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Cluster Head Selection Optimization Based on Genetic Algorithm to Prolong Lifetime of Wireless Sensor Networks

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Abstract

Wireless sensor networks gain ample interest because of their wide range of applications. Efficient energy consumption of nodes is the prime design issue for these networks. Clustering approaches prolong the network lifetime with the load balanced network. To achieve load balancing clustering algorithm rotate the role of cluster head among the nodes so, cluster head selection process is pivotal for clustering algorithms. Work of this paper presents a genetic algorithm based cluster head selection for centralized clustering algorithms to have a better load balanced network than the traditional clustering algorithm. Simulation shows that the proposed solution finds the optimal cluster heads and has prolonged network lifetime than the traditional clustering algorithms.

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1. Introduction

Wireless sensor networks^{1,2} have wide range of application area such as habitat monitoring³, field surveillance⁴, automobiles⁵ and many more. Wireless sensor networks consist of various densely deployed sensor nodes inside or very near to application area. Advancement in micro-electro-mechanical-systems (MEMS) provides low cost small sized yet powerful sensor nodes that are capable of sensing, data processing and wireless communication and carry a limited power battery. Sensor nodes work in collaboration to complete the task in time and to provide information accurately. Sensor nodes sense the application area and send the data to base station located inside or outside the application area via single hop or multi-hop. User accesses the collected data through some remote access.

Sensor nodes work with severe limited resources like battery power, bandwidth, memory and etc. Lifetime of wireless sensor networks depends upon battery power of nodes as every operation of node consumes energy, hence node goes out of energy. Harsh/remote application area makes it impossible to recharge or replace the battery of nodes. So, efficient energy consumption of nodes is the prime design issue for wireless sensor networks from the circuitry of sensor nodes to application level to network protocols.

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Clustering algorithms^{6,7} are considered energy efficient approach for wireless sensor networks. Clustering divides the nodes in independent clusters and selects a head for each cluster. Nodes send sensed data to respective cluster head; cluster head applies data fusion/aggregation^{8,9} to reduce the collected data to some meaningful information and sends aggregated data to base station. Communication between two nodes is the main energy consuming process that depends upon the distance between the two. Clustering avoids long distance communication of member nodes and only cluster heads are communicating to base station. To load balance the network, role of cluster head is rotated among all nodes.

Cluster head selection is decisive for the performance of clustering algorithms. Total intra-cluster communication distance and total distance of cluster heads to base station depends upon number of cluster heads. If numbers of cluster heads are less, total distance of cluster heads to base station decreases while total intra-cluster communication distance increases. When numbers of cluster heads are more, total intra-cluster communication distance decreases but there is increase in total distance of cluster heads to base station. Clustering algorithm proposed in this paper selects and optimize number of cluster heads by applying genetic algorithm. Proposed solution considers trade-off between intra-cluster communication and distance of cluster head to base station and remaining energy of nodes for cluster head selection. Simulation results show that proposed solution effectively optimize number and selection of cluster heads and have significant improvement over to tradition clustering algorithms.

Rest of paper is organized as: section 2 describes related work for energy efficient clustering algorithms. Detail of considered network model is given in section 3. Section 4 describes genetic algorithm to optimize cluster head selection. Section 5 describes simulation results and finally section 6 concludes the work of paper.

2. Review of Literature

Low Energy Adaptive Cluster Hierarchy (LEACH)¹⁰ is fully distributed clustering algorithm. In set-up phase, cluster head selection, cluster formation and TDMA scheduling of nodes are performed. In steady phase, nodes send data to cluster head and cluster head aggregates the data. Aggregated data is send to base station. Re-clustering is done over regular time periods to rotate role of cluster head among all nodes that makes network load balance. LEACH does not consider remaining energy of nodes for cluster head selection, i.e. all nodes have equal probability of cluster head.¹¹ addresses problem of fixed round-time in LEACH and proposed a network adaptive round-time for LEACH. Round-time is adaptive to number of nodes alive in network.

