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RESEARCH ARTICLE

A EFFICIENT ROUTING PROTOCOL BASED ON OPTIMIZED CLUSTER HEAD ELECTION IN WIRELESS SENSOR NETWORK

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ABSTRACT

Reducing energy consumption and prolonging the network lifetime are the important issues of routing protocol for wireless sensor network. The paper presents an improved algorithm of optimized cluster head election for the randomness of cluster head election and uneven energy distribution in LEACH (Low Energy Adaptive Clustering Hierarchy). In consideration of the location of nodes, residual energy, the number of elected cluster head and other factors as well as by LEACH analysis, the cluster head is reasonably selected. Simulation results show that the performance of IM-LEACH is better in terms of energy consumption, number of packets received and network lifetime compared with LEACH and DEEC.

INTRODUCTION

Wireless Sensor Network (WSN) is distributed and self-organizing wireless network composed by a large number of sensor nodes. It integrates and sends a variety of environmental information (temperature, pressure, light) monitored by itself to the base station for processing by collaboration between the sensor nodes. Due to the flexibility of the wireless sensor network deployment and simple maintenance, it is used in all fields of military, medical, agriculture, mining and others (**Ren *et al*., 2003**), (**Yu *et al*., 2006**), (**Zhang *et al*., 2007**), (**Shen and Shi 2008**). In order to achieve current and potential applications of wireless sensor network, the efficient and advanced routing protocols must be developed for a variety of applications, while the wireless sensor network (WSN) is different from traditional Ad-hoc network, which the size of sensor nodes is smaller and the energy is limited (**Handziski *et al*., 2003**), (**Durresi, 2005**). The unreasonable routing protocol may cause that some nodes prematurely consume their energy and nodes are failure and quit the network. Therefore, How to balance the energy consumption of nodes and prolong the network lifetime is key issue for routing protocol design.

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The main function of wireless sensor network routing protocols is to find and establish efficient transmission path between the sensor nodes and sink nodes to improve transmission performance and service quality of the network (**Sun *et al*., 2005**). The routing protocol can be divided into two categories according to the logical structure of the network: flat routing protocol and clustering routing protocol (**Li and Gao, 2008**). In the flat route, the status of each node is equal, so it does not need to set up nodes with special features, which is easy to implement; however, the scalability of network is poor, there is rarely optimal management of communication resources, which needs a lot of control information exchange to maintain routes, and the generating additional energy consumption limits the scale of the application. The typical flat routing algorithms include Flooding, SPIN and Directed Diffusion. Heizelman W *et al* first proposed clustering idea in the (9) LEACH. They divided nodes into ordinary node and cluster head node and introduced the concept of "round" to make the nodes to take turn as the cluster head which is a typical hierarchical routing protocol based on clustering structure (**Shen *et al*., 2006**). Leach-C (**Heizelman *et al*., 2002**) is an improved protocol based on Leach. The improvement of LEACH-C is mainly reflected in two aspects: cluster heads selection is concentrated selection rather than random selection and the base station needs to know the energy information and the location information of each node.

PEGASIS (**Lindsey *et al.*, 2002**) (Power-Efficient Gathering in Sensor Information System) is developed on the basis of Leach. The algorithm uses the greedy algorithm to form a chain network structure, only a cluster head is selected in each round and the node only communicates with adjacent nodes, which reduce the energy consumption of communication. However, the chain structure will lead to too long transmission delay. In addition, if a single node dies, PEGASIS protocol needs to re-cluster. Based on a similar network model in LEACH, this paper improves the LEACH and optimizes cluster head election in considering the residual energy of nodes, distance with the base station, the number of elected cluster head and other factors. In the steady-state phase, the LEACH transmission path is improved, energy consumption is decreased and network lifetime gets prolonged by multi-hop communication.

