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An Energy Efficient Multilevel Clustering Algorithm In Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) are composed of a large number of inexpensive power-constrained wireless sensor nodes, which detect and monitor physical parameters around them. The challenging issues in wireless sensor network are energy efficiency, secure routing and load balancing. In order to solve the issues more efficiently, several methods are proposed most of which suggest the formation of so called clusters which are nodes grouped with a specific cluster head. In this paper we proposed a novel clustering approach for improving the energy efficiency and network lifetime in WSN. This new approach divides the entire network into various zones geometrically and cluster head is selected in every zone using PSO. Simulation results show that the proposed approach outperforms the LEACH significantly with prolonging the network lifetime over 30%

Index Terms: Network lifetime, Routing protocol, WSN, Cluster based routing, PSO.

Introduction

Wireless sensor networks consist of small intelligent sensors which are deployed to collect physical data from environments without human intervention. They are usually packed with small batteries and have limited lifetime. They are usually placed in hostile environments for tactical purposes. They are used in applications such as object tracking, intrusion detection, environmental monitoring, traffic control, inventory management in factory and health related applications and so on[1] [2]. The data from these sensor nodes are critical in most of the cases. Since the sensors have limited life time due to their small battery capacity, energy efficient techniques are required to prolong their lifetime.

Various methods have been proposed to prolong the lifetime of the wireless sensor networks. The nodes are usually placed in dense manner[3]. Closely spaced nodes may collect similar data. It becomes redundant for a number of nodes to send similar data. Several algorithms have been presented to increase the life time of the network by limiting the nodes from sending redundant data. Certain nodes can be made inactive for a period of time. The energy required to send the data to the base station increases squarely with distance from the base station to the nodes. Therefore nodes which are far away lose energy quickly while transmitting data to the base station than the nodes which are nearer to the base station.

This led to the method of clustering which split the entire network into groups of nodes which are nearer in distance and transmit similar data. Not all nodes transmit data to the base station. A single node in a cluster which is called as a cluster head aggregates the collected data from all the nodes in the cluster and transmits data to the base station [4]. Cluster heads tend to lose more energy than normal nodes because they transmit data to a larger distance than the normal nodes. Therefore cluster heads are swapped periodically for each round. The energy consumption in a cluster is highly related to the selection of cluster head and they had to be in a rotational basis. The selection of cluster head also determines the load sharing between the clusters and network lifetime.

In this paper we propose an algorithm in which the entire network is divided geometrically into zones and sectors. The cluster heads in the network are elected by the fitness value of each node using PSO (Particle Swarm Optimization). According to the value the radii of the zones are varied and the entire network can be rotated dynamically this reduces the load in the network by increasing the network lifetime and node death. The paper is organized as follows: Section 2 comprises of the existing distributing algorithms in WSN Section 3 explains briefly about the Network structure and cluster head selection of our proposed algorithm. Section 4 evaluates the simulation results of the proposed algorithm. Section 5 gives the conclusion and Section 6 exhibits the acknowledgement for the research work.

Related Works

The deployment of Wireless Sensor Networks are designed in such a way that they can withstand the limiting conditions of the network such as battery life, mobility etc. Various algorithms have been proposed which are much effective in overcoming these limitations.

In recent years, many clustering routing algorithms for WSN have been proposed in order to avoid the cluster head consume too much energy and to reduce the communication traffic. The low energy adaptive clustering hierarchy algorithm (Low Energy Adaptive Clustering Hierarchy, LEACH) is presented in [5]. It uses circular random clustering methods and each node in the network can be a cluster head in rotation, this makes the energy carrying of the network balancing to each node, extending the lifetime of the network, but LEACH uses a single hop communication mode, the cluster head and the base station can communicate directly, this causes a large cluster head communication overhead.

HEED algorithm is distinguished from the LEACH in cluster head selection mechanism [6]. Meanwhile, the speed of clustering in the HEED algorithm is also improved and the cost of communication within the cluster has been taken into account. Moreover, the residual energy of node is as an important parameter to be introduced in cluster head selection mechanism, since it makes cluster heads competent for data aggregating and forwarding to form a more rational network topology. In HEED more CHs are generated than the expected number and this also accounts for unbalanced energy consumption in the network. Also Some CHs, especially near the sink, may die earlier because these CHs have more work load.

DWEHC (Distributed Weight-based Energy-efficient Hierarchical Clustering protocol) creates a multi-level structure for intra-cluster communication and limits a parent node's number of children [7]. The structure of multi-level cluster is that a node either becomes a CH or becomes a child in a cluster, and a node is covered by only one CH. It is a fully distributed clustering method that is based on a function of the sensor's energy reserve and the proximity to the neighbors for CH election. DWEHC generates more well-balanced CHs distribution and achieves significantly lower energy consumption in intra-cluster and inter-cluster routing than HEED. Since there is single-hop inter-communication, DWEHC may result in significant amount of energy consumption and it produces a relatively high control message overhead.

