Improvement for LEACH Algorithm in Wireless Sensor Network

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Abstract. According to the energy bottleneck of the wireless sensor network, the LEACH algorithm is improved in this paper, in the LEACH algorithm, it maybe that the cluster head nodes are far from the base station, and cluster head node has non-uniform distribution, in this case, nodes soon died after consuming energy, so the focus from three aspects of the optimal number of the cluster head and uniform distribution and many jump communication to improve, the improved algorithm through the simulation tests show that network node energy has been obviously saved, at the same time the lifecycle of the system is also effectively extension. In the application of the wireless sensor, we should always hold the principle of energy-first, therefore the LEACH which is a hierarchical routing protocol can save energy has played a crucial role, but the optimal number of the cluster head and uniform distribution can't be archived because of the change of the location of the cluster head nodes. In addition, when the cluster head far away from center sink node communicate with center sink node, the cluster head will exhaust energy quickly to die, that may affect lifecycle of whole of monitoring network and lead to worse expansibility. For some problems of the LEACH algorithm, the LEACH algorithm is improved in this paper from three aspects of the optimal number of the cluster head and uniform distribution and many jump communication, the improved algorithm through the simulation tests show that network node energy has been obviously saved.

Keywords: LEACH · Routing strategy · Effective path · Wireless sensor network

1 Introduction

LEACH (low energy adaptive clustering hierarchy) algorithm [1] is an adaptive clustering topology algorithm implemented with "round" as unit period, and a round circulation is consist of two phases, one is the implementation of initialization and another is the steady data transmission.

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1.1 Physical Basis

The LEACH algorithm use first order radio energy dissipation model [2] which include the following several significant features as shown in Fig. 1:

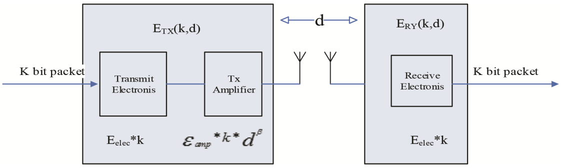

Fig. 1. First order radio energy dissipation model

(1) Base station is located where far from WSN and has enough energy to supply;
(2) The energy dissipation of radio signals in each direction of WSN is both same;
(3) In the WSN, All the nodes are exactly the same and have the same limited energy.

Thus, to transmit a kit-bit message using our radio model, the radio expend:

$$E_{send} = k * E_{elec} + k * \varepsilon_{amp} * d^{\beta} \tag{1}$$

and to receive this message, the radio expend:

$$E_{receive} = k * E_{elec} \tag{2}$$

ε_{amp} is the amplification factor and E_{elec} is the radio dissipates from transmitter or receiver circuitry. In this case, both the radio dissipates can be regarded as equivalence because the actual dissipations from transmitter and receiver are no different. β is a constant value depend on the radio channel and d is the distance which signal transmitted. From the formula $k * E_{elec} \ll k * \varepsilon_{amp} * d^{\beta}$, we can find that, the shorter distance signal transmitted, the less energy the circuitry dissipated. The variable is set as $\beta = 2$ when the distance from channel models were used to transmitter is small, and the variable is set as $\beta = 4$ when the distance is long. In this case, it is called Double path model [3].

1.2 Implementation

LEACH algorithm is implemented with "round" as unit period, the time consumed in the initialization phase must be less than the time consumed in the steady data transmission phase. The initialization phase of each round, First network to randomly selected some nodes self-organized way as cluster heads, select the cluster heads broadcast next, and ordinary nodes will be able to pass judgment signal strength to consider themselves the join of head, the principle of selection is near itself and signal stronger cluster heads. When all the nodes to join the cluster heads, each node with CSMA mechanism to inform themselves to join the cluster of cluster nodes, after the cluster formation, as the cluster head nodes will be responsible for build a TDMA time slot for cluster nodes within the table. When the cluster building work is completed, According to the rules of TDMA, ordinary nodes will be sent every needle data collected, eventually sent to the cluster head nodes, and the cluster head nodes to send data through fusion processing backwardness to center node or base station.

(1) The stage of establishing a cluster

In the stage of establishing a cluster, the percentage of total nodes of cluster nodes in the network and the number of nodes act as cluster head nodes past determines whether a node of the cluster head nodes act as a basis. Any node n randomly generate a random number between 0, 1, joining the random number is less than the threshold T (n), the node n was elected to the current round of cluster head nodes information broadcast itself.