LEACH and Energy Model

LEACH is a Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. It puts forward the concept of "round" (one round is one cycle). Its basic idea is to make each mode to take turns to become the cluster head and balance the energy consumption of each node and then balance network load and prolong the network lifetime. Each round of LEACH is divided into two stages: cluster establishment phase and steady-state phase. In the cluster establishment phase, all nodes generate a random number range 0-1. If this random number is less than the given threshold value T (n), and then the node will be selected as cluster head of this round. The calculation equation of T (n) can be expressed as

$$T(n)=\begin{cases}\dfrac{P}{1-P*[r\bmod(1/P)]} & n\in G\\ 0 & otherwise\end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Here P is the percentage of cluster head in all nodes, r is the current number of rounds of election, r mod $(1/P)$ is on behalf of the number of node which is elected as cluster head nodes in the round, G is the set of nodes that have not been elected in the past $1/P$ rounds of election. In every $1/P$ round, if the node has been elected as the cluster head, it will not be re-elected until the next $1/P$ round. After node is elected as the cluster head, it will broadcast the information that it is the cluster head to the rest of the nodes. The remaining nodes select the closest cluster head to join according to the distance between them and each cluster head and inform the cluster head. In the steady-state phase, the cluster nodes send data to the cluster head in their allocated transmission slot. The cluster head will receive the data for data aggregation and then send the aggregation data to the base station.

The disadvantages of LEACH are as follows: First, the cluster head election takes random rotation way, which does not consider other factors and then cause some nodes death prematurely. Second, the distribution position of the cluster head nodes can't get guarantee, the distribution of cluster head nodes might be too concentrated or too scattered, which is not conducive to the network energy load balancing. Third, the protocol allows the direct communication between nodes and between nodes and base station which consumes too much energy and limits the scalability.

The energy model used by LEACH during the transmission procedure is First Order Radio Model. The energy consumption of sensor nodes for delivering Kbit data can be expressed by

$$E_{TX}(k,d)=E_{TX-elec}(k)+E_{TX-amp}(k,d)=\begin{cases}k*E_{elec}+k*\varepsilon_{fs}*d^2, & d<d_0\\ k*E_{elec}+k*\varepsilon_{amp}*d^4, & d\ge d_0\end{cases} \quad \ldots\ (2)$$

The energy consumption of sensor nodes for receiving Kbit data can be expressed by

$$E_{RX}(k)=E_{RX-elec}(k)=k*E_{elec} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

In the above formula, $E_{TX-elec}$ is the energy consumption for transmission circuit, $E_{RX-elec}$ is the energy consumption for receiving circuit, d is the distance between nodes, ε_{fs} and ε_{amp} are respectively amplification of power amplifier in the free space channel model and multi-path fading channel model. The Eq. (2) shows that the longer the distance between the nodes is and the higher the energy consumption is.

Improvement of LEACH

Problem Formulation

LEACH uses a distributed algorithm to make nodes act as cluster head node in turn, to make nodes in the network self-organize clusters, make the cluster head receive data sent by cluster nodes and undertake the task of data aggregation. This hierarchical idea is relatively simple to implement and achieves the purposes of energy savings and reducing data traffic. However, in the process of actual operation, because LEACH does not consider the residual energy of nodes, geographic location, other factors in the cluster head election phase and the data transmission among nodes uses the single-hop path, so the clusters are uneven and the nodes farther from the base station are faster death, thus greatly limiting the efficiency of the algorithm. Therefore, the cluster head election and data transmission methods should be optimized in the proposed algorithm.

Like LEACH, the proposed algorithm uses First Order Radio Model. The network has the following assumptions:

- The sensor nodes are isomorphic and the energy is limited.
- Once the geographical location between base station and sensor nodes is established, it will be fixed within the subsequent network lifetime.
- The sensors nodes can adjust transmit power by power control to complete the data transmission at different distances.

Algorithm Statement

Selection of Cluster Head and Clustering Process

- The average residual energy $\overline{E(r)}$ of the network in r round is calculated based on Eq. (4), each node will compare $\overline{E}(r)$ with its residual energy , if its residual energy is more than $\overline{E}(r)$, then continue; Otherwise, it becomes a common node, loses the qualification of cluster head election and goes to the stage 4.

$$\overline{E}(r) = \frac{1}{n}\sum_{i=1}^{n} E_i(r) \quad (4)$$

- Considering the residual energy of nodes, rewrite threshold calculation equation to make the nodes with higher residual energy be elected as cluster head with greater probability, and the threshold calculation equation is

$$P_{new} = P * \frac{E_r}{\overline{E}(r)} \quad (5)$$

Where, P is the percentage of cluster head nodes in all nodes, E_r is the residual energy of the current node, $\overline{E}(r)$ is the average residual energy of all nodes in rth round.

