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An Energy Balanced Algorithm of LEACH Protocol in WSN

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Abstract

In wireless sensor networks (WSNs), due to the limitation of nodes' energy, energy efficiency is an important factor should be considered when the protocols are designing. As a typical representative of hierarchical routing protocols, LEACH Protocol plays an important role. In response to the uneven energy distribution that is caused by the randomness of cluster heads forming , this paper proposes a new improved algorithm of LEACH protocol (LEACH-TLCH) which is intended to balance the energy consumption of the entire network and extend the life of the network . The new algorithm is emulated by Matlab simulation platform, the simulation results indicate that both energy efficiency and the lifetime of the network are better than that of LEACH Protocol.
Keywords: *LEACH Protocol; Energy consumption; Network lifetime; Matlab simulation.*

1. Introduction

As a new information acquisition and processing technology, wireless sensor network （WSN）has a wide range of applications in military, environmental monitoring, smart furniture and space exploration and so on [1]. Wireless Sensor Network can be described as an autonomy system consisting of lots of sensor nodes designed to intercommunicate by wireless radio， and it can collaborate in real time monitoring, perceiving and collecting information of various environmental or monitoring objects and transfer this information to the base station．It does not need a fixed network support，and it has rapid employment, survivability and other characteristics，so it has a good application prospect．

Until now the research on sensor network generally has gone through two stages, the first stage is primarily intended for node, the second one is for network-level issues, the main research works in this stage involve the network layer and MAC layer protocol based on energy optimization, node localization technology, clock synchronization technology and data fusion technology [2]. Study of routing protocols in wireless sensor networks is one of the hot topics at this stage.

LEACH Protocol is the first protocol of hierarchical routings which proposed data fusion, it is of milestone significance in clustering routing protocols. Many hierarchical routing protocols are improved ones based on LEACH protocol [3]. So, when wireless sensor networks gradually go into our lives, it is of great significance to research on LEACH protocol.

2. Brief Introduction to LEACH Protocol

LEACH Protocol is a typical representative of hierarchical routing protocols. It is self adaptive and self-organized. LEACH protocol uses round as unit, each round is made up of cluster set-up stage and steady-state stage, for the purpose of reducing unnecessary energy costs, the steady-state stage must be much longer than the set-up stage. The process of it is shown in Figure 1.

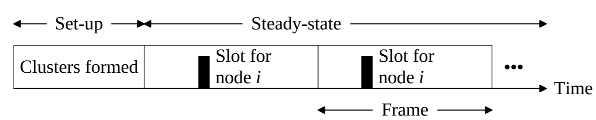

Fig.1 LEACH Protocol process.

At the stage of cluster forming, a node randomly picks a number between 0 to 1, compared this number to the threshold values $t(n)$, if the number is less than $t(n)$, then it become cluster head in this round, else it become common node. Threshold $t(n)$ is determined by the following:

$$\mathbf{t}(n) = \begin{cases} \dfrac{p}{1 - p*(r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{if } n \notin G \end{cases} \quad (1)$$

Where p is the percentage of the cluster head no des in all nodes, r is the number of the round, G is th e collections of the nodes that have not yet been head nodes in the first 1/P rounds. Using this threshold, al l nodes will be able to be head nodes after 1/P round s. The analysis is as follows: Each node becomes a cl uster head with probability p when the round begins, the nodes which have been head nodes in this round will not be head nodes in the next 1/P rounds, becaus e the number of the nodes which is capable of head n ode will gradually reduce, so, for these remain nodes, the probability of being head nodes must be increase d. After 1/P-1 round, all nodes which have not been head nodes will be selected as head nodes with proba bility 1, when 1/P rounds finished, all nodes will retu rn to the same starting line.

When clusters have formed, the nodes start to transmit the inspection data. Cluster heads receive data sent from the other nodes, the received data was sent to the gateway after fused. This is a frame data transmission. In order to reduce unnecessary energy cost, steady stage is composed of multiple frames and the steady stage is much longer than the set-up stage.

3. A new improved algorithm based on LEACH Protocol (LEACH-TLCH)

In LEACH protocol, due to the randomness of clusters forming, the energy of cluster head is very different, so do the distances between cluster heads and base station. Cluster heads are responsible not only for sending data to the base station but also for collecting and fusing the data from common nodes in their own clusters. In the process of data collection and transmission, the energy consumed by data transmission is greater than that of data fusion [4]. If the current energy of a cluster head is less or the distance to base station is much far, then the cluster head will be died quickly because of a heavy energy burden. To address these issues, this article proposes a new improved algorithm on how to balance the energy loads of these cluster heads.

