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Implementation of Energy Efficient Clustering Using Firefly Algorithm in Wireless Sensor Networks

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Abstract. Wireless Sensor Network (WSN) is a major and very interesting technology employed in different applications like monitoring the inaccessible conditions in a specific area. Each sensor node consists of a battery, transmitter, receiver and a processor. Replacing or recharging the battery is not possible every time. Therefore maximizing the network lifetime by decreasing the energy consumption of the entire sensor nodes and load balancing are the main challenges in the research of the routing protocols in WSNs. In this paper, Energy efficient clustering for wireless sensor networks using Firefly algorithm is implemented at the base station. A new cost function has been defined to minimize the intra-cluster distance to optimize the energy consumption of the network. The improvement in performance is presented in comparison with the previous protocols LEACH (Low Energy Adaptive Clustering Hierarchy) and PSO-C (Centralized Particle Swarm Optimization).

Keywords: Wireless Sensor Network, Clustering methods, Firefly algorithm, Centralized algorithm, Energy efficient clustering.

1. Introduction

A Wireless Sensor Network is formed by spatially distributing small sensor nodes communicating among themselves using radio signals and deployed randomly or manually to sense, monitor and understand the required area. Wireless sensor nodes have many limitations that make the designing wireless sensor network protocol difficult. One of them is limited power supply. In low-power wireless integrated micro sensor technologies recent improvements have been made to those sensor nodes available in large numbers, at a low cost. They are employed in a wide range of applications in military, medical, environmental monitoring and many other fields [1]. Therefore energy efficient clustering algorithms have become a key part in the network lifetime of WSNs.

1.2. Clustering in Wireless Sensor Network

Here, the sensor nodes are divided into small groups, which are called clusters. Each cluster will be having a cluster head (CH), which will monitor the remaining nodes. Nodes in a cluster do not communicate with the sink node directly. They will collect the data and send to the cluster head. Cluster head will aggregate this data and transmit it to the base station. So the energy consumption and number of messages transmitted to the base station will be reduced and number of active nodes in communication is also reduced. In this way the network lifetime is increased.

For the last few years a variety of upgrades have been published to limit the energy requirement in WSN, as mainly energy dissipation is more for wireless transmission and reception. Main approaches proposed so far are focused on making the changes at MAC layer and network layer. Two more major challenges are to fix the cluster heads over the grid and number of clusters in a network. To tackle with all these challenges clustering has been found to be the efficient technique. Basically clustering can be classified

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into three methodologies.

First method is ‘centralized clustering’ where the base station will configure the network into clusters, second method is distributed clustering where nodes configure themselves into clusters and third method is Hybrid clustering formed as the resulting configuration of the above two methods. Several protocols have been proposed earlier to maximize the sensor network lifetime. One of the well-known techniques is LEACH (Low Energy Adaptive Clustering Hierarchy) [2]. LEACH is a distributed clustering algorithm, where nodes make decisions without any centralized control. All nodes have a chance to become Cluster Head to balance the energy spent per round by each sensor node. In this paper, a centralized, energy aware cluster-based protocol to extend the sensor network lifetime by using Firefly algorithm has been developed. It makes use of a high-energy node as a cluster head and produces clusters that are evenly positioned throughout the whole sensor field. The main idea in the proposed protocol is the selection of intra cluster distance between itself and the cluster member and optimization of energy management of the network.

The remaining part of the paper is organized as follows: Section II gives a brief description of the important papers that are reported. Section III introduces proposed system model for clustering the sensor network. Section IV discusses the implementation of the system for combined coverage and connectivity. Section V shows the experimental results achieved so far. Section VI presents conclusion and future work.

2. Related Work

Heinzelman et al look at the communication protocols [2] which can reduce the overall energy dissipation of the wireless sensor networks and they proposed a new protocol called Low Energy Adaptive Clustering Hierarchy (LEACH). It is a clustering based protocol that uses the randomized rotation of cluster heads to evenly distribute the energy load among the sensors in the network. They compared the results with previous algorithms. A node becomes a CH for the current round if the randomly chosen number is less than the following threshold:

$$T(n) = \begin{Bmatrix} \dfrac{p}{1 - p\left(r mod\left(\dfrac{1}{p}\right)\right)} & if\ n \in G \\ 0 & Otherwise \end{Bmatrix} \tag{1}$$

Where, p is the cluster head probability, r is the current round number and G is the group of nodes that have not been cluster- heads in the last 1/p rounds.