In order to solve this, chain based protocol PEGASIS [8] is introduced which provides improvement over LEACH algorithm. In PEGASIS, each node communicates only with a close neighbor and takes turns transmitting to the base station, thus reducing the amount of energy spent per round. Using greedy algorithm, the nodes will be organized to form a chain, after that BS can compute this chain and broadcast it to all the sensor nodes. Energy saving in PEGASIS over LEACH takes place by many stages: First, in the local data gathering, the distances that most of the sensor nodes transmit are much less compared to transmitting to a cluster-head in LEACH. Second, only one node transmits to the BS in each round of communication. PEGASIS outperforms LEACH by limiting the number of transmissions, eliminating the overhead of dynamic. But still the energy level of the cluster head has not been considered in this algorithm and also the data transmission to the base station may be redundant in nature, because the CH alone conveys the message to the base station.

In EECS, [9] dynamic sizing of clusters takes place which is based on cluster distance from the base station. The results are an algorithm that addresses the problem that clusters at a greater distance from the sink requires more energy for transmission than those that are closer. Ultimately it provides equal distribution of energy in the networks, resulting in network lifetime. Thus main advantage of this algorithm is the full connectivity can be achieved for a longer duration. So we can say it provides reliable sensing capabilities at a larger range of networks for a longer period of time. It provides a 35 percent improvement in network life time over LEACH algorithm

An uneven clustering algorithm, called EEUC (Energy-Efficient Uneven Clustering) [10] is proposed, this algorithm is calculated according to the distance of the candidate cluster head to the base station, the network is divided into different size classes of non-uniform structure of clusters by geographical location in order to balance the load of cluster head. But in the cluster head election, the residual energy of the nodes is not considered, and the iterative phenomenon can be raised easily in the clustering process, and the overhead of clustering is relatively large.

However, the long distance communication problems when transmitting data between clusters have not been considered in these routing algorithms.

Proposed Approach- Multilevel Clustering In WSN

Network Model

Above all, the network model is introduced. Assume that the wireless sensor network consists of N nodes. Nodes are distributed in the area of a fixed size. Assume the *i*-th node is s_i , and the node set $S = \{ s_1 , s_2 , s_3 ,..., s_{N-2} , s_{N-1} , s_N \}$,

In addition, the wireless sensor network has the following assumptions:

The network is static in nature which has only one base station or sink node located outside the sensing area.

1. All nodes have the same properties and functions. Each node has a unique identifier.
2. All the nodes and the base station have the information of their location in the network.
3. Transmit power can be controlled, a node can adjust the size of the transmit power based on distance.

In this paper, the wireless channel model in [11] - Radio Hardware Energy Dissipation - is applied. The model assumes a threshold d_0 . And if the distance d between node is shorter than d_0 , then the energy consumed by the node for sending data is proportional to the square of the distance between two nodes. If $d > d_0$, the energy consumed by the node to send data is proportional to the fourth power of distance between two nodes. These two different energy loss calculation models are known as the free space model and multi-path fading model

Node *A* to node *B* sends *l* bytes of data, the distance between two nodes is *d* , the energy loss is:

$$E_{Tx}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d)$$

$$= lE_{elec} + l\varepsilon_{amp} f(d) \quad (1)$$

Node *B* receives the energy consumed by the *l* bytes of data:

$$E_{Rx}(l,d) = E_{Rx-elec}(l) = l * E_{elec} \quad (2)$$

Threshold d_0 is determined as follows:

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}} \quad (3)$$

In the above equation, $E_{Tx}(l, d)$ means the energy consumed by sending *l* bits of data to the distance *d* away from its position; $E_{Tx-elec}(l)$ means the energy consumed by starting the wireless transmitter circuit; $E_{Rx-elec}(l)$ means energy consumed by the Receiver circuit; $E_{Tx-amp}(l,d)$ means the energy consumed by enlarging the transmission signal; E_{elec} means energy consumed by transmission circuit and receiving circuit to send or receive per-bit data; ε_{amp} means multiple of the signal amplifier; $\varepsilon_{fs}d^2$, $\varepsilon_{mp}d^4$ means radio power amplifier loss.

Network Structure
After sensor nodes are deployed in the sensing area, base stations broadcast a "hello" message across the sensing area and the entire network is divided into the concentric circles of different radii.

