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Genetic Algorithm Based Energy Efficient Clusters (GABEEC) in Wireless Sensor Networks

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Abstract

In this paper, a genetic algorithm based method (GABEEC) is proposed to optimize the lifetime of wireless sensor networks. The proposed method is a cluster based approach like LEACH. Genetic algorithm is used to maximize the lifetime of the network by means of rounds. The method has 2 phases which are Set-up and Steady-state phase. In the set-up phase, the clusters are created and are not changed throughout the network. The clusters are not recreated for each round. In each round, there are static clusters with dynamically changing clusterheads. A simulator is developed in MS Visual C# 2010 development environment to validate the proposed method. In the simulation, 100 nodes are randomly distributed in 50x50 square meters area. The results show that the proposed method is found to be more efficient than LEACH.

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1. Introduction

Wireless Sensor Network (WSN) is used in many application environments. Most known applications are target tracking, habitat monitoring, surveillance and security [1][3]. A WSN contains sensor nodes that are small, battery constrained, low-cost. One of the major problems for a WSN is energy consumption during communication between sensor nodes. The longer distance between sensor nodes, the more they consume energy. Therefore to extend the lifetime of the WSN, there are several studies on communication distance of the sensor nodes.

Approaches that are cluster-based are useful for environment monitoring [2]. The use of clusters for sensor networks reduces communication distance for most sensor nodes, demanding only few nodes to

transmit long distances, e.g., BaseStation (BS). A cluster-based protocol divides the network into a number of clusters. Each cluster has a cluster-head (CH) that collects data from all member nodes in its cluster. These CHs then aggregate the collected data and send it to the BS. This approach intensely reduces the communication cost of the sensor nodes so that the lifetime of the network greatly expands.

In this work, static clustering with dynamic CH selection is used. At the end of each round a member node, called associate, becomes CH depending on the residual energy of the current CH and the average energy amount of the member nodes in the cluster. And we use genetic algorithm (GA) to minimize the communication distance in the network and maximize the lifetime of the network.

2. Related Work

In [4], Heinzelman et al. describe LEACH (Low-Energy Adaptive Clustering Hierarchy), which is a cluster-based energy efficient routing protocol. The application field is divided into several clusters in a random fashion, where the number of CHs are pre-determined (5% of the sensor nodes). The protocol has two phases. The first one is “Set-up Phase”. In this phase clusters are formed and cluster heads are selected based on a certain probability. The second phase is “Steady state Phase”, in which the member nodes transmit their data to the CHs based on a TDMA schedule. Subsequently CHs fuse and transmit the data to the BS. When all CHs send its aggregated data to BS a round is over. After a round is over set-up phase is performed again and new clusters are created with new cluster heads.

In [5], Heinzelman et al. propose a new protocol that improves the set-up phase of LEACH protocol, called LEACH-C (LEACH-Centralized). Selecting random cluster heads in each round does not greatly affect total performance. They use a central control algorithm to form the clusters may produce better clusters by dispensing the CH nodes throughout the network. During the set-up phase of LEACH-C, each node sends information about its current location and energy level to the BS. In addition to determining good clusters, the BS needs to ensure that the energy load is evenly distributed among all the sensor nodes. At the end of each round BS forms clusters using a simulated annealing algorithm. This algorithm attempts to minimize the amount of energy for the member nodes to transmit their data to the CH, by minimizing the total sum of squared distances between all member nodes and the closest CH.

Hussain and Matin [6] describe a hierarchical cluster-based routing protocol (HCR) where nodes self-organize into clusters and each cluster is managed by a set of associates called head-set. Each associate functions as a CH by using round robin technique.

In [7], Hussain et al. improve the HCR protocol by using a heuristic-based approach like [5]. They use a GA to determine the number of clusters, the cluster heads, the cluster members, and the transmission schedules. They compare their results with HCR and LEACH. The results show that using GA-based hierarchical clusters expands the lifetime of the network.

Maraiya et al. [9] describe ECHSSDA (Efficient Cluster Head Selection Scheme for Data Aggregation) protocol. It has two phases same as LEACH, set-up phase and steady phase. They improve cluster head selection method to expand the lifetime of the network. When a round is completed, the BS checks the residual energy of the current CHs and the average energy of non-CH nodes for each cluster. If a cluster head's energy is lower than the average energy of the non-cluster head nodes, BS selects an associate CH from non-CH nodes based on its energy level for the next round. After associate CHs are selected, all the current clusters are destroyed and a new set-up phase is performed. In simulation results they prove that this CH selection method is more energy-efficient than LEACH and LEACH-C.