N.A.Latiff, et al presented [3] the energy aware clustering for wireless sensor networks using Particle Swarm Optimization (PSO) algorithm, which is implemented at the base station. The aim of PSO is to find the particle position that results in the best evaluation of a given fitness function. During each generation, each particle uses the data about its earlier best individual position and global best position to update its candidate solution.

V. Kumar et al proposed [4] an algorithm to maximize network lifetime in Wireless Sensor Networks (WSNs). The paths for data transfer are selected in such a way that the total energy consumed along the path is minimized. In order to support high scalability and fine data aggregation, frequently sensor nodes are grouped into non-overlapping; disjoint groups or subsets, which are called clusters. Clusters will create hierarchical Wireless Sensor Networks, which develop efficient utilization of limited resources (power) of sensor nodes, so that they extend lifetime of the network.

Wei Cheng el al [5] studied the impact of nodes heterogeneity, in terms of their data amount and energy. They proposed a novel distributed, adaptive, energy efficient clustering algorithm an Adaptive Energy Efficient Clustering (AEEC) for wireless sensor networks, which suits better for the heterogeneous wireless sensor networks.

To the best of authors knowledge lot of work towards clustering is done, but none has studied the application of Firefly algorithm to choose the optimal number of cluster heads.

3. System Model

3.1. Network Model

In this section the network model is discussed. Assume that the network consists of N different sensor nodes which can sense, monitor and acquire information and are randomly deployed uniformly within an M×M square region. The following assumptions are made for modeling the network.

- All the nodes in the network are stationary and energy constrained.
- Each and every node can perform sensing tasks periodically and always has the data to transfer to the sink (Base Station).
- A fixed base station can be presented inside or outside the network sensor fields.
- All nodes are capable of varying their transmitted power.
- All nodes are eligible to operate either in cluster head mode or cluster member mode.
- Data fusion is used to remove the redundant data.
- Data communication is based on the single hop.

3.2. Radio Energy Model

The energy model for the sensor nodes is implemented based on the first order radio model, which is used in [5]. Here the energy dissipation of transmitter is due to running the radio electronics and power amplifier while the dissipation of energy in receiver is because of radio electronics as shown in Figure 1. The energy dissipation is directly proportional to the square of the distance. For longer distances the energy consumption is proportional to d^4 where d is the distance between sender and receiver nodes. In order to attain an acceptable SNR for transmitting an l bit message over a distance d, the radio spends the energy given by:

$$E_{TX}(l,d) = E_{TX-elec}(l,d) + E_{TX-amp}(l,d) \tag{2}$$

$$= \begin{cases} l.E_{elec} + l.\varepsilon_{fs}.d^2 \ \ if\, d < d_0 \\ l.E_{elec} + l.\varepsilon_{mp}.d^4 \ \ if\, d \geq d_0 \end{cases} \tag{3}$$

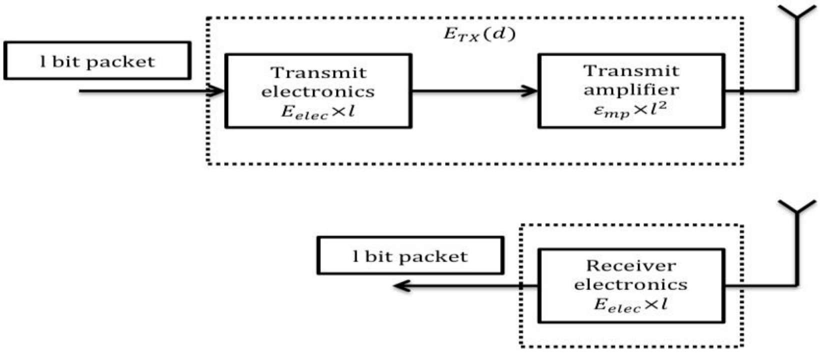

Fig. 1: The First order radio model

While receiving an l bit message, the radio spends:

$$E_{RX}(l,d) = l.E_{elec} \tag{4}$$

WhereE_{TX} is transmitter radio energy dissipation, E_{RX} is the receiver radio energy dissipation, E_{elec} is the energy consumption per bit to run the transmitter or the receiver circuit, ε_{fs} and ε_{mp} depend on the transmitter amplifier model used and d0 is the threshold transmission distance which is given by