T (n) calculation is as follows:

$$T_{(n)} = \begin{cases} \dfrac{p}{1 - p * (r \bmod \dfrac{1}{p})} & if \;\; n \in G \\ 0 & other \end{cases} \tag{3}$$

Among them, the P said cluster head accounted for the proportion of the number of network nodes, r is said round number, $r \bmod (1/p)$ says the number of nodes, these nodes in the current cycle has been elected cluster heads, G represents a collection, the collection of all the nodes in the current loop was no cluster head.

(2) The stability of data transmission phase

In the whole network of cluster composition and also generate the TDMA time slot of cluster nodes table, begin to transmit data, which has entered the phase of stable data transmission. The nodes in the network will be constantly monitoring data, the node will be in his own time slot will be collected in each frame of monitoring data to the cluster head nodes, in order to save energy, ordinary nodes will be in its own time slot has not come close the transceiver. But the working state of the cluster head nodes must be in continuous, because to receive the quantity of nodes of cluster nodes to send over some of the data, every time after a round of data transmission, cluster head nodes to send data through fusion processing backwardness to center node. Due to Multiple clusters work together at the same time, will inevitably have an impact on each other, aiming at this problem, different cluster internal adopted CDMA (Code Division Multiple Access) system.

2 LEACH Algorithm is Improved

2.1 The Choice of the Optimal Cluster Number

Probability of cluster nodes in the LEACH, a certain effect on the lifespan of relative network. Because of too much will greatly increase the energy consumption of cluster nodes, thus shortening the life cycle of the entire network; Cluster nodes and less because of the cluster members of cluster nodes will make the node number, communication load heavy, die soon run out of energy, making the network life cycle shorten. To attain the longest network life cycle, therefore, must have a best cluster head probability value, this article first from the point of optimal number of cluster head LEACH algorithm is improved.

The optimal number of cluster head is based on the analysis of network on the basis of energy consumption [4]. First of all, we hope that each round of minimum energy consumption and energy consumption on all nodes, the goal is to will pick the optimal number of cluster heads to obtain minimum total energy consumption.

We assume that the monitoring area is the area of the M * M, Distribution in this area have N nodes, k clusters is contained in another network, This will tell you a single number of nodes in the cluster as the N/k, ordinary members of the number of nodes is N/k – 1, according to the working process of the (1) and algorithm: A single cluster of energy consumption is mainly used for ordinary nodes information after receiving, and the processing of the data fusion of data sent to the center in the process of gathering node.

So a single cluster head nodes within a frame for energy consumption:

$$E_{CH} = l\,E_{elec}(\frac{N}{K} - 1) + l\,E_{DA}\,\frac{N}{K} + l\,E_{elec} + l\,\varepsilon_{amp}\,d^4_{toBS} \tag{4}$$

The said l single transfer data on the number of bits, d_{toBS} is the length of the cluster heads to center gathered node, E_{DA} for fusion energy consumption after processing. Because within the cluster, common member nodes and cluster heads are not far apart, we can look for a free space model.

So the ordinary node energy consumption within a frame as follows:

$$E_{non-CH} = l\,E_{elec} + l\,\varepsilon_{amp}\,d^2_{toCH} \tag{5}$$

Among them, the cluster and d_{toCH} represents the member length between nodes.

Because the area of the monitoring area is M * M, So a single cluster is responsible for the monitoring area is about M^2/k, It is assumed that the probability of any node distribution meet $\rho(x, y)$, Cluster way can get the ordinary node of the square of the length of the mathematical expectation is as follows:

$$E\left[d^2_{toCH}\right] = \iint (x^2 + y^2)\rho(x, y)dxdy = \iint r^2\rho(r, \theta)rdrd\theta \tag{6}$$

In addition if the monitored area is a circular, and the radius of the circle is $R = (M/\sqrt{\pi k})$, can get the following formula:

$$E\left[d^2_{toCH}\right] = \int_{\theta-0}^{2\pi}\int_{r-0}^{M/\sqrt{\pi k}} \rho\, r^3\, drd\theta = \frac{\rho}{2\pi}\frac{M^4}{k^2} \tag{7}$$

In the case of uniform distribution of the nodes, the next step can be (8):

$$E\left[d^2_{toCH}\right] = \frac{1}{2\pi}\frac{M^2}{K} \tag{8}$$

We can get the following (9) by (8) and (7):

$$E_{non-CH} = l\,E_{elec} + l\,\varepsilon_{amp}\frac{1}{2\pi}\frac{M^2}{K} \tag{9}$$

Clusters within a single frame energy as the following Eq. (10):

$$E_{cluster} = E_{CH} + \left(\frac{N}{k} - 1\right)E_{non-CH} \approx E_{CH} + \frac{N}{K}E_{non-CH} \tag{10}$$

