Comprehensive Energy Efficient Algorithm for WSN

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Abstract: Wireless sensor networks has been widely used. Energy problem is one of the important problems influencing the complete application. Sensor nodes use batteries as power source and have quite limit lifetime. So, efficiency of energy management becomes a key requirement in wireless sensor network design. Based on particle swarm optimization and ant colony optimization, a comprehensive algorithm with weight analysis has been proposed in the paper. In the algorithm, optimization method would be firstly used to determine the nodes number; then, particle swarm optimization would be used to divide the networks into some clusters; finally, ant colony optimization is used to require the best transmission path and select the cluster head. The simulation results show that the new algorithm has higher energy efficiency and balanced energy consumption. It can extend the network lifetime.
Keywords: Wireless Sensor Network (WSN), particle swarm optimization, ant colony optimization, energy efficiency.

1 Introduction

Wireless Sensor Networks (WSNs) offer a new way of real-time monitor systems that can be used in ample of real life applications, such as temperature, sound, pressure, and so on [1]- [4]. It is a wireless network and often composed of many nodes or sensors to monitor vast kinds of conditions. Generally speaking, WSN consists of vast number of sensors which should be cheaply enough to use in low cost. Then, there would be many limitations on the nodes, such as cheap power sources, cheap circuit, and so on. Sensors play critical role in the collection of information, and the power source is quite important. Usually, the sensor use battery as power source and due to the wireless network, the battery can not be charged or replaced, so, it is quite important to develop proper algorithms to reduce the energy consumption.

LEACH is one of the most popular clustering mechanism in WSN. Many communication protocols based on LEACH for WSN have been developed. The main research fields are energy efficiency, wireless link reliability [5], real-time capabilities [6], or quality-of-service. For the reason of sensor nodes just can use battery without power input. So, energy efficiency research is always a key issue in WSN design with high reliability. Many methods and algorithms based on LEACH have been proposed, such as improved LEACH [7]- [10], NDEA [11], TB-LEACH [12], LEACH-SM [13], energy balanced based routing protocol [14], V-LEACH [15], TL-LEACH and DD-LEACH [16], LEACH-HPR [17], etc. Research of energy efficiency is an endless research, and more and more methods to extend lifetime of nodes or networks would be proposed.

In this paper, a comprehensive algorithm based on particle swarm optimization and ant colony optimization with weight analysis has been proposed. The algorithm is mainly used in multi-hop conditions, which can not be set many base stations. In the algorithm, firstly, particle swarm optimization would be used to divide the networks into more than one clusters; secondly, cluster head would be elected with existing energy and distance weighted; thirdly, ant colony optimization would be used to require the best information or data transmission path.

The remainder of the paper is organized as follows: LEACH algorithm would be revisited in section 2. Comprehensive LEACH algorithm and simulation and verification would be expressed in section 3. Section 4 would give the conclusion.

2   LEACH

LEACH protocol is a kind of algorithm. In the network, the nodes work in cluster. In the cluster, a node would be selected as the cluster head [18]- [20]. The process is organized in periodical manner, and each round would be divided into two steps: cluster building step and stable data communication step. In the first step, close nodes would make a cluster dynamically, and one node would be chosen to be the cluster head, which collects, processes and send information to a sink node. In the second step, each node in the cluster would sent message to the cluster head, and then the head would deal with and send it. In the process, head node would collect and fuse information and send it to sink node, so it would consume more energy than other nodes. Leach algorithm could meet the demand that each node in one cluster would have equal possibility to be the head node to balance the exist energy.

The election algorithm of head node in LEACH would be described as following: (1) every node would produce a random number between 0 and 1, and if the number is less than a predefined value $T(n)$, then it would be elected as cluster head and send declaration to other nodes, and if the node has been the cluster node before, and the $T(n)$ would be set to 0. It means that the node cannot be head again. If a node has not been the head node before, the probability of being selected is $T(n)$. $T(n)$ would increase with the number of being head node increases. So the nodes, which have not been head node before, would have a bigger probability. When just one node of not being elected as cluster head node has left, $T(n)$ of the node would be set as 1. That means the node would be cluster head.

$$T(n) = \begin{cases} \frac{p}{1-p(r \bmod (1/p))}, if(n \in G) \\ \\ 0 \quad otherwise \end{cases} \tag{1}$$

Where, p means the probability of the number of cluster head in all nodes of the cluster; r is the number of the current round, G is the nodes which have not been the head node before. After the election of the head node, the head node would send information to other nodes. And other nodes would join different clusters dynamically based on the distance and some other indexes. When all the nodes join the clusters, they would send message to the cluster head and the cluster head would produce the time message TDMA to inform all the nodes in the clusters. Due to keep the nodes in one cluster to join another, the head node would also send CDMA code at the same time. Each node would send message to the head node in time-interval after they receive the TDMA and CDMA code. When the transmission is over, cluster head would collect and process the data and results would be sent to sink node and the round would be going into next.