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{5}$$

3.3. Protocol Description

Firefly Algorithm (FFA): Firefly algorithm is one of the Meta-heuristic algorithms developed recently [6] by Dr. Xin She yang at Cambridge University in 2007, modeled after the flashing behavior of fireflies. The aim of Firefly Algorithm is to find the particle position that results in the best evaluation of a given fitness function. In this algorithm, there are three main rules:

- All fireflies are unisex i.e. a firefly will be attracted by other fireflies regardless of their sex.
- Firefly's attractiveness is directly proportional to its brightness and it decreases as the distance increases.

- The objective function gives the brightness of a firefly.

The pseudo code for the Firefly algorithm can be prepared based on these three rules.

3.3.1 Attractiveness and Light Intensity:

The light intensity varies according to the inverse square law. The light intensity can be determined as shown below

$$I(r) = I_0 \exp(-\gamma r^2) \tag{6}$$

Where I(r) is the light intensity at a distance r and I_0 is the intensity at the source, γ is the absorption coefficient of the medium. The attractiveness of a firefly is proportional to the light intensity seen by the adjacent fireflies. So the attractiveness β of a firefly is given by the equation (7).

$$\beta = \beta_0 \exp(-\gamma r^m) \tag{7}$$

Where β_0 is the attractiveness at r=0. $r_{i,j}$ is the distance between any two fireflies i and j, which are located at x_i and x_j respectively. The Cartesian distance is given by the equation

$$r_{i,j} = \sqrt{\sum_{k=1}^{d} \left(x_{i,k} - x_{j,k}\right)^2} \tag{8}$$

Where $x_{i,k}$ is the k^{th} component of the spatial coordinate x_i of the i^{th} firefly and d is the number of dimensions. The movement of a firefly *i* towards more attractive (brighter) firefly j is given by

$$x_i = x_i + \beta_0 e^{-\gamma r_{i,j}^2}\left(x_j - x_i\right) + \alpha\epsilon \tag{10}$$

Where the second term is due to the attraction while the third term α is the randomization parameter.

3.4. Cluster setup using Firefly algorithm

The protocol is a centralized algorithm in which the Base Station runs Firefly Algorithm to determine the best K CHs that can minimize the cost function, which is defined as

$$cost = \beta \times f_1 + (1-\beta) \times f_2 \tag{11}$$

$$f_1 = \max_{k=1,2,\ldots K}\left\{\sum_{\forall n_i \in C_{p,k}} \frac{d(n_i, CH_{p,k})}{|C_{p,k}|}\right\} \tag{12}$$

$$f_2 = \frac{\sum_{i=1}^{N} E(n_i)}{\sum_{k=1}^{K} E(CH_{p,k})} \tag{13}$$

Where f_1 is the maximum average Euclidean distance of nodes to their associated cluster heads and $|C_{p,k}|$ is the number of nodes that belong to cluster C_k of particle p. f_2 is the function which is the ratio of total initial energy of all the nodes (n_i, i = 1, 2…. N) in the network to the total current energy of the cluster head candidates in the current round. The constant value β is a user defined constant to weigh the contribution of each of the sub-objectives. For a sensor network with N nodes and K predetermined number of clusters, the wireless sensor network can be clustered as follows:

1. Initialize *S* particles to contain *K* randomly selected cluster heads among all the eligible cluster head candidates.
2. Calculate the cost function of each particle:
    a. For each node $n_i, i = 1,2 \ldots N$ calculate the distance $d\left(n_i, CH_{p,k}\right)$ between node n_i and all cluster heads $CH_{p,k}$.
    b. Assign node ni to cluster head $CH_{p,k}$ where: $d\ (n_i, CH_{p,k}) = \ min\left\{d\left(n_i, CH_{p,k}\right)\right\} for\ k = 1,2 \ldots K$
3. Rank the fireflies and find the current best.
4. Update the position of the particle and limit the change in the particles position value.
5. Map the new updated position with the closest (x, y) coordinates.
6. Repeat the steps 2 to 5 until the maximum number of iterations is reached.