LEACH-C¹² is the centralize variant of LEACH. In the set-up phase nodes send information about the energy and location to base station. Base station applies simulated annealing¹³ to select cluster heads and the forms clusters. Base station sends cluster head and cluster information to nodes along with their TDMA schedules. Steady phase is same as of LEACH. LEACH-C outperforms LEACH to extend lifetime of network¹⁴. LEACH-F¹⁵ is a fix cluster variant of LEACH. Nodes send their location information to base station once. Base station groups nodes in clusters which are fixed throughout the network lifetime. Base station sends the complete information to nodes. TDMA schedule is fixed. Steady phase is same as of LEACH.

In¹⁶, author uses Fuzzy C-Means (FCM)¹⁷ clustering approach to find optimal number and location of cluster heads in wireless sensor network to prolong the network lifetime. Euclidian distance is used by the approach to partition the sensor network in clusters and Xie and Benis (XB) index is used as validity measure of clusters.

Adaptive Decentralized Re-clustering Protocol(ADRP)¹⁸ selects a cluster head and set of next heads for upcoming few rounds based on residual energy of each nodes and average energy of cluster. A round of ADRP has two phases: initial phase and cycle phase. In the initial phase, nodes send status of their energy and location to base station. Base station partitions the network in clusters and selects a cluster head for each cluster along with a set of next heads. In the cycle phase, cluster head aggregates the data and sends to the base station. In the re-cluster stage, nodes transit to cluster head from set of next heads without any assistance from base station. If the set of next heads is empty, initial phase is executed again. Re-clustering energy consumption is avoided for few rounds but node death from next cluster head list make network unbalanced.

3. Network Model

For the proposed protocol following network assumptions are considered:

- All sensor nodes are homogenous.
- All nodes are stationary once deployed in the field and have location information.
- There is single base station located outside the field.
- The nodes are considered to die only when their energy is exhausted.

In wireless sensor networks, nodes are deployed randomly, i.e. positions of nodes are not pre-engineered. Most of the energy of nodes is dissipated due to communication between two nodes and it depends on the distance between them. Both sending and receiving of data consumes energy. Energy dissipation model is shown in Fig. 1 and explained next.

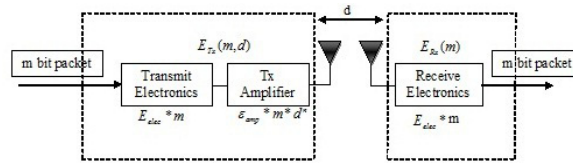


Fig. 1. Radio Energy Model

For sending m bit data over a distance d , the total energy consumed by a node is as follows:

$$E_{Tx}(m, d) = E_{Tx-elec}(m) + E_{Tx-amp}(m, d) \quad (1)$$

$$E_{Tx}(m, d) = \begin{cases} m \times E_{elec} + (m \times E_{fs} \times d^2) & d < d_{crossover} \\ m \times E_{elec} + (m \times E_{amp} \times d^4) & d \geq d_{crossover} \end{cases} \quad (2)$$

where $d_{crossover}$ is crossover distance, while the energy consumption for receiving that message is given by:

$$E_{Rx}(m) = m \times E_{elec} \quad (3)$$

Considered network model for proposed scheme assumes energy required for running the transmitter and receiver electronic circuitry E_{elec} as 50nJ/bit and for acceptable SNR required energy for transmitter amplifier for free space propagation E_{fs} as 100pJ/bit/m² and for two ray ground E_{amp} as 0.0013pJ/bit/m⁴. The crossover distance $d_{crossover}$ is considered 87m.

4. Proposed Genetic Algorithm for Cluster Head Selection

4.1. Overview Genetic Algorithms

Genetic algorithm (GA)^{19,20} is a randomized search and optimization technique and is widely used for solving optimization problems that have large number of possible solutions. GA is based on survival of fittest theory. GA starts with a set of possible solutions called initial population which is generated randomly. Each individual solution is called chromosome. Length of each chromosome must be same. A fitness function calculates fitness value of each chromosome. Chromosome with high fitness value is closer to optimal solution. Two parent chromosomes are selected for crossover to produce two offspring. Mutation is applied to randomly selected chromosome to obtain a better solution. Crossover and mutation generate next population. Few best fitness value chromosome of previous population are also selected in new generated population to ensure that the new generation is at least as fit as the previous. This process is known as elitism. This entire process is repeated until some stopping criteria are not matched.