Because cluster head election is relative to geographical location of nodes and the number of times a node is elected as cluster head. Considering the above factors, the modified threshold calculation equation is expressed as:

$$T(n) = \frac{P_{new}}{1 - P_{new}[r \bmod (1/P_{new})]} * (1 - \frac{d}{5R}) * \frac{P_{new}}{Times + 1} \quad (6)$$

Here r is the current rounds, d is the distance between nodes and base station, R is the length of network area, $Times$ is the times of elected cluster head. The nodes with higher residual energy, nodes closer to the base station and these nodes with fewer times of cluster head election have larger probability to become a cluster head and its energy load of network is more balanced.

- After the cluster head is selected, each cluster head broadcasts an advertisement message (ADV) using a non-persistent carrier-sense multiple access (CSMA) MAC protocol. The message contains the node's ID and a header that distinguishes this is an announcement message.
- The ordinary nodes judge which cluster head is the nearest to it by the received signal strength and decide to join the cluster; meanwhile, they send request message Join-REQ to the cluster head, including its own ID, a header and residual energy.
- After the cluster head receives all request messages, it establishes a TDMA schedule and transmits this schedule to all members of the cluster, which makes sure that there are no collisions among messages. Members can turn off the radio components at all times except during their transmit time to minimize energy consumption.

Steady-State Phase

Data Transmission within the Clusters

The communications within the clusters use single-hop communication, i.e. members directly send the data to the cluster head. The operation in steady-state phase is broken into frames. The members send data to the cluster head at most once per frame during their data transmission slot.

Data Transmission between Clusters

Generally, the distance between cluster head and the base station is longer than d_0. As shown in Eq. (2), the channel transmission use multi-path fading channel model if the single-hop communication is used, the transmission energy consumption is farther than that in Friss free space channel model. Therefore, the multi-hop route is used. In the process of establishing multi-hop routing links, in theory, the nodes which hold higher residual energy and are the closest to base station should first become father nodes and can forward more data and balance energy load. Setting up the weight value W_c of cluster head nodes, each cluster head node will calculate their weight values and broadcasts this value and node ID to the rest of cluster heads, then selects the cluster head node which the weight value is larger than their owns and the distance is the nearest as level I farther node. Thus, a stepwise multi-hop path will be formed between cluster head nodes. The node with the maximum weight value will be the last root node. The cluster head progressively deliver the aggregation data to root node and to base station along the multi-hop path. Weight value expression is as follows:

$$W_c = \alpha * \frac{E_r}{E_0} + (1-\alpha) * \frac{d_{max} - d}{d_{max}} \quad (7)$$

Here E_r and E_0 are respectively residual energy and primary energy of the cluster head, d is the distance between cluster head and base station, d_{max} is the maximum distance of the cluster head from the base station, α is constant ranged from 0 to 1. In addition, if the distance of cluster node from the base station is closer than that of other cluster heads, the data can be directly sent to the base station.

Performance Analysis

In order to evaluate the performance of the proposed protocol, MATLAB is used to perform simulation by using various tests. In this simulation, the performance of the proposed protocol has been compared with LEACH and DEEC (distributed energy-efficient clustering algorithm). In this simulation, the wireless sensor network is composed of 100 nodes which are randomly deployed and distributed in a 100*100 square meter area. The coordinates of the base station is (50, 50). The main parameters of the simulation are given in Table 1

Table 1. Simulation Network Parameters

Parameter Name	Value
Region Size	100m*100m
Number of Nodes	100
Coordinates of Base Station	(50,50)
E_0	0.5J
E_{elec}	50nJ/bit
ε_{fs}	10pJ/bit/m^2
ε_{mp}	0.0013pJ/bit/m^4
E_{DA}	5nJ
P	0.1

In the simulation, we evaluate the different protocols based on two performance indices: network lifetime and the energy consumption of network. The network lifetime is measured using FND (First Node Dies), TND (10% of Nodes Dies), LND (Last Node Dies). Fig.1. Shows the number of alive nodes in three protocols LEACH, IM-LEACH, DEEC over time. For LEACH, the first node is death in 735 rounds, while node death began to appear in 1322 rounds for the proposed protocol. The FND, TND and LND are respectively 735,805 and 1264 in LEACH, and respectively 897,975 and 1373 in DEEC, while respectively 1322, 1513 and 1872 in the proposed protocol. Comparing with LEACH, the lifetime respectively increases by 79%, 87% and 48%.