3   C-LEACH

Comprehensive LEACH (C-LEACH) is aiming at low cost, lifetime extended WSN.

3.1   Main idea of C-LEACH

The flowchart of C-LEACH is shown in figure 1. It includes some main steps: (1) particle swarm optimization would be used to divide the network into more than one clusters with similar number of nodes; (2) cluster head would elected with existing energy and distance weighted; (3) ant colony optimization would be used to require the best information or data transmission path.
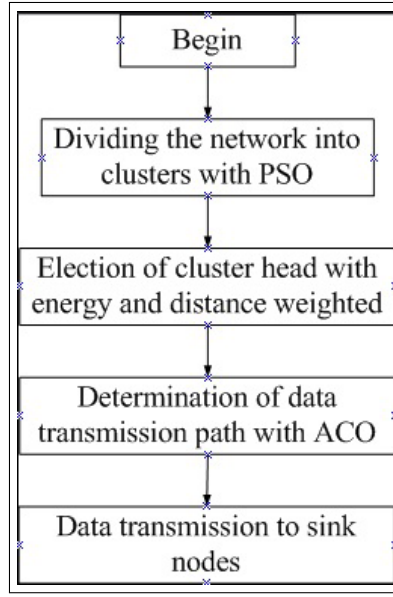
Figure 1: Flowchart of C-LEACH

3.2 The detail steps of algorithm

Step 1: Division of the network into some clusters

(1) It is assumed that there are N nodes in the network, and would be going to split into M clusters, this means there are N/M nodes in every cluster. Firstly, draw a splitter to make the whole network into two domains with same nodes number, and the split line would be expressed as:

$$U = (x, y, \theta).(7)$$

Where, (x, y) is location on the splitter of nodes, θ is the angular between the splitter and x-axle.

Define the function $fitness$ as the following:

$$fitness = (c_1 - f_1 N)^2 + (c_2 - f_2 N)^2.(8)$$

Where, $c_i(i = 1, 2)$ is the number of nodes in domain i. f_i would be determined as the following:

$$f_i = \frac{M_i}{M}, i = (1, 2).(9)$$

Where, M_i is the expectation of number of cluster nodes in domain i.

Then, we would complete the first division.

The algorithm of cluster division is composed of some steps:

(1) All nodes in the network send data (including all kinds of information) to sink node. Sink node would split the network into many clusters after received the message and define Q particles;

(2) Set random number to parameters of x, y, θ, and construct the split line. The whole network would be divided into $Q \times 2$ clusters. Due to the location of nodes in the network are known, $c_i(i = 1, 2)$ of each node would be determined to calculate the values $fitness$.

(3) Compare the value of $fitness$ with minimum $fitness$ value in the last round, the less one would be elected as a general extrum P_{gd}; Compare the $fitness$ value of individual node, the least would be elected as individual extrum P_{id}, and update the value of x, y, θ:

$$X_{xid} = X_{xid} + v_{xid}.(10)$$

$$X_{yid} = X_{yid} + v_{yid}. (11)$$

$$X_{\theta id} = X_{\theta id} + v_{\theta id}. (12)$$

Where, X_{xid}, X_{yid} represent the location of particle; $X_{\theta id}$ is the angular of the splitter; $v_{xid}, v_{yid}, v_{\theta id}$ are the search speed in three dimensions, and they would be determined as following:

$$v_{xid} = \omega v_{xid} + c_1 \times rand()(P_{id} - X_{xid}) + c_2 \times rand()(P_{gd} - X_{xid}). (13)$$

$$v_{yid} = \omega v_{yid} + c_1 \times rand()(P_{id} - X_{yid}) + c_2 \times rand()(P_{gd} - X_{yid}). (14)$$

$$v_{\theta id} = \omega v_{\theta id} + c_1 \times rand()(P_{id} - X_{\theta id}) + c_2 \times rand()(P_{gd} - X_{\theta id}). (15)$$

Where, c_1 and c_2 are the study factor, and $c_1 = c_2 = 2$; rand () is random number between 0 and 1; ω is the weighted factor.