So the total energy consumption of k clusters together for (11) style:

$$E_{total} = k\,E_{cluster} = l\left(E_{elec}N + E_{DA}N + E_{elec}N + k\,\varepsilon_{amp}d_{toBS}^4 + \varepsilon_{amp}\frac{1}{2\pi}\frac{M^2}{k}N\right) \tag{11}$$

Finally, the method of derivation by seeking to obtain the optimal minimum number of clusters k as head:

$$k_{opt} = \sqrt{\frac{N}{2\pi}}\frac{M}{d_{toBS}^2} \tag{12}$$

2.2 Evenly Distributed Cluster Head Node

For LEACH, may appear far from the center of the cluster head node converge quickly energy depletion and death for this problem LEACH face, In this paper, the original algorithm was improved, by setting the type of (3) p value [5], makes from the center aggregation node distant cluster region contains more heads. Cluster establishment phase, the node type is used to calculate the threshold value (3), but for a different region, Their p value calculation method will be different, they will p value for their respective region distance monitoring center gathered node length and different, from near to far value is $(1-x)p$ 、 p 、 $0 < x < 1$. In this way, Node cluster nodes farther away from the center will have a relatively large threshold, the probability that elected cluster head is relatively large, so as to achieve the goal of a uniform distribution of cluster heads.

2.3 Multi-hop Communication Between the Cluster Head

For LEACH protocol, all nodes in the network, including base stations can communicate directly included, but for those relatively distal from the center of the cluster head node aggregation node will be a big challenge, because the longer the transmission distance, energy consumption will increases, because the cluster head End energy consumption and death, and ultimately shorten the lifetime of the network, of course, network scalability will become poor. In this paper, the energy problem facing LEACH algorithm, a wireless multi-hop sensor networks idea that is farther from the center of the convergence of the cluster head node provides a relay station, which is the distance from the center to select some more recent collection of nodes as a distant cluster head relay station cluster head, cluster head node so far as to save some energy.

Improve ideological algorithm in a stable transfer phase, either in the choice of a cluster head node upstream forwarding node itself, it must send a message you want to own node energy consumption and the ratio of residual energy consumption into account, in addition, the cluster head node to send a large amount of information from the member nodes in the cluster, so the choice of upstream forwarding node when not only consider their distance from the issue, and to consider more efficient routing, routing efficiency level, mainly to see its forwarding information can consumption, the number is sent to the center in the convergence node.

3 Emulation

3.1 Embedded Operating System TinyOS and NesC Language Introduction

TinyOS [6] is a UC Berkeley to develop open-source wireless sensor networks designed specifically for embedded operating systems. TinyOS including distributed servers, network protocols, data identification tools and sensor-driven and some other components, it has a very good event-driven model that supports scheduling is very flexible and, in addition, there is a very good power management, currently, TinyOS gradually been used on many platforms and some sensing board, so TinyOS research has far-reaching significance and value. TinyOS was originally designed to provide a dedicated embedded operating system for wireless sensor networks, TinyOS just started using C and assembly language programming. Many workers engaged in scientific research through in-depth study found, C language can not meet the application of wireless sensor networks embedded operating system development and sensor networks. Therefore, researchers later on the basis of C's proposed NesC [7] language.

3.2 The Introduction of Simulation Software: TOSSIM

TOSSIM is a discrete event simulation software which TinyOS comes with. It can compile the application programs of TinyOS to the simulation framework in which we can use standard development tools to debug code. TOSSIM can simulate integrated application programs of TinyOS and the operating principle replacing the hardware components by simulation components. The component level which TOSSIM can replace is flexible. It could replace both the packet level communication component and radio frequency chip on bottom layer to get more exact simulation result.

3.3 The Performance Simulation of Improved Optimal Number of Cluster Heads

(1) Simulation environment and parameters

To simulate the performance of improved optimal number of cluster heads, we put 100 nodes in the monitored area of 50 m * 50 m randomly. The setting of simulation parameters is listed below in Table 1 (ε_{amp} represents amplification factor, E_{elec} represents energy consumption of transmitting and receiving, E_{DA} represents energy consumption after fusion processing)

Table 1. The simulation parameters of optimal number of cluster heads

Parameter Name	Parameter values
Area of zone	(0, 0) to (50, 50)
Number of nodes	100
Location of base station	(25, 150)
E_{elec}	50nJ/bit
ε_{amp}	0.0013pJ/bit
E_{DA}	5nJ/bit/signal
Initial energy	0.25 J

(2) The simulation results and analysis

In TOSSIM, we simulate the process with 100 nodes and get the relationship between average energy consumption per round and the number of cluster heads, as listed below (Table 2):