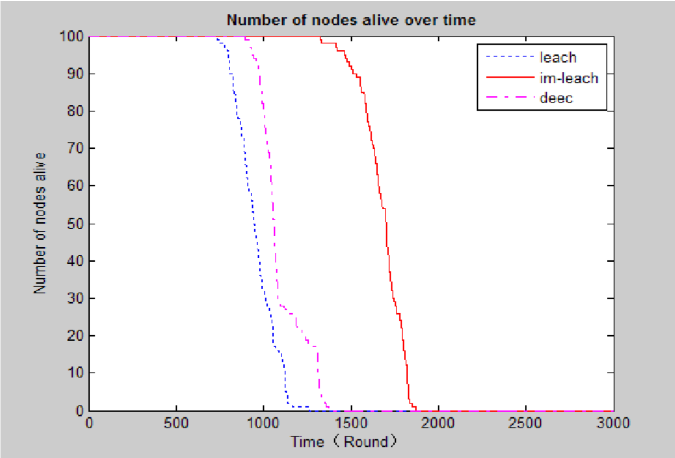

Fig.1. Number of alive nodes over time

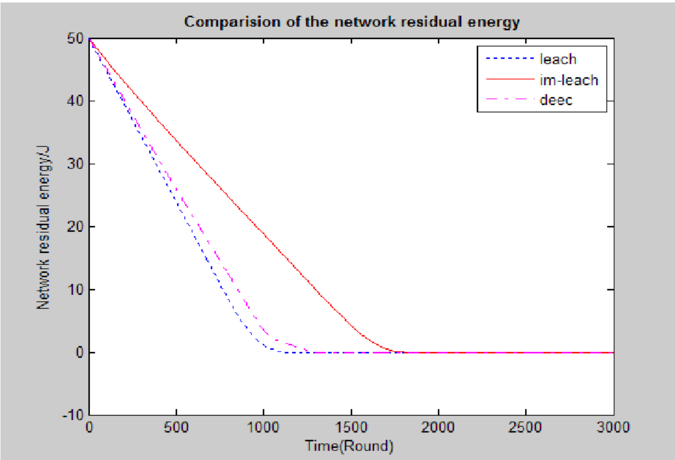

Fig.2. Comparison of the network residual energy

Comparing with DEEC, the lifetime respectively increases by 47%, 55% and 36%. This shows that the network lifetime of the proposed protocol is longer than that of LEACH and DEEC. Fig.2. gives the network residual energy of all three protocols. In the 735th round, LEACH appears the first death node. At this time, the residual energy of network is 10.9J, while the residual energy of the proposed algorithm and DEEC are respectively 26.2J and 15.1J. As shown in Fig.2, the proposed protocol act better than other protocols in balancing the energy consumption among cluster heads and more energy saved in result. In summary, compared with LEACH, the proposed protocol is more efficient and more robust, which allows the most of the nodes to completely consume energy and die within a similar time, and ultimately prolongs the network lifetime.

Conclusion

In this work, for the disadvantage of LEACH, we proposed a energy efficient routing protocol for prolong the network lifetime. On the basis of comprehensive consideration of residual energy of nodes, location and other factors, the cluster head is reasonably selected and the data transmission is performed by multi-hop path between clusters. Simulation results show that the proposed protocol exhibits a better performance in terms of cluster heads election, reducing energy consumption and prolonging network lifetime. The proposed protocol in this paper still can be proposed in cluster heads election. How to keep the uniform distribution of cluster heads and alleviate the funneling effect can be considered as a future work.

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