(4) After the update of x, y, θ, go to step 2 to continue the research process. When the value of $fitness$ is 0 or equal to the maximum times of search, the process would finished. Ideally, if the value of $fitness$ is approximately 0, and the whole network would be divided into two clusters with equal nodes.

(5) Use the method of above to divide the clusters, until get the demanded number of clusters.

Step 2: Search the nearest multi-hop path by ACO

In this step, first of all is electing cluster head. High existing energy of nodes would be elected as cluster head followed by LEACH.

This search is based on single cluster, so the path in each cluster would be different. And one search path has no influence to that of others. That is to say path search in each cluster is independent. Cluster nodes send data or information to sink nodes, if need multi-hop would adopt this algorithm to find the nearest path.

According to the definition described before, forward neighbor nodes would be expressed as:

$$N_f(i) = \{v_j | v_j \in V, d_{i,j} \le r, \alpha_{i,j} \le \beta_i\} . (16)$$

Each node would have a storage model to reserve the information between self and neighbor nodes, including location, existing energy and neighbor node location and existing energy, and so on. In order to express the pheromone, each node would have a record τ_{ij} to store the density of pheromone. Ant in the network is a data package with memory and storage capability, which just require minimal space. The ant would have characteristics as following:

(1) The ant can remember the information of nodes it passed;

(2) The ant has capability of recording the nodes it passed with a proper order and forming a path, the ant would return after it get to the cluster node and update the pheromone.

(3) Ant just can jump to the forward neighbor nodes;

(4) Ant can read and modify the information it locates. Ants in the network would begin with source node, and goes to the cluster head with a way of multi-hop to find a nearest way between source node and cluster head node. Ant locates at v_i would calculate the jump probability $P_{i,j}^k$ according to the information of pheromone and existing energy of the neighbor nodes. $P_{i,j}^k$ represents the probability of ant k jump to forward neighbor nodes. It is calculated as following:

$$P_{i,j}^k = \begin{cases} \dfrac{[\tau_{i,j}]^{\mu} \cdot [\eta_{i,j}]^{\lambda}}{\sum\limits_{v_H \in N_f(v_f)} [\tau_{i,H}]^{\mu} \cdot [\eta_{i,H}]^{\lambda}}, v_j \in N_f(v_i) \\ \\ 0 \qquad otherwise \end{cases} \qquad (17)$$

Where, $\tau_{i,j}$ is value of path $l_{i,j}$ from node v_i to its neighbor node v_j; μ is a factor about distance and pheromone and it means the effect of information accumulated to the travel of ants. Bigger the value of μ is, shorter path the ant would choose. λ is a factor of energy, which means the effect of energy in the path selection. If value of λ is bigger, the ant would choose a higher existing energy node to jump. At first time t_0, pheromone $\tau_{i,j}(t_0)$ on the path $l_{i,j}$ of nearby nodes. It can be calculated as:

$$\tau_{i,j}(t_0) = \frac{d_{i,D}}{d_{i,j} + d_{j,D}} \times (1 - \frac{d_{i,j}}{\sum\limits_{v_H \in N_f(v_i)} d_{i,H}}).(18)$$

$\eta_{i,j}$ is a function of energy, which can be calculated as following:

$$\eta_{i,j} = \frac{e_j}{\sum\limits_{v_H \in N_f(v_i)} e_H}.(19)$$

Where, e_H is existing energy of forward neighbor node $v_H \in N_f(H)$ of node i.

Forward neighbor nodes set limits the jumped node. After the v_j is elected to be the next jump node of v_i, next jump node of v_j would be calculated according to the location of cluster head. Following the same method, the ant would jump to the cluster head. In the searching path, if the current sensor j has no forward neighbor nodes, it would be marked as invalid node. The ant would return to node i, and node j with no forward neighbor node would be deleted. Then, the ant would select the next jump node again. If all nodes in forward neighbor nodes set are deleted, this means there is no available path between source node and cluster head. If a source node has no available path to the cluster head, it has to transmit the information to its nearest node outside the forward neighbor nodes set, and choose the best path with the method described before. An ant travel from source node to cluster head and return back to the source node with the pheromone information updated is defined to be a process. All ants finish a process, we can say a loop is completed and loop index t would plus 1. In the loop , the pheromone density in the path l_{ij} would be adjusted according to equation as following:

$$\tau_{i,j}(t + 1) = (1 - \rho)\tau_{i,j}(t) + \sum_{k=1}^{m} \Delta\tau_{i,j}^k(t).(20)$$

$$\Delta\tau_{i,j}^k(t) = \begin{cases} \frac{Q}{L^k(t)}, & \text{If ant k pass} \\ \\ 0, & \text{otherwise} \end{cases} \quad (21)$$