Table 2. The relationship between average energy consumption per round and the number of cluster heads

NCH / EC	0	1	2	3	4	5	6	7	8	9
AECPR(J)	4.5	3	2.1	1.6	1.4	1.7	2.5	3.5	4.6	6

NCH : Number of Cluster Heads
EC : Energy Consumption
AECPR : Average Energy Consumption Per Round

Converting the table of the relationship between average energy consumption per round and the number of cluster heads to the graph as below Fig. 2:

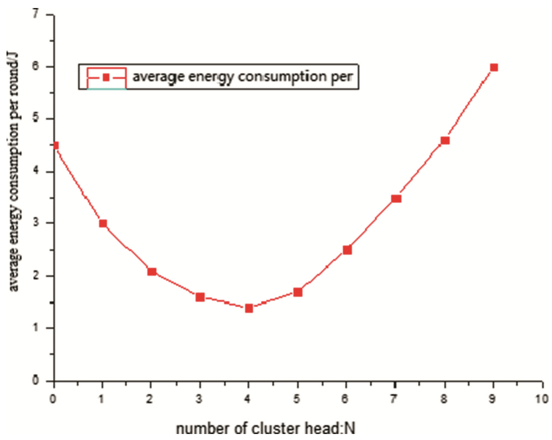

Fig. 2. The average energy consumption per round of different number of cluster heads

From Fig. 2, we know that when the number of cluster heads is 3, 4 and 5, the whole energy consumption of the network is less. Bringing the simulation parameters into the formula (12), we can get $1 < k_{opt} < 6$. So the simulation results are similar to that calculated theoretically which illustrates the optimal number of cluster heads in the area set by experiment is 3, 4 or 5, saving energy more effective. The big number of cluster heads in network will increase the expenses, while small of that will result in network paralysis.

3.4 The Performance Comparison Between Single Hop Communication and Multi-hop Communication Among Clusters

This paper simulates the network in the mode of single hop communication and multi-hop communication in energy consumption for 100, 200, 300, 400, 500, 600 and 700 rounds with the same 100 nodes distribution randomly and the same total energy 25 J. The results as below Table 3:

Table 3. Total energy consumption variation with the simulation rounds

RS / TEC	100	200	300	400	500	600	700
OLA(J)	**6**	**12**	**15.5**	**19.5**	**22.5**	**25**	
IA (J)	3.5	7.5	11.5	15.6	19	22	24

RS : Rounds of Simulation
TEC : Total Energy Consumption
OLA : Original LEACH Algorithm
IA : Improved Algorithm

Converting the table of energy consumption in the mode of single hop and multi-hop communication to graph, as below Fig. 3:

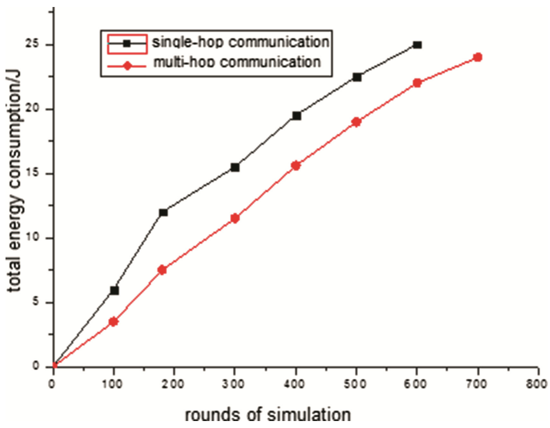

Fig. 3. The energy consumption comparison between single hop and multi-hop communication

3.5 The Life Cycle Comparison Between the Original LEACH and Improved LEACH

(1) Simulation environment and parameters

Simulate the original LEACH and improved LEACH in different energy in which the probability of taking the nodes of cluster heads is 5 % and make x equal 2. The distance between the nodes of cluster heads and base station in original LEACH algorithm uses the multipath fading model. It means $\varepsilon_{amp} = 0.0013\text{Pj/bit}/m^4$. Other parameters as below Table 4:

Table 4. Simulation parameters of network cycle

Parameter names	Parameter values
Area of zone	(0, 0) to (50, 50)
Number of nodes	100
Location of base station	(85, 90)
E_{elec}	50nJ/bit
ε_{amp}	100pJ/bitm2
E_{DA}	5nJ/bit/signal
Initial energy	0.25 J 和 0.5 J
Length of message packer	2000bit
Length of broadcast message	64bit

(2) The simulation results and corresponding analysis

For 100 nodes, when the initial energy of each node is 0.2 J, LEACH is obtained by simulation before and after improving algorithm, in which the relations of simulation time and the number of live node in the network are shown in Table 5 below.

