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Choosing Proper Cluster Heads to Reduce Energy Consumption in Wireless Sensor Networks Using Gravitational Force Algorithm

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Abstract

Wireless sensor networks, as a new generation of real time and embedded systems, have been very applicable in situations that using traditional networks is not possible. However, they are calculation, energy and memory limited. As the energy is really a big challenge in these networks, using different types of clustering models have been introduced to address this problem. In these structures, the sensor nodes are grouped in some clusters and in each cluster a central node is chosen as cluster head. Choosing a proper cluster head has a significant impact on reducing power consumption which increases network lifetime. In this paper, a new approach based on Gravitational force algorithm has been proposed to achieve a good clustering model and choosing proper cluster heads. The proposed approach is based on three main descriptors, energy, distribution and data integrity. The simulation results illustrate that the network lifetime was increased significantly in comparison with other strategies which use local information to choose the cluster heads.

Keywords: wireless sensor networks, clustering, cluster head, life time, gravitational force algorithm

Introduction:

A wireless sensor network is constituted from hundreds or thousands nodes, randomly distributed in an abounded or dangerous region. These nodes are responsible for collecting information from the environment they are working on. Actually, because of the conditions of these environments, gathering

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information is really hard to do. Each wireless sensor includes a sensing unit, a calculation unit, memory and a wireless communication unit with limited communication range.

In the recent years, wireless sensor networks have been very applicable for addressing military, medicine and environment issues. By the way, recharging or replacing the power source of network nodes is really hard and sometimes is impossible. Hence, reducing power consumption and therefore, increasing the network lifetime is the most important challenge [1]. As mentioned previously, the main duty of the sensors is gathering information from the environment. Because the sensors' power source is limited and because the Base Station (BS) or sink is usually far from distributed nodes, transmitting data directly from sensors to sink is almost impossible. Consequently, multiple hop approaches are employed for routing. However, there are always some nodes that compared to the others, are used as transmission media more and their power consumption and percentage of fail increase.

Different clustering models have been introduced to solve this problem. In clustered structures, the sensor nodes are grouped in some clusters and for each cluster a central node is chosen as cluster head. Usually, the cluster head has more energy rather than the others. The cluster head is responsible for collecting information from other nodes in cluster and forwarding them to BS. If it fails, because of any possible reason, a new cluster node must be chosen. The selection of cluster head must be done accurately because of their important role in network lifetime and performance. A not proper cluster head can reduce network lifetime and throughout significantly.

The previous works can be grouped in two main categories. The first category includes those works that consider only energy to choose the cluster head [2] which is not a good idea for complicated networks particularly. For example, a high level energy node may be located in a corner of the region. So, other nodes should consume a lot of energy to send their information to the selected cluster head. The second category includes approaches which consider not only the energy factor, but also more parameters including distance and movement [3-5].

In this paper, we have used Gravitational force algorithm to improve network lifetime. In this approach each node knows its energy level, its location, its neighbors' energy level and their locations. Based on this prepared information and using gravitational force algorithm the cluster head node is determined. The result confirmed the effectiveness of the proposed approach.

The rest of the paper is organized as follows. In section 2, the previous works will be discussed. Section 4 will bring some descriptions about the gravitational force algorithm and in section 5 the proposed method will be introduced. Section 6 shows the results of the proposed approach and finally in section 7, we will briefly conclude this paper.

Related works

Wireless sensor networks are very applicable in different domains. There are different algorithms proposed to handle the clustering and selecting the cluster head issues. LEACH algorithm proposed in 2000 is a hierarchical protocol, in which most nodes transmit their data to the cluster heads. LEACH is a centralized, self-configuring algorithm which uses a random approach to achieve an evenly energy load

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distribution. Each node uses a stochastic algorithm at each round to determine if it will become a cluster head in this round or not. To choose the proper cluster head, all nodes produces a random number between 0 and 1. If a particular node's generated number is less than a predefined threshold, it will be chosen as cluster head. The threshold is calculated as follows:

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

where p is the probability of being chosen as cluster head, r is the round number and G is the set of nodes which have never being considered as cluster head in the last 1/p rounds. Because of using local information for choosing the cluster head, there are some problems with this algorithm including: 1) the number of cluster heads is not fixed. In some rounds it may be less or more than the optimum number. 2)

The cluster head may be at a corner of the region. Therefore, other nodes have to consume more energy for submitting their data. 3) Each node has to generate a random number and a threshold in each round.