4.2. Genetic Algorithm for Proposed Solution of Cluster Head Selection

- Population- Population consists of various individual solutions for the problem. Larger the size of population, higher is the accuracy of algorithm. Length of individual depends upon number of nodes in network as a 1 in individual represents node as cluster head while a 0 means nodes is member node. Initial population is generated randomly.

- **Fitness Function-** Survivability of an individual depends upon its fitness value. Fitness value of each individual is calculated according a fitness function. In our work, fitness function consists of following three parameters.
 - Remaining Energy (E)
 - Number of Cluster Heads (CH)
 - Total Intra-cluster Communication Distance (IC)
 - Total Distance from Cluster Heads to Base Station (BSD)

Value of last to parameters depends upon first. Less number of cluster heads has less total distance from cluster heads to base station but has high total intra-cluster communication distance. While high number of cluster heads has less total intra-cluster communication distance but has more total distance from cluster heads to base station.

After scaling the fitness function, we have fitness function as:

$$Fitness = E + (N - CH) + \frac{IC}{N} + \frac{BSD}{N} \quad (4)$$

where N is total number of nodes in network. Fitness function shows that there is more emphasis on decreasing total distance from cluster heads to base station.

- **Selection-** Selection is the process of choosing individuals from current population for new population. The purpose of the selection process in a genetic algorithm is to give more reproductive chances to those population members that are better fit. The selection procedure may be implemented in a number of ways like Roulette Wheel selection, Tournament selection, Boltzmann selection, Rank selection, Random selection, etc. In this work Roulette Wheel selection procedure is applied to select chromosomes for generating new population.
- **Crossover-** In this paper, one-point crossover method is used. The crossover operation takes place between two chromosomes with probability specified by crossover rate. These two chromosomes exchange portions that are separated by the crossover point. The following is an example of one point crossover.

Individual 1	1	1	1	0	0	1	1	1	0
Individual 2	0	1	0	1	1	0	0	1	0

After crossover, two offspring are created as below:

Offspring 1	1	1	1	0	1	0	0	1	0
Offspring 2	0	1	0	1	0	1	1	1	0

- **Mutation-** The mutation operator is applied to each bit of a chromosome with a probability of mutation rate. After mutation, a bit that was 0 changes to 1 and vice versa.

Before Mutation	1	1	1	0	0	1	1	1	0
After Mutation	1	1	0	0	0	1	1	1	0

4.3. LEACH-GA

Proposed clustering algorithm, LEACH-GA, is a base station assisted approach. Nodes send their energy and location information to base station. Base station applies proposed GA to optimize number and selection of cluster heads. Base station assigns cluster head to all nodes. TDMA schedule is constituted for each cluster and all the information about clusters and TDMA is broadcasted to the network. Nodes wake up and send sensed data to respective cluster head as their time slot in TDMA schedule encounter. Nodes are in sleep state otherwise. Re-clustering is done after round-time is over.

5. Simulation Results and Analysis

Network parameters are listed in the table 1. Performance of proposed LEACH-GA is compared with LEACH and LEACH-C.

Table 1. Parameters

Parameter	Value
Number of Nodes(N)	100
Network Area	100×100 m ²
Size of Population	N
Length of Chromosome	N
Selection Type	Roulette wheel
Crossover Rate	0.7
Mutation Rate	0.01
Base Station Location	75, 150
Initial Energy	0.5J
Packet Header Size	25 bytes
Data Packet Size	500 bytes

Following simulation metrics are considered for the analysis of effect of heterogeneous nodes on the performance of clustering algorithms.