3. Genetic Algorithm Based Energy Efficient Clusters (GABEEC)

In this work we proposed a Genetic Algorithm based method to optimize the lifetime of WSN. The method is cluster-based approach like LEACH. There are two phases in the proposed method which are set-up phase and steady-state phase.

Set-up Phase:

First phase is the set-up phase and it is performed only one time. In the set-up phase, pre-defined numbers of sensor nodes are chosen as cluster heads. The number of CHs also indicates the number of clusters in the network. Non-CH nodes are assigned to the clusters based on their distances to the CHs. These non-CH nodes join into the clusters.

Steady-state Phase:

In this phase, all nodes start to communicate with their CHs. Each node uses a Time Division Multiple Access (TDMA) schedule to communicate with CH. TDMA is a technology that allows multiple access to share same radio channel and divides each channel into time slots to enable data transmissions. After the CH receives from all member nodes, it fuses the data packets into one packet and sends it to the base station (BS). When all CHs send their data to BS, a round is completed. At the end of each round the BS checks the energies of CHs and the member nodes. If the energy of a CH is under the average energy of the member nodes of its cluster, an associate CH is selected from the member nodes of the cluster. The member node which has the highest energy is selected as the new CH and the old CH becomes a member node. The clusters are not recreated as is done in [4] and [9]. The members of each cluster do not change and they are located in the same cluster.

In the proposed method, the clusters that are created in the set-up phase are not changed throughout the network. The selection of the new CH is based on the residual energy of the current CH and its member nodes. The clusters are not recreated for each round. So in each round, there are static clusters with dynamically changed CHs.

3.1 Problem Representation

In the method, GA is used to maximize the lifetime of the network by means of rounds. Binary representation of the network is used and each sensor node corresponds a bit. CHs are represented as “1” and non-CH nodes are represented as “0”. The representation of a network is called a *Chromosome* or *Genome*, a collection of bits. Initially the GA starts with a population, a pre-defined number of chromosomes, consists of randomly generated individuals.

Then GA evaluates each chromosome by calculating its fitness. Fitness of a chromosome depends on some fitness parameters that are explained in Section 3.2. After evaluating the fitness of each chromosome in the population, GA selects the best fit chromosomes by using a specific selection method based on their fitness values and then applies two operators, *Crossover* and *Mutation*, respectively. These operations are carried out to produce a new population better than the previous one for the next generation.

3.2 Fitness Function

The aim is to maximize the lifetime of the network. The fitness function has 3 parameters. These parameters are:

- R_{FND} : The round which first nodes dies,
- R_{LND} : The round which last node dies,

- C : The cluster distance.

The cluster distance is the sum of the distances from the member nodes to the CH and the distance from the CH to the BS. For a cluster with k member nodes the cluster distance is denoted as follows [7]:

$$C = \sum_{i=1}^k d_{ih} + d_{hs} \quad (1)$$

Where d_{ih} is the distance from node i to the cluster head h and d_{hs} is the distance from the cluster head h to the BS node s .

The fitness function, F , is a function of all parameters described above and used in the genetic algorithm. It is defined as follows:

$$F = \sum_i (f_i \times w_i), \forall f_i \in (R_{FND}, R_{LND}, -C) \quad (2)$$

The w value is an application-dependent weight of a fitness parameter that indicates which parameter is more effective for the function. We can make a fitness parameter more important than the other by changing its weight or we can give them equal importance by setting the weights equal.

3.3 Selection

This process determines which of the chromosomes from the current population will create new child chromosomes by doing crossover and mutation. The new child chromosomes join the existing population. The new population with new child chromosomes will be the basis for the next selection. The chromosomes which have better fitness values have bigger chance to be selected. There are a number of selection methods, e.g., Roulette-Wheel selection, Rank selection and Tournament selection [8]. In the proposed method, Roulette-Wheel selection method is used.

3.4 Crossover

Crossover is a genetic operator that generates two new child chromosome from two parent chromosome. The easiest way to do this to choose a random crossover point and the two parent chromosomes exchange information after that point. A sample is shown in Figure 1:

Parent 1: 1110 0101
Parent 2: 1011 1110
Child 1: 1110 1110
Child 2: 1011 0101

Figure 1. A cross-over example

Crossover is done after the selection process and depends on a probability defined initially before GA starts. The probability that the crossover will take place depends on the crossover rate.

3.5 Mutation

After a crossover is performed, mutation takes place. This is to prevent falling all solutions in population into a local optimum of solved problem. Mutation changes every bit of the new child chromosome with a probability called mutation rate as shown in Figure 2.