LEACH-C is another centralized algorithm designed for addressing this task [3]. In centralized algorithms, all nodes send their data to a specific node which is responsible for choosing the cluster head, according to received information. This approach leads to a lot of energy consumption itself. AHP algorithm proposed in [4] considers nodes' energy, movement and distance to the cluster head together. This approach is centralized and the sink determines which node will be the cluster head.

In the method proposed in [6], according to the nodes' distance from each other, the node at the center of cluster is selected as cluster head. This strategy may force other nodes to consume more power to send their data to the central node chosen as cluster head.

In [7] presented FSCA (Fuzzy Self Clustering Algorithm). Each sensor node uses the energy level local density within its sensing range and time as parameters for clustering, re-clustering, and merging existed clusters by using fuzzy logic technique. CFGA (Clustered wsn using fuzzy logic and genetic algorithm) presented in [8]. At the beginning of each round , after checked its fuzzy module by each node [20], if the cluster head capability exists, it would be ready, then at the base station by optimum network nodes are determined..

GSAGA(Global Stimulated Annealing Genetic Algorithm) present in [9]. GSAGA is used to create energy efficient clusters for routing in WSNs. The focus of the work is based on the optimization properties of genetic algorithm. The main idea is the selection of a cluster head that can minimize the maximum intra-cluster distance between itself and the cluster member, and the optimization of energy management of the network.

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Energy Model

The energy model for transmitting and receiving one bit of data has been assumed to be in accordance with LEACH energy model [10]. Assume that the distance between transmitter and receiver is d in the energy model mentioned above. If the distance between the transmitter and the receiver (d) is more than d0, the multi-path model (with path loss coefficient 4) is used. Otherwise the open space model (with pass loss coefficient 2) is used.

$$E_{TX}(I,D) = E_{TX-elec}(I) + E_{TX-amp}(I,d) = \begin{cases} IE_{elec} + I\varepsilon_{fs}d^2 & d < d_0 \\ IE_{elec} + I\varepsilon_{mp}d^4 & d \geq d_0 \end{cases} \quad (2)$$

E_{elec} is the required energy to activate the electrical circuit. ε_{fs} and ε_{mp} are the activating energies for power amplifiers in multi-path and open space cases, respectively. A more general form of (2) with constant coefficients p and q is represented as (3)

$$E_{TX}(I,d) = p + qd^a \quad (3)$$

On the receiver side, the consumed energy to receive one bit of data is as (4).

$$E_{RX}(I) = E_{RX-eiec}(I) = IE_{eirc} = P \quad (4)$$

In the presented asymmetrical networks, the initial energy of supernodes is assumed to be several times greater than the that of typical sensors. The consumption energy of a monitoring node and a relay in each round are denoted by Es_1 and Ec_1, respectively [11].

Local search algorithm based on gravitational force:

Voudoris et al. suggested GLS algorithm for the first time in 1995, to search within solution space for a NP-hard problem [12]. Webster in [13] introduced this algorithm and named it GELS. This algorithm has been inspired from the gravitational force in the nature and uses it to search for a desired solution. Each solution has some neighbors which can be categorized according to the problem parameters. The neighbors categorized in each group are called neighbors of a specific dimension. An initial velocity is considered for each dimension so that more initial velocity means better solution. In other words, the better solution leads to a more initial velocity.

GELS looks for solutions using two different approaches. In the first approach, one solution, from the current solution's neighbor nodes is selected and the gravitational force between them is calculated. On the other hand and in the second approach, gravitational force between current solution and all of its neighbors is mutually considered.

Moving within search space to find the answer is done using two different approaches too. The first one is moving toward a solution within the current cluster. The second approach is to find a solution from outside of the current solution's neighborhood. Each of these moving strategies can be combined with GELS calculation approaches. Consequently, there are four methods for using GELS algorithm.

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In 2007, Blachandar used GELS to solve Traveling Salesman Problem (TSP) and compared it with hill climbing and Simulated Annealing algorithms [14]. Simulation results indicated that when the size of the problem is small, all algorithms act the same. But when the problem size became bigger, GELS showed better performance. In [15], the authors proposed a hybrid algorithm for task scheduling in grid computing to decrease missed task using GELS. In [16], the main characteristics of heuristic algorithm borrowed from Newton's law have been discussed. A new method for reservation and scheduling using GELS algorithm was proposed in [17]. Blachandar et al proposed a meta-heuristic algorithm for set covering problem based on gravity [18]. Random GELS was used in [19] to solve timing in open shop problem.