- **Node Death Rate:** It demonstrates number of alive nodes over rounds. A lower node death rate happens because of load balanced network. The region of the node death rate is divided as stable region and unstable region. All nodes are alive in the stable region while unstable region is rest of the region.
- **Network Lifetime:** It can be defined as the working period of network.²¹ defines classifies network lifetime in three parts First Node Death (FND), Half Node Death (HND).

Fig. 2 shows convergence of proposed solution for number of cluster heads selected for a round. Proposed solution optimizes number of cluster heads considering remaining energy of nodes and inter-and intra-communication distance of clusters.

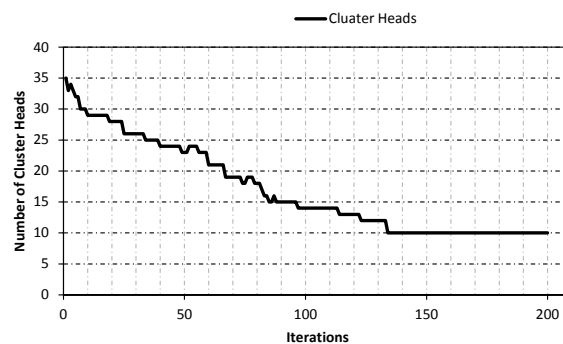


Fig. 2. Number of Cluster Heads over Generations

Figure 3 shows comparison of node death rate of LEACH, LEACH-C and proposed LEACH- GA. Node death rate is divided into two parts: stable region and unstable region. In stable region all the nodes are alive and hence unstable region have less number of alive nodes. LEACH has random selection of cluster heads so there are chances of selection of nodes with less remaining energy which will die early and makes load of network unbalanced. LEACH-C does not consider trade-off of intra-cluster communication distance and distance of cluster heads to base station and also does not optimize number of cluster heads in each round. Proposed LEACH-GA optimize number and selection of cluster heads hence has better load balance of network compared to LEACH and LEACH-C. Stable region of

proposed LEACH-GA is extended as compared to LEACH and LEACH-C. It can be seen from the figure 2, node death rate of LEACH-GA is always better than LEACH and LEACH-C.

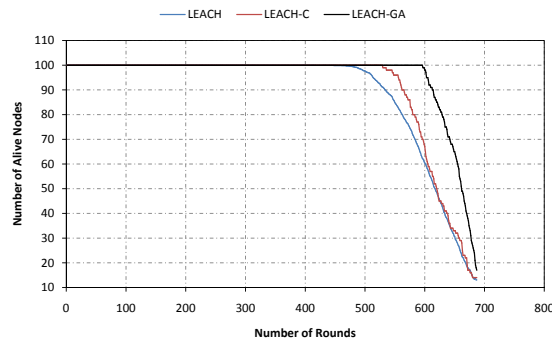


Fig. 3. Node Death Rate

Table 2 compares network lifetime of LEACH, LEACH-C and LEACH-GA. As analyzed previously, proposed LEACH-GA has longer stable region than LEACH and LEACH-C so first node death appear later in case of LEACH-GA. Cluster head of proposed LEACH-GA protocol selects cluster head by optimizing the both intra- and inter-cluster communication distance. So the network is better load balanced as compared to LEACH and LEACH-C. There is increase of 25% and 12% in first node death for LEACH-GA compared to LEACH and LEACH-C respectively. There is increase of 7% and 6% in half node death for LEACH-GA compared to LEACH and LEACH-C respectively.

Table 2. COMPARISON OF NETWORK LIFETIME OF LEACH, LEACH-C, LEACH-GA.

Protocol	FND	HND
LEACH	479	617
LEACH-C	529	620
LEACH-GA	596	662

6. Conclusion

cluster head selection is pivotal for clustering algorithm. A centralized cluster head selection scheme based on genetic algorithm to optimize the selection is proposed in the paper that selects head according to their residual energy and takes care of trade-off of inter- and intra-cluster communication distance. Proposed scheme also optimizes the number of cluster head for a round. Simulation results also asserted that proposed scheme has prolonged network lifetime as compared to LEACH and LEACH-C.

7. References

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