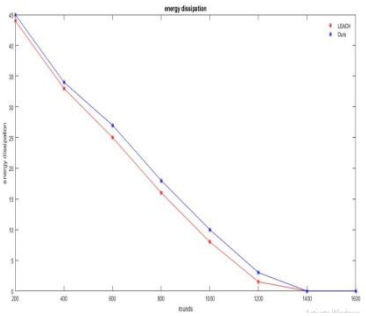

Fig.7. Energy dissipated per round

The figure 7 shows the energy dissipation graph for a number of communication rounds. The simulation is carried out for 1400 rounds with the initial energy of 20J.

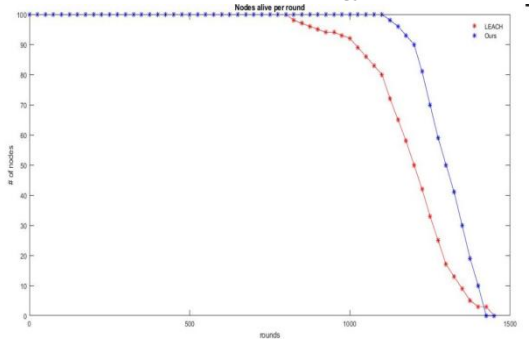

Fig.8. Network Life Time

From figure 8, it is evident that the proposed algorithm has more number of alive nodes when compared with LEACH after each iteration. It shows that the life time of proposed GA based algorithm have more stable period compared to LEACH. The proper selection of CHs and the cluster establishment made the network more stable. GA based method have 156 higher rounds compared to LEACH.

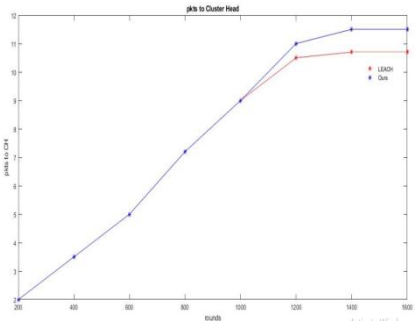

Fig.9. Number of packets sent to CHs

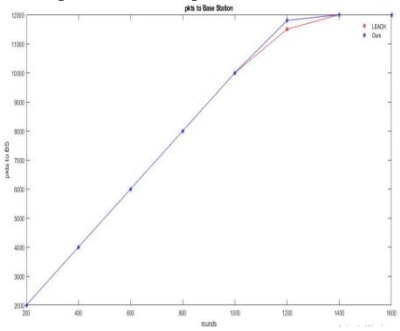

Fig.10. Number of packets sent to Base Station

From figure 9 and 10, it is obvious that both the inter cluster and intra cluster throughput are significant (number of packets from member nodes to CH and from CH to base station) is larger in the proposed algorithm than in LEACH because of the lower overhead.

8. Conclusion

In this paper, a hybrid technique of GA and ACE is proposed and implemented, where the entire network is divided into clusters and CHs for each cluster is selected after each iteration based on the novel fitness function. This algorithm finds better results than LEACH in terms of network life, energy dissipation and throughput. The increase in network lifetime is obtained by the proper selection of CHs in a load balanced way. Better results would be obtained by changing the value of different weight coefficients in the fitness function as required in GA. This work can be further extended to heterogeneous network and more energy can be saved by using multi hop technique.

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