GELS parameters

- **maximum speed**: determines the maximum allowed speed to prevent using speeds that are not useful according the problem definition.
- **radios**: determines the value of radios in the gravitational force formula. It can be used to increase or decrease the gravitational force.
- **repetition**: determines the number of loops to make sure that algorithm execution will be finished finally.
- **pointer**: it is used to identify an element movement direction.

Gravitational force

The gravity between two different solutions can be calculated using the following formula:

$$F = G\left(\frac{CU-CA}{R^2}\right) \qquad (5)$$

where G=6.672 (universal gravitational constant), CU is the value of fitness function for the current solution, CA is the value of fitness function for the candidate solution and R is the radios.

The proposed approach

In previous works, a cluster head was chosen either distributed or centralized. In distribution approach, the energy consumption is high. In centralized approach, because there is only one determiner node, the traffic rate is high. Besides, if the determiner node fails, the entire network will fail. In this paper, to reduce the calculation and energy consumption and to increase the network lifetime, the following conditions have been considered:

- A value has been considered for minimum energy level. If the energy level of a node is less than this threshold, it cannot be considered as cluster head.

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- If a node is placed at the blind point of a cluster or if the number of its neighbors is too small, it cannot be considered as cluster head.

- Each node calculates a chance parameter that indicates a probability by which the cluster head can be determined. If two nodes have the same chance values and if they are neighbors, one of them is removed from candidate list of this round, to save energy and to increases network lifetime.

In the proposed approach, each node knows its own and its neighbors' chances. It compares the chance values and chooses itself as cluster head if it has the maximum chance value. Otherwise, it tries to be member of nearest recently chosen cluster head. A node with greatest chance value announces itself as cluster head. So, other nodes will be member of this new cluster head. The algorithm is decentralized and each node is a determiner itself.

In the proposed approach, the cluster head is chosen based on gravitational force and it is not centralized. There are a lot of parameters which can be used for determining the cluster head. But using more parameters leads to a bigger rule table. Consequently, computation, time cost and energy consumption increase.

In each round, all nodes calculate their chance based on energy, distribution and their location. All nodes contribute in the cluster head selection process and finally, a node that its conditions are better than its neighbors introduced itself as the cluster head. The parameters used in our simulation can be found in table 1. An example of algorithm response in a 250*250 environment has been shown in Figure 1.

Table 1: the parameters used in the simulation

Primary Energy	$0.1j$
Eelect	$50\ nJ/bit$
Efs	$10\ pJ/bit/m\text{^}2$
Dco	$87\ m$
Eda	$5\ nJ/bit/signal$
Packet Size	$4000\ bits$
Calculation Energy	$50\ nJ/bit$
Send_near Energy	$Packet_Size * (Elect + Eda) + Packet_Size * Efs * dis\text{^}2$
Send_far Energy	$Packet_Size * (Elect + Eda) + Packet_Size * Emp * dis\text{^}4$

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Receive Energy	$(Packet_Size * (Elect + Eda) * 0.05)$
Combination&Compacting	$(Packet_Size * (Elect + Eda) * 0.05) * 0.05$