3.1 The idea of improved algorithm

LEACH-TLCH (LEACH Protocol with Two Levels Cluster Head) is an improved one based on LEACH Protocol, the methods of cluster-head selection and clusters forming are same as LEACH protocol. If a cluster head's current energy is less than the average energy, that is $E_{cur} < E_{ave}$, where $E_{ave} = \sum_{1}^{N} E(i)_{cur}$ is the average energy of all nodes in the network, or the distance between the cluster head and base station is longer than the average distance, that is $d > d_{ave}$, where $d_{ave} = \sum_{1}^{N} d_i$ is the average distance of all nodes' distance to base station, then the common node with maximum energy in this cluster will be selected as the secondary cluster head. If $E_{cur} \geq E_{ave}$ and $d \leq d_{ave}$, it is unnecessary to select a secondary cluster head.

In a cluster which has secondary cluster head, the secondary cluster head is responsible for receiving and fusing data collected from the member nodes and sending them to its cluster head, the cluster head is only responsible for transporting data to base station. In a cluster without secondary cluster head，the cluster head is responsible for collecting data from the member node and sending them to base station after the data was fused. It is clear from the first-order energy transfer model (Figure 3) that the energy consumption of data receiving and data fusion are less than that for data transferring [5]， especially for long distance data transferring, so the life of clusters with secondary cluster heads will not be extended a lot so as to bring new energy imbalance of energy consumption of entire network. The network topology of the improved algorithm is shown in Figure 2.

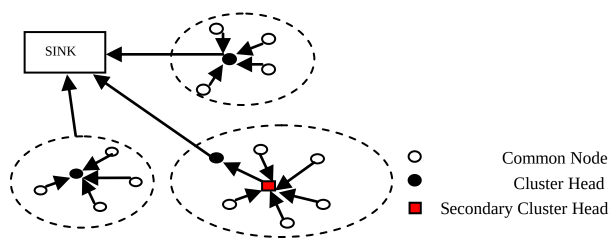

Fig.2 Network topology

3.2 First-order wireless transmission model

This article uses first-order wireless communication model, it is shown in Figure 3.

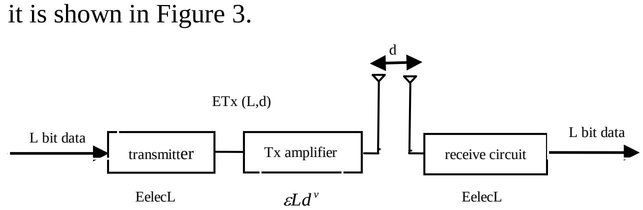

Fig. 3 The wireless communication model

The total energy consumed in Figure 3 is calculated by formula (2) and (3) [6],

$$E_{Tx}(L,d)=\begin{cases}LE_{elec}+L\varepsilon_{fs}d^2, d\le d_0\\ LE_{elec}+L\varepsilon_{mp}d^4, d>d_0\end{cases} \quad (2)$$

$$E_{Rx}(L)=LE_{elec} \quad (3)$$

Where E_{elec} represents the energy consumed to transmit or receive 1 bit message; ε_{fs} is the amplification coefficient of free-space signal and ε_{mp} is the multi-path fading signal amplification coefficient, their value depend on the circuit amplifier model; d represents the distance between transmitter and receiver; L is the bit amount of sending information.

3.3 The optimal number of cluster heads

In LEACH Protocol, all nodes are divided into n clusters randomly, if the value of n is too small, each cluster head burdens so heavily that some clusters will die earlier due to energy draining, this will affect the network lifetime; If the value of n is too large, this also results in some unnecessary overhead because clusters need to send broadcast messages to all nodes. Suppose N nodes are randomly distributed within the square area of the edge length M, assuming that the base station locates in the centre of region, and the distance of each node or cluster-head to the base station is less than or equal to d_0, where $d_0=\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$, we know by references [6] that the optimal number of cluster heads should be

$$n_{opt}=\sqrt{\frac{N}{2\pi}}\frac{M}{d_{toBS}} \quad (4)$$

If some nodes' distance to base station is greater than d_0, we can also get formula (5) by the same method which was used in references [6] and [7].

$$n_{opt}=\sqrt{\frac{N}{2\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}\frac{M}{d_{toBS}} \quad (5)$$

So the optimal probability for nodes to become cluster heads is

$$p_{opt}=\frac{n_{opt}}{N} \quad (6)$$

By the formula (4) and (5) we know that the optimal number of cluster heads only relates to the number of network nodes N, the regional side length M, as well as the location of the base station. We can set these parameters in the network initialization. In this article, the optimal probability for nodes to become cluster heads is chosen as 7% according to formula (6) and the parameters we have set.