Where, m is the number of ants; $\Delta\tau_{i,j}^k(t)$ is pheromone left on path l_{ij} at loop t; $L^k(t)$ is the length of ant k moves at loop t; Q is a constant about pheromone. ρ is also a constant which describe the volatilization of pheromone. Value of ρ is often between 0 and 1 to keep the convergence of the algorithm. In addition of judgment, nearest path of each node would be found.

3.3 Simulation and verification

The simulation result of C-LEACH would compared with the result of ACO with the whole network as a cluster and all information of each node transfer directly to sink node without to cluster node. Same model has been used to verify the advance of two algorithms. Figure 2 shows

the energy consumption of the two algorithm in sending 100 data packages. It is easy to see the energy saving with C-LEACH.

Figure 3 shows the efficiency of node energy with different algorithm in sending 100 data packages. It can be seen that energy efficiency is higher under C-LEACH than that under ACO algorithm.

Figure 4 shows the success rate in path search with different algorithm. It can be seen that success rate of less nodes in the network with C-LEACH is lower than that under ACO and when the network with more nodes, the success rate under C-LEACH is higher. The reason may be the division of the network, and each cluster has less nodes. We can make a decision that the method used in network with more nodes would have a better effect.
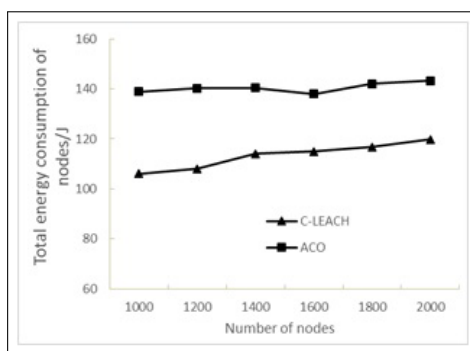

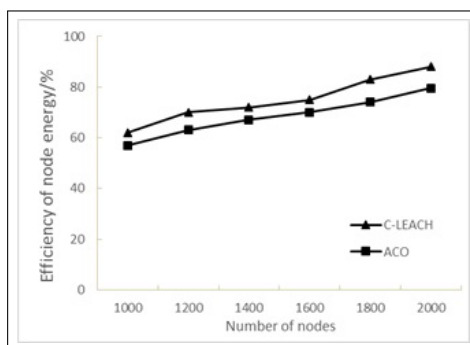Figure 2: Node energy consumption with different algorithm

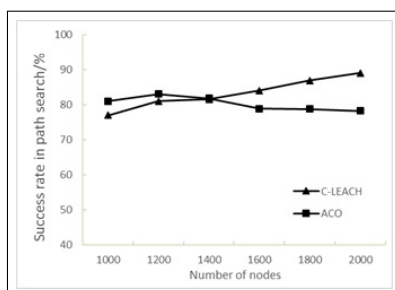Figure 3: Efficiency of node energy with different algorithm

Figure 4: Success rate in path search with different algorithm

Figure 5 shows the lifetime of the network with two different algorithms. From the figure, we can see the lifetime of network under C-LEACH is longer than that under ACO.
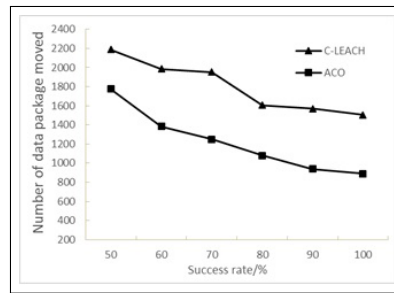
Figure 5: Lifetime of network

4 Conclusion

The paper proposed a comprehensive method to save energy of WSN. It uses PSO dividing the whole network into clusters and then ACO has been used to find the nearest path to transfer the data package. Results of the simulation show that, C-LEACH is an effective method used in the WSN with multi-hop conditions, especially used in vast area with more nodes. The method can extend the lifetime of the network and increase the energy efficiency.

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