Original Chromosome: 11100101 Mutated Chromosome: 11000111

Figure 2. A mutation example

4. Simulation and Results

A networking simulator is developed using MS Visual C# 2010 development environment and object oriented programming techniques. The main window of the simulator is shown Figure 3. In the first simulation we compare our method with LEACH. 100 nodes are randomly distributed in 50x50 square meters area and the BS is located 100 meters away from the network. We use the radio model denoted in [4]. The radio dissipates $E_{elec} = 50 \text{ nJ/bit}$ to run the transceiver or receiver and $\epsilon_{amp} = 100 \text{ pJ/bit/m}^2$ for the transmit amplifier. To transmit an n -bit message a distance d using this radio model, the radio expands:

$$E_{Tx}(n, d) = E_{elec} * k + \epsilon_{amp} * n * d^2 \quad (3)$$

And to receive this message, the radio expands:

$$E_{Rx}(n) = E_{elec} * n \quad (4)$$

The following GA parameters are used during the simulation:

- Population Size: 20
- Generation Size: 120
- Crossover Rate: 0,60
- Mutation Rate: 0,001

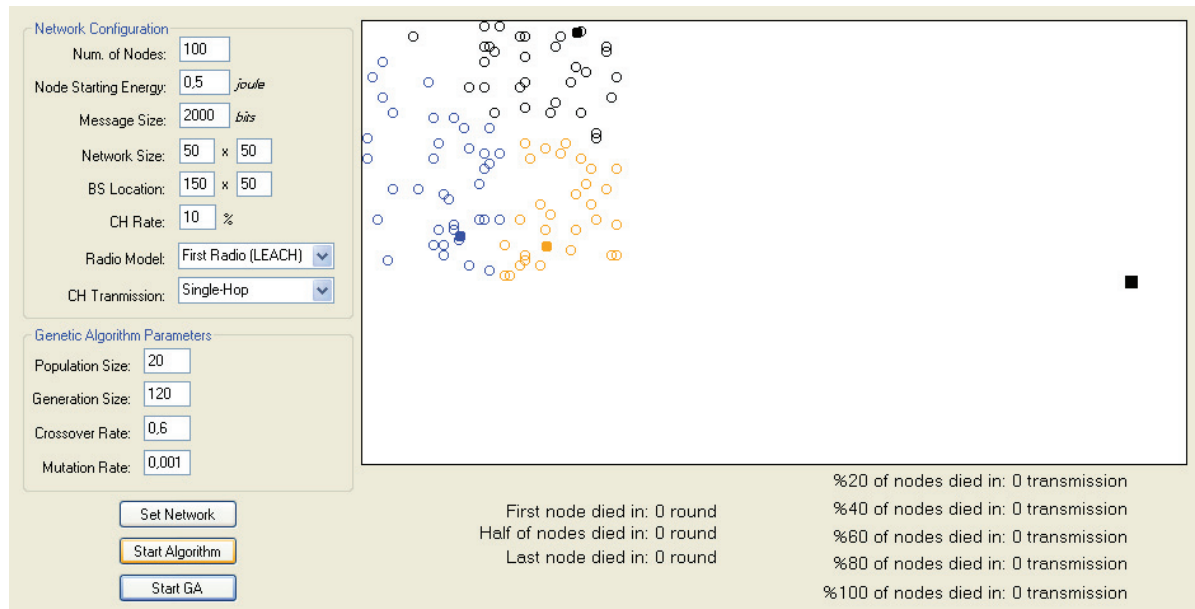


Figure 3. Main window of the simulator

We ran the simulation 3 times and at each time the node's starting energy (0,25J, 0,5J and 1J) was different. Table 1 and Figure 4 show us the comparison of the proposed method with LEACH. We

simulated the network with three different starting energy of node and found that it takes approximately 1,5 - 1,6 times longer for the first node to die and approximately 1,15 - 1,2 times longer for the last node to die in proposed method than LEACH. The performance of using a GA-based approach can be clearly seen in Figure 4. The proposed method outperforms LEACH.