3.4 The description of improved algorithm

The parameters need to be used in description of algorithm are as following: Threshold value, as shown in formula (1)； Average energy of all nodes is $E_{ave}=\sum_1^N E(i)$； Average distance between nodes and base station is $d_{ave}=\sum_1^N d(i)$.

- The stage of cluster forming

First, a node choose a number between 0 to 1, if the number is less than $T(n)$, then the node becomes cluster head, else, normal nodes it becomes. Cluster heads broadcast their own information to other nodes, the other nodes will listen to the broadcasting messages. All normal nodes determine which cluster they should join in this round based on the strength of the signal they received. After determining which cluster they should belong, CSMA Protocol will be used to send a confirmation message to their cluster heads. At this point, the clusters forming stage is finished.

- The selecting of secondary cluster head

Each cluster head decides whether to set a secondary cluster head according to the current energy itself and the distance to the base station, if $E(i)<E_{ave}$ or $d(i)>d_{ave}$, then these kinds of cluster heads should choose the node with maximum energy as secondary cluster head in its cluster, otherwise, the secondary cluster head is not required.

- To create a transport schedule

All clusters are divided into two categories, in clusters with secondary cluster heads, the secondary cluster head broadcasts message of being secondary cluster head to the other ordinary nodes and builds a schedule (uses TDMA access channel, a time slot is assigned to each node), informs the schedule to the other nodes. In clusters without secondary cluster head, the cluster heads distribute sending time slot to the others after get the join information of normal nodes. The stable stage begins when each node have gotten its sending time slot.

- Data transferring

When clusters have formed and the TDMA schedule is determined, the nodes start to transfer the monitoring data. The secondary cluster heads receive data from the other nodes and fuse these data, these fused data was sent to the cluster heads, then cluster heads send these data to base station by single-hop method. In those clusters without secondary cluster head, the cluster heads receive the information from other nodes, fuse them and send them to base station.

4. Simulation of improved algorithm

This article uses Matlab7.0 as simulation platform to emulate LEACH protocol and the improved protocol (LEACH-TLCH), the improved algorithm aims at balancing the total energy consumption of nodes and extending the network's survival time. So we measure the improved protocol performance from two aspects: the lifetime and the total energy consumption of the network. The lifetime of network means the time from the beginning of simulation to the time when the last node died. As the energy of WSN is limited, so the energy consumption in its lifetime is a meaningful indicator to measure the performance of it.

4.1 Simulation parameters

Simulation scenarios in this article are:
1. Sensor nodes are randomly distributed in a square region;
2. Sensor nodes are homogeneous and have a unique ID number throughout the network, nodes energy is limited. The node's location is fixed after deployed;
3. The base station is in the center of region with fixed-location;
4. Nodes communicate with base station via single-hop or multi-hop;
5. The wireless transmitter power is adjustable.
Specific parameters are shown in table 1.

Table1: Simulation environment parameters

parameters		parameters	
area	200*200	Packet size	4000bits
Nodes number	200	Eelec	50nJ/bit
Initial energy	0.5J	ε_{fs}	10pJ/bit/m2
CH proportion	p=7%	ε_{mp}	0.0013pJ/bit/m4
BS location	(100,100)	EDA	5nJ/bit

4.2 Analysis of simulation results

200 nodes randomly distribute within the square area of the 200m*200m, the base station is located in the centre of the region, the base station coordinates is (100,100). It can be seen from the figure 4 that the nodes' distribution are not very evenly.

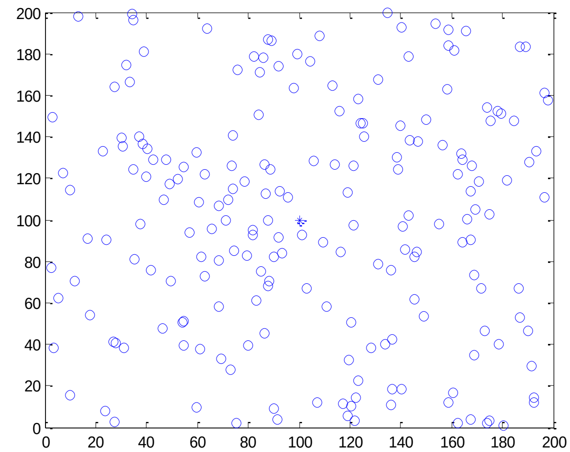

Fig. 4 Randomly distributed nodes

4.2.1 The network lifetime

The network lifetime in this article is defined as the time from the beginning of the simulation to the time when the last node died. In WSN, the network life is divided into stable and unstable period [6]. Stable period usually means the time from the beginning of the simulation to the time when the first node dies, the unstable period refers to the time from the death of first node to the end of simulation.