The base station has identified the optimal set of cluster heads and their associated cluster members.

4. Simulation Results

The performance of the Firefly algorithm is evaluated using MATLAB. The simulated network is for 100 nodes in a 200m×200m network area and the base station is located at the center of the area. The following table gives the data considered during the simulation of the network. The performance of proposed protocol is compared with the previously proposed algorithms Particle Swarm Optimization-Centralized (PSOC) and LEACH. The number of clusters is set to be 5 percent of the total number of sensor nodes. The simulations continued until all the nodes consumed all their energy.

Table. 1: Summary of parameters values

Parameter	Value
E_{elec}, E_{DA}	50*nJ/bit*, 50*nJ/bit/signal*
ε_{fs}, ε_{mp}	10$pJ/bit/m^2$, 0.0013$pJ/bit/m^2$
l	4000 *bits*

Figure 2 shows the network lifetime, which clearly demonstrates that the proposed protocol can prolong the network life time when compared with LEACH and PSOC protocols. This is because FFA gives better network partitioning with minimum intra-cluster distance and also cluster heads that are optimally distributed across the network. So the energy consumed by all the nodes for communication can be reduced.

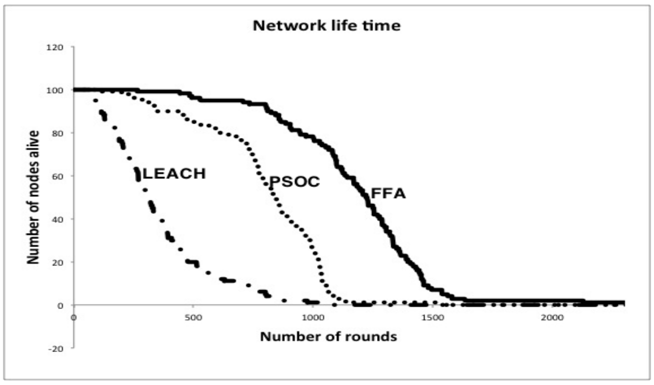

Fig. 2: Network lifetime for the nodes with non-uniform energy

Figure 3 gives the network lifetime of nodes having homogeneous energy. From the results it can be clearly understood that Firefly algorithm gives better network life time when compared to other two protocols.

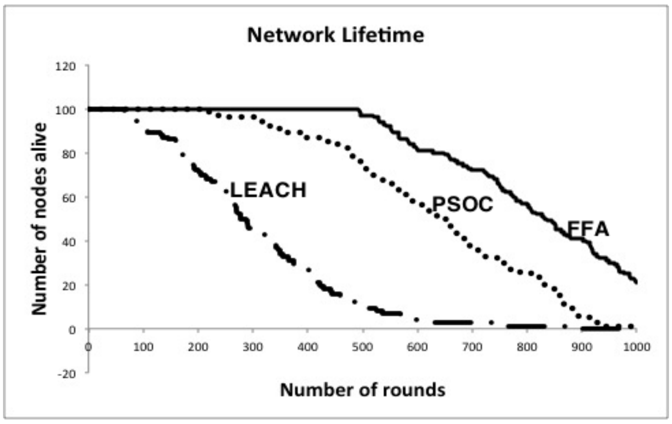

Fig. 3:Network lifetime for the nodes with uniform energy

5. Conclusion

In this paper an energy aware cluster based protocol for wireless sensor networks using Firefly algorithm is implemented for the first time. A new cost function is mentioned, which can take the maximum distance between the cluster head and cluster members and the remaining energy of the cluster head candidates into the account. Results from the simulations indicate that clustering using Firefly algorithm gives a better network lifetime when compared to LEACH and PSOC. Future scope includes the implementation of hybrid optimization technique for clustering in wireless sensor networks.

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