Table 5. Correlation table of change in live node along with simulation time

LN \ ST	0	50	100	150	200	300	345	369	354	450	550
TILA(N)	**100**	**100**	**100**	**100**	**99**	**97**	**50**	**10**	**0**		
AAI	100	100	100	100	100	100	99	64	41	18	0

ST : Simulation Time
LN :Live Node
TILA : The Initial LEACH Algorithm
AAI : Algorithm After Improvement

LEACH algorithm in the network before and after the improvement for the node number and simulation round number relational tables into a diagram in Fig. 4 as follows:

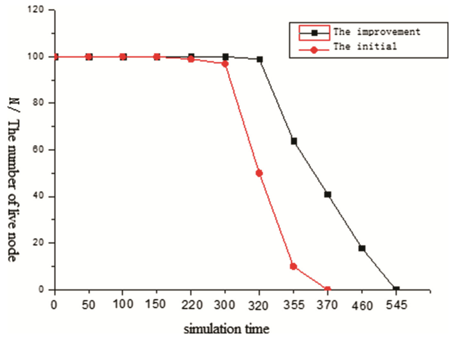

Fig. 4. Life to compare two algorithms of node

In above Fig. 4, in line with the circle said node number of survival of the original algorithm, improved algorithm with the black line of the box says the number of nodes to survive. The simulation results show that the improved algorithm makes the nodes in a network of the consumption of energy to get the uniform, thus avoiding a single node energy consumption by its larger and premature death.

3.6 The Comparison of LEACH Time Delay Before and After Improvement

In this paper, the improved algorithm respectively before and after in clusters expectations for 1 to 10 cases of packet delay are simulated, and their delays shown in the table below (Table 6):

Table 6. Packet delay change with clusters of expectations contrast figure

CE / PD	1	2	3	4	5	6	7	8	9
IA (s)	**1.72**	**1.22**	**0.9**	**0.78**	**0.62**	**0.55**	**0.5**	**0.48**	0.47
ILA(s)	1.25	0.92	0.75	0.61	0.55	0.45	0.4	0.39	0.4

CE : Clusters Expectations
PD : Packet Delay
IA : Improved Algorithm
ILA : Initial LEACH Algorithm

Converts packet delay table to delay curve in Fig. 5 as follows:

It Can be seen from the Fig. 5, with the continuous increase of clusters expectations, before and after improvement average delay is becoming more and more small, two algorithms of cluster number is, the more the corresponding time delay is continuously decreasing, and this is also consistent with the actual wireless sensor network. But also obvious reaction from the picture has a drawback, the improved algorithm is improved algorithm delay slightly bigger than the original algorithm, because of the improved algorithm is used in many communication mode, most of the cluster head nodes not will collect the data directly to the base station, first to be sent to its upstream trunking cluster

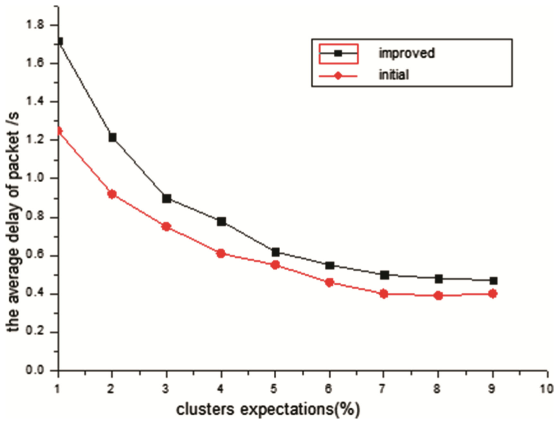

Fig. 5. Before and after the improvement of the comparison of two kinds of algorithm on the network average delay before and after improvement of two kinds of algorithm on the network average delay

head nodes, this has been more jump transmission, will produce certain delay between obviously, is a good phenomenon, increase gradually as clusters of expectations, the time delay of two algorithms are consistent.

4 Conclusions

This chapter first describes the original LEACH communication model and implementation process of the algorithm are introduced, then some problems in the face of the LEACH algorithm is analyzed, because these problems of wireless sensor network to the life cycle of caused great influence, therefore, these problems, this article from the optimal number of cluster head, cluster heads the multi-hop communication of even distribution and network of the three aspects of LEACH algorithm is improved. Simulation tests show that the improved algorithm has dramatically save the energy of each node, at the same time, the life cycle of the network has been effectively prolong, scalability of the network also has been enhanced, but throughout the network average delay, compared to the original LEACH algorithm, the improved algorithm on average delay somewhat larger than, but difference decreases continuously decreases as the clusters expectations.

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