If it happened that some nodes begin to die, the network operation may become unstable and unreliable data transferring will occur. Therefore, the longer the stable period is, the better the performance of the network. In LEACH Protocol, cluster heads are responsible not only for communicating with the base station, but for the data fusing. Randomly distributing the nodes and randomly selecting the cluster heads causes some cluster heads die earlier because of the low energy or the long distance to base station. Secondary cluster heads are set for these clusters to be responsible for the communication with common nodes and data fusing, this balances the energy load of cluster heads and avoids premature death of these cluster heads, so the stable period of network lifetime will be prolonged.

Figure 5 is network lifetime in simulation, simulation results indicates that the network lifetime of the improved protocol and LEACH Protocol are about the same, the first node died in LEACH Protocol in round 561, the first node died in the improved Protocol in round 857. When 90% nodes died, the network reliability is extremely reduced and the running is almost meaningless. We may as well to define the time from the simulation beginning to the time 90% nodes died as effective lifecycle, analyzing from figure 5, we know that the effective lifecycle of the improved algorithm is longer 9% than that of LEACH protocol. The percentage of stable period of lifecycle in LEACH Protocol is 28%, the one in the improved protocol is 43%, The percentage of stable period of lifecycle in improved algorithm increases 15%. This indicates that the running performance of improved protocol is much better than that of LEACH Protocol. The analysis of simulation results is consistent with the theoretical analysis.

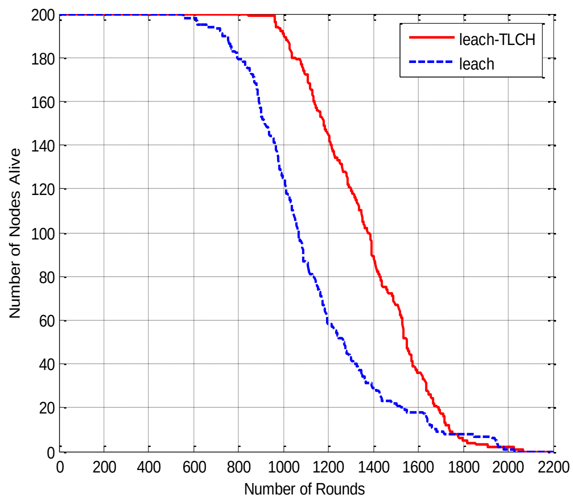

Fig. 5 The network lifetime

4.2.2 The total energy consumption

Figure 6 is the energy consumption curve. Improved algorithm reduced the energy consumption of few cluster heads which has low energy or is far away to base station by setting secondary cluster heads reasonably. This balanced the energy consumption of the whole networks, extended the lifetime of cluster heads which may die earlier and optimized the performance of the network thereby reduced the total energy consumption of the effective lifecycle.

From the analysis of Figure 6, we know that in the whole running of the network, the energy consumption of improved algorithm is much lower than that of LEACH Protocol at the same round of simulation. These results are consistent with the design purposes of improved algorithm.

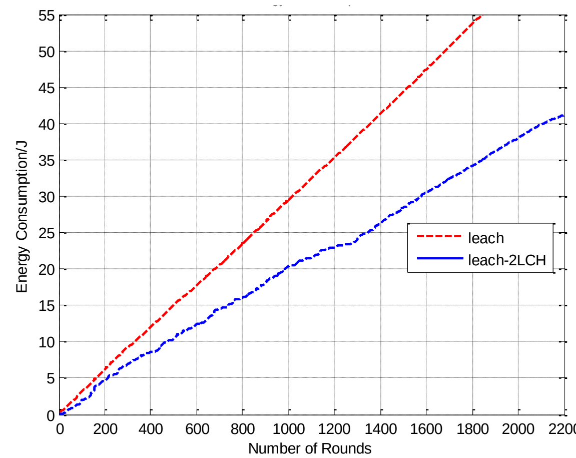

Fig.6 The total energy consumption

5. Conclusions

Electing cluster head randomly in LEACH protocol causes that the current energy of some cluster heads are less or their distances to base station are far, because of the heavy energy burden, these cluster heads will soon die. For this issue, this article proposed a new improved algorithm of LEACH protocol which is aim at balancing energy consumption of the whole network and extending the network lifetime by balancing the energy consumption of these cluster heads. The new improved algorithm is emulated by Matlab platform, the simulation results indicate that the energy efficiency and the lifetime of network are both better than that of LEACH Protocol.

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