Based on the distance to the base station and remaining energy, the nodes in the network calculate the competition radii which are also known as cluster radii. The competition radius of node i is given by the following equation.

$$R_{cmp} = \frac{c * d_{max} - d(si, BS)}{d_{max} - d_{min}} + \frac{E_{res}}{E_{init}} \quad (4)$$

Among them, d_{min} and d_{max} are the shortest and longest distance between sensing area and the base station, respectively. $d(s_i,BS)$ is the distance from node i to the base station. From this equation we infer that the cluster radius R_{cmp} of node varies with residual energy of node and the distance between nodes to the base station. If the node is closer to base station, the residual energy of the node will be lower and the radius of the clusters will be small

Clustering Mechanism
The circles have the base station as their centre and are concentric in nature. The circles of radii are further divided by lines (N) originating from the base station further dividing them into sectors. Number of zones in the network can be manipulated by using the product of number of concentric circles and N. Every zone acts as a cluster in the network and thus the number of zones is equal to the number of clusters.

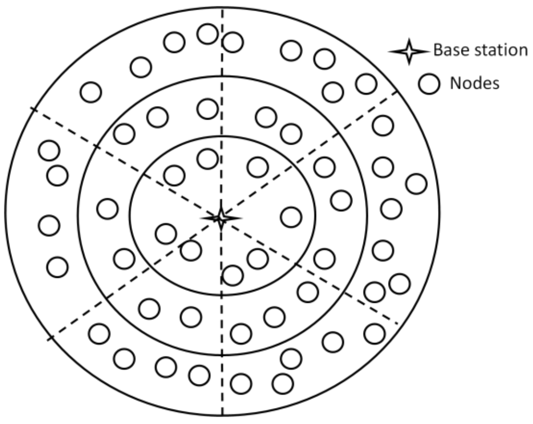

Figure 1: Network Structure Divided Into Zones

The cluster head selection is carried out by using PSO (Particle Swarm Optimization Algorithm) which is an evolutionary algorithm. In this a swarm refers to a number of potential solutions to the optimization problem, where each potential solution is referred to as a particle. The aim of the PSO is to find the particle position that results in the best evaluation of a given fitness function. In the initialization process of PSO, each particle is given initial parameters randomly and is flown through the multi-dimensional search space. During each generation, each particle uses the information about its previous best individual position and global best position to maximize the probability of moving towards a better solution space that will result in a better fitness. When a fitness better than the individual best fitness is found, it will be used to replace the individual best fitness and update its candidate solution according to the following equation

$$V_{new(i)} = V_{old(i)} + c1 * w * \left(P_{best(i)} - V_{old(i)}\right) + c2 * w * \left(G_{best} - V_{old(i)}\right) \quad (5)$$

$$X(i) = X_{old(i)} + V_{new(i)} \quad (6)$$

Where $V(i)$ is the velocity of particle, $Pbest(i)$ is the personal best of the particle,

$Gbest$ is GlobalBest, w is the damping ratio or simply referred as weight which will be linearly decreasing during the iterations, c1,c2 are the constants, $X(i)$ is the current position of the particle and $X\_old(i)$ is the previous position of the particle To ensure that only nodes with a sufficient energy are selected as cluster heads, the nodes with an energy level above the average are eligible to be a cluster head candidate for this round. Next, the base station runs the PSO algorithm to determine the best K cluster heads that can minimize the fitness function, as defined by:

$$max\left(\sum_{1}^{n} \frac{E_n}{b_n^2} \right) = f(deg, r_i) \quad (7)$$

where n is the no of available cluster heads, E_n is the energy of the cluster head, b_n is the cluster head distance from base station and r_i is the number of circles. The degree of the entire network is aligned within the constraints $-20 < deg < 20$.

According to the fitness function equation the PSO aligns the network geometrically by using the offset degree and circle radii and each time the best geometry in selected which has minimum energy consumed by the clusters. The set of cluster heads selected according to the equation will be acting as CH (Cluster Head) for the initial round.

After the CH is selected for every zone or cluster, a node is assigned to the nearest cluster head based on the distance between the node and cluster head defined by

$$D = \sqrt{(S_i.xd - Sc.xd)^2} - (S_i.yd - Sc.yd)^2 \quad (8)$$

where S is the node set, x_d is the x dimension axis of node, y_d is the y dimension axis of node and S_c is the cluster head.

Proposed Algortihm For Building The Cluster Using PSO

For a sensor network with N nodes and k predetermined number of clusters, the sensor network can be clustered as follows:

Step 1: Divide the entire network into concentric circles of radii calculated by $R_{cmp.}$

Step 2: Divide the circles into zones by using the N number of lines to obtain the zones which are called as clusters k

Step 3: Using the fitness function of PSO evaluate the best geometry of the network and select the set of cluster heads.

Step 4: Nodes are assigned to the cluster heads according the distance between nodes and cluster heads

Step 5: Repeat steps 2 to 4 until the maximum number of cycles is reached.