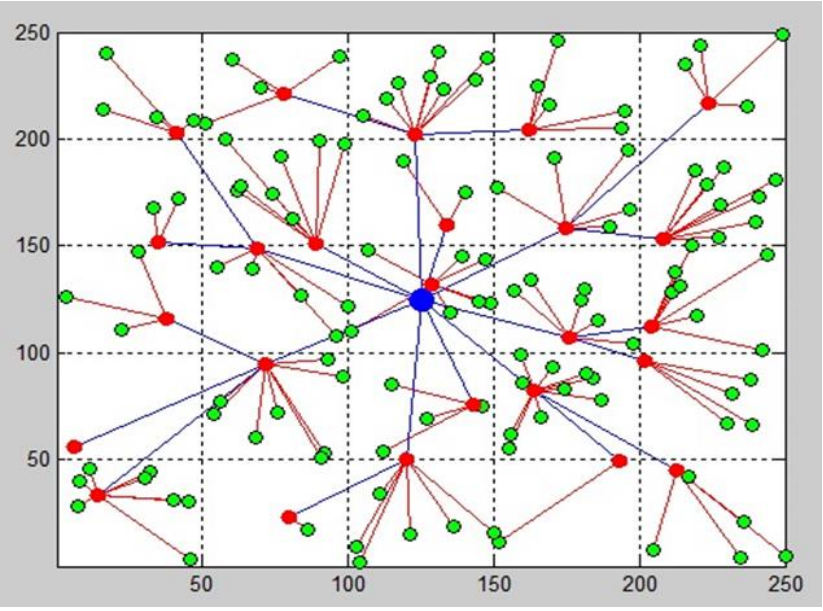


Fig.1: an example of the proposed algorithm response

Experimental Results

The simulation results will be shown in this section. The implementation has been done using C# on a system with a Pentium IV, 2.4 GHz processor and 1 GB RAM. The FND (First Node Dies) approach [1] has been considered to calculate network lifetime. It means the network can keep working until one of its nodes reaches to minimum energy level.

As mentioned previously, in this algorithm, a node cannot be a candidate for being cluster head if it has only one good characteristic. It must have all good parameters together. The goal of the proposed approach is combining all considerable parameters and selecting a node which has the best situation collectively. A node may have high level energy but does not have a good location so that all other nodes have to consume a lot of energy to submit their information to.

Table 2 shows the FND time for the proposed algorithm (GELS_CWSN) compared to LEACH [4], FSCA [7], CFGA [8] and GSAGA [9]. As can be seen, the improvement of network lifetime is remarkable and

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the proposed approach increased the first node die time in comparison with the competitors. Furthermore, the time for each round has been significantly decreased because of the proposed method's simplicity and low overload. Figure 2 is graphical demonstration of Table 2 to make it more illustrative and comparable.

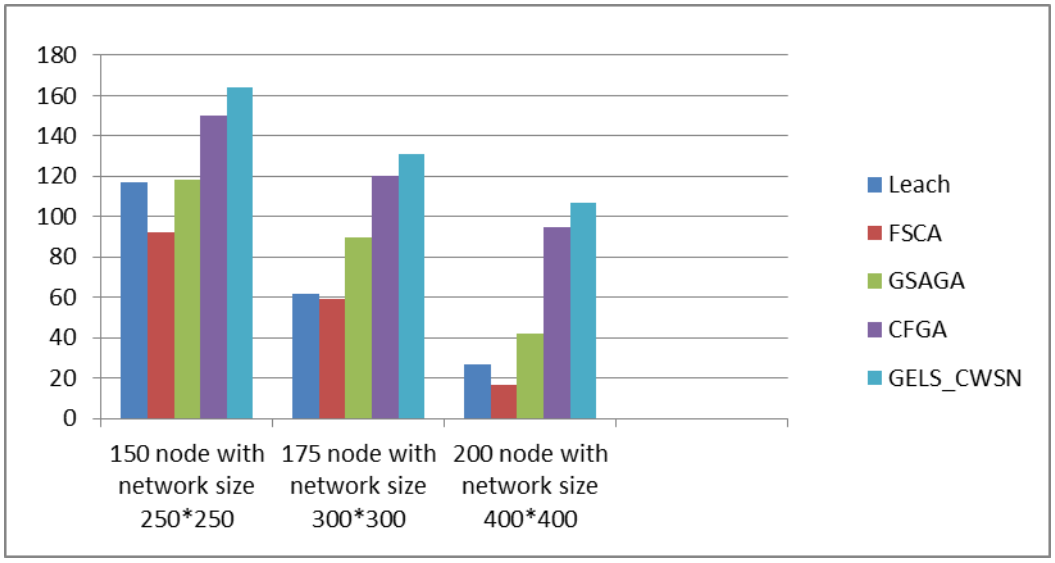


Fig.2. FND time for different algorithms

Table 2: the FND time achieved by algorithms according to the passed rounds

Network parameters	**Type algorithm**				
	Leach[4]	FSCA[7]	GSAGA[8]	CFGA[9]	GELS_CWSN
150 node with network size 250*250	117	92	118	150	164
175 node with network size 300*300	62	59	90	120	131
200 node with network size 400*400	27	17	42	95	107

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Conclusion:

In this paper, gravitational emulation local search (GELS) has been employed to reduce energy consumption in wireless sensor networks, by choosing proper cluster heads. Besides, a new method for evaluating appropriateness of solutions has been proposed. Speed, low time cost, increasing network lifetime, reducing energy consumption and improving network throughout can be mentioned as advantages of the proposed method. Simulation results indicated that the proposed algorithm has better performance in comparison with other ones [7-9].This improvement is more sensible in larger systems.

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