Table 1. Lifetimes using different amounts of starting energy for the nodes

Starting Energy (j/node)	Method	Round first node dies	Round last node dies
0,25	LEACH	394	665
	GABEEC	651	771
0,5	LEACH	932	1312
	GABEEC	1226	1571
1	LEACH	1848	2608
	GABEEC	2776	2918

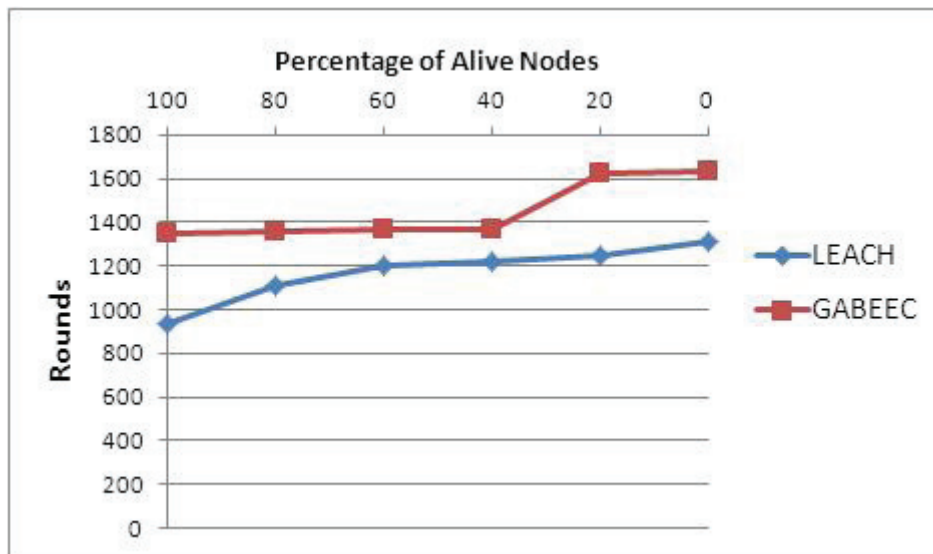


Figure 4. Network lifetime using LEACH and GABEEC with 0,5 J/node.

The second simulation is based on different network configuration used in [6] and [7] to compare our method with HCR [6] and HCR-GA [7]. 200 nodes are randomly distributed in 100x100 square meters area and the BS is located 200 meters away from the network. We use the radio model denoted in [7]. The radio dissipates $E_{elec} = 50 \text{ nJ/bit}$ to run the transceiver or receiver and $\epsilon_{amp} = 10 \text{ pJ/bit/m}^2$ for a short range transmission and $\epsilon_{amp} = 0,0013 \text{ pJ/bit/m}^4$ for a long range transmission. The energy consumed for data aggregation is $E_{DA} = 5 \text{ nJ/bit}$. GA parameters are set as in the first simulation. Figure 5 shows the results of the second simulation. It can be clearly seen that GABEEC outperforms HCR and HCR-GA in terms of CH transmission.

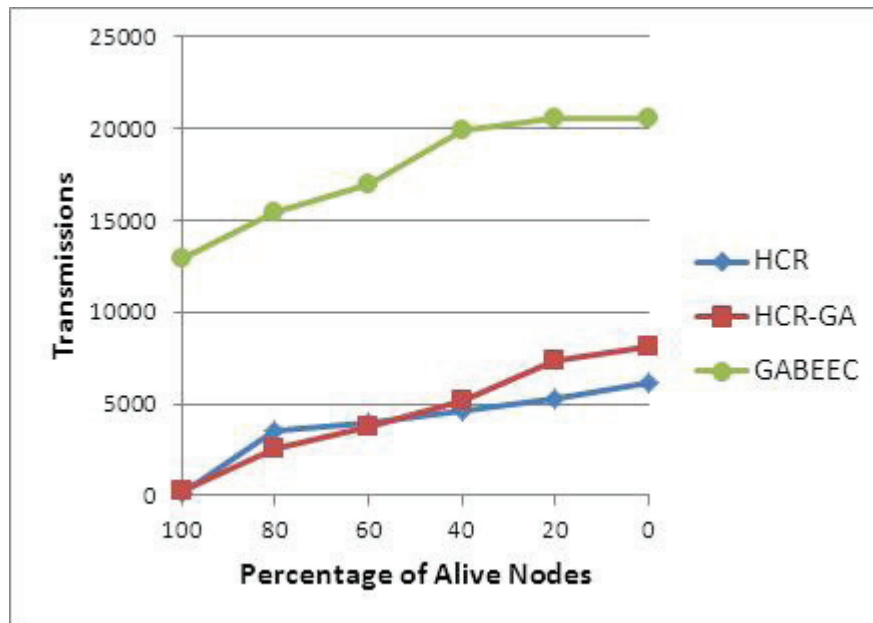


Figure 5. Network lifetime using HCR, HCR-GA and GABEEC with 2 J/node.

5. Conclusion

The proposed method (GABEEC) expands the lifetime. The simulation results imply that using a GA-based method increases the lifetime of the network. The method begins with randomly generated nodes in a network to be cluster-heads. By using a GA, the proposed method is able to find an applicable number of cluster-heads and their locations. Simulation results show that the proposed method is an energy-efficient way to expand the lifetime of the network.

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