Measuring The Load Balancing In Cluster

To measure the degree of load balancing, the variation of the load in the clusters σ^2 is defined as

$$\sigma^2 = \sum_i^k \frac{\left((N/k)-l_i\right)^2}{k} \quad (9)$$

Where k is the number of clusters formed, N is the number of nodes, l_i is the load of the ith cluster,

Load variance is a direct measure of non-uniformity of load between cluster heads. If the load variance value is higher then there is a possibility that some cluster heads in the network are rapidly losing energy. This will affect the overall energy consumption of the network. Hence reducing the load variance will improve the energy efficiency of the cluster and increase the network lifetime.

Simulation Results

In the simulation experiments, WSNs nodes are randomly distributed in the 100 m × 100 m area.

Table 1: Simulation Parameters

Parameter	**Value**
Area(m)	100X100
Location of Base Station	(50,50)
Number of nodes	100
Initial Energy	0.5 J
E_{elec}	500nJ/bit
Packet size	4000 bits
E_{fs}	10pJ/bit/m^2
E_{amp}	0.0013pJ/bit/m^4

The proposed algorithm is compared with the classical LEACH and PEGASIS, by observing the network lifetime and load variance especially. The simulation is carried out in MATLAB R2012b.

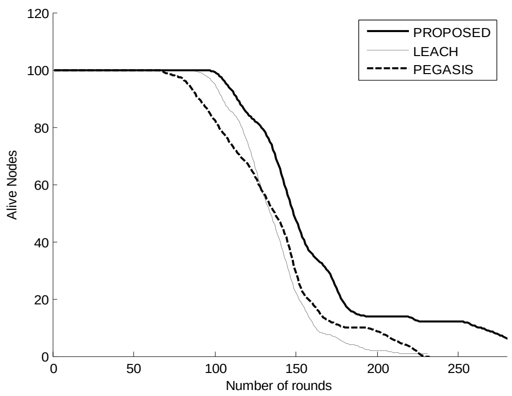

Figure 1: Comparison of Network Lifetime

Figure 1 shows the network lifetime comparison of various algorithms as simulated in MATLAB. Network lifetime can be defined as the time until the first node in the network dies. The simulation result shows that the death of the first node is at 120 rounds for the proposed approach whereas in all other algorithms the node death is before 100 rounds. Even after 250 rounds 10% of nodes in proposed approach are still alive whereas all the nodes are dead in LEACH and PEGASIS algorithm.

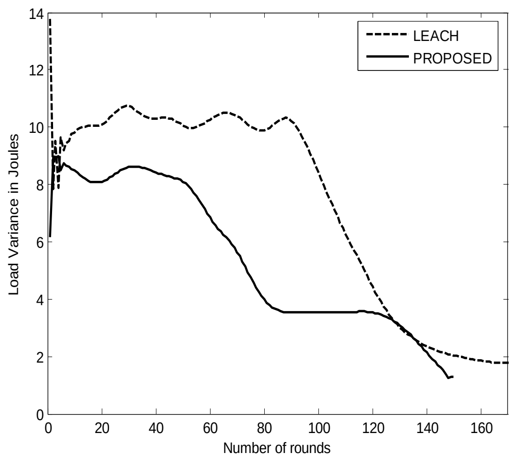

Figure 2: Comparison of load variance between LEACH and Proposed approach

Figure 2 shows the comparison of load variance between proposed algorithm and LEACH algorithm. Load variance of proposed approach varied from 2 Joules to 9 Joules whereas LEACH varied from 2 Joules to 14 Joules. The proposed algorithm was nearly twice as best to LEACH algorithm in balancing the load between clusters.

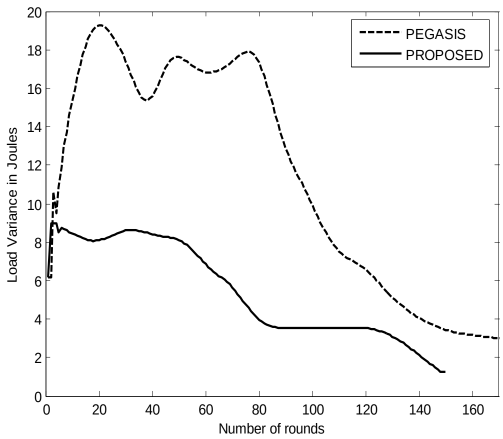

Figure 3: Comparison of load variance between PEGASIS and Proposed approach

In Figure 3, the Load variance of proposed algorithm varied between 2 Joules to 5 Joules whereas PEGASIS varied from 4 Joules to 20 Joules. The proposed algorithm was nearly thrice as best to PEGASIS algorithm in balancing the load between the clusters.

Conclusion

The paper proposes an algorithm based on the energy, node location and geometry to improve the network lifetime and reduce the average energy consumed. The entire network is divided into various sectors and zones geometrically for an efficient data transfer. The simulation demonstrates that the proposed algorithm has reduced energy consumption and improved network lifetime.

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