Study on the LEACH protocol based on hierarchical cluster heads probability

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Abstract

In this paper, we systematically analyze the clustering routing LEACH protocols, and make an in-depth study of how the protocol works. The ECHNL routing algorithm based on the probability of hierarchical cluster head is proposed and the improved algorithm simulation environment is built using NS2 platform. Then we compare the algorithm performance of ECHNL, LEACH and RPUCDH. The results show ECHNL algorithm performs well in optimizing the cluster head election, balancing energy consumption of the network nodes, and effectively enhancing network lifetime.

Keywords: wireless sensor network, LEACH protocol, ECHNL algorithm, hierarchical cluster heads probability, energy balance

1 Introduction

With the development of science and technology in recent years, Internet has transformed the lives of human beings and brings them into an information age. The advancements in the microelectronic system, low-power embedded computing and wireless communication technology, etc. promote the rapid, leap-style development of wireless sensor network technology which is critical for the next generation Internet and attracts the interest of the academia, industry and military circle [2].

Wireless Sensor Network (WSN) is composed of a large quantity of cheap micro sensor nodes deployed over the monitored area, forming a multi-hop self-organizing network through wireless communication. It aims to sensing, collecting and processing the information of the monitored objects, which will then be transferred to the observers. Differently equipped sensors will have different functions, such as to monitor temperature, humidity, pressure and dust concentration, etc. Network of these sensors is important in a variety of military and civilian applications, including traffic management, environment protection, medical care, fire pre-warning etc. As a new tool for us to understand the world, it plays an important role in the production and living of human beings in 21st century [4, 5]. The broad application prospect of WSN gains the attention of the academia, industry and military circle.

As the first proposed clustering routing protocol, LEACH occupies an important position in the routing protocols for WSN. It is well-known for high routing scalability and is the basis of many clustering routing protocols, such as PEGASIS, etc. But LEACH protocol also has the following defects: 1) the cluster head election mechanism of LEACH protocol is inadequate: the cluster head election based on the threshold $T(n)$ is random; cluster heads are unevenly distributed; the structures and scales of each cluster are different; energy consumption of cluster head nodes is unbalanced; 2) Cluster head election in LEACH protocol does not consider the energy load constraint of the nodes. The failure of low-load cluster head node will lead to the occurrence of communication blind area, which goes against prolonging the network lifetime; 3) The distribution of cluster heads is not considered in the cluster head election mechanism of LEACH protocol, which will result in a waste of communication energy; 4) The LEACH protocol has a limited fault-tolerant mechanism that can only deal with relatively simple problems. Provided energy constraint of WSN node, we propose WSN clustering algorithm ECHNL which is based on hierarchical cluster head probability as well as the residual energy, retaining the clustering routing of LEACH protocol. By combining node residual energy and hierarchical cluster head election strategy with the known clustering strategy to minimize the node energy consumption as much as possible, the lifetime of whole network can be prolonged.

2 LEACH protocol

2.1 THE MECHANISM OF LEACH PROTOCOL

Heinzelman and Chandrakasan, et al. from MIT first proposed LEACH protocol for WSN. Through randomized rotation of cluster-heads and evenly distribution of relay communication, LEACH protocol achieves energy reduction and effectively prolongs the lifetime of the network.

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LEACH protocol adopts random cluster head election strategy, and the operation is broken into round so that all nodes can be a cluster node periodically, reducing energy consumption of the whole network system. In LEACH protocol, cluster head node aggregates data from nodes within the cluster to compress the amount of data sending to the base station via hop, thereby minimizing energy consumption. The application of Media Access Control further reduces the sensor node energy consumption in LEACH protocol. Using Time Division Multiple Access (TDMA) in the MAC layer, cluster head allocates a different time slots for each cluster member node of WSN for data transmission to reduce energy consumption. Time slots minimize communication interference with the cluster to some extent.

Each round of LEACH begins with a set-up phrase which is followed by a steady data transmission phase. At cluster set-up phrase, a random number between 0 and 1 is chosen by each node, and then is compared with threshold $T(n)$ in this round: if it is smaller than $T(n)$, the node becomes a cluster head. The calculation Equation of $T(n)$ is (1):

$$T(n)=\begin{cases}\dfrac{p}{1-p(r\bmod(1/p))} & n\in G\\ 0 & n\notin G\end{cases}, \tag{1}$$

where p is the percentage of cluster heads, r represents the current round number, G is the set of nodes that have not been cluster-heads in the latest r round. The flow chart of cluster set-up phrase is shown in Figure 1.

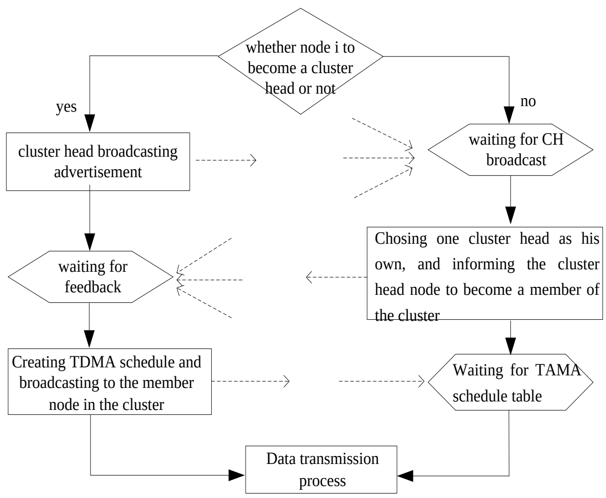

FIGURE 1 Flow Chart of Cluster Setup Phase in LEACH Protocol

Steady data transmission phrase: this phrase is partitioned into multiple frames which are further divided into multiple time-slots corresponding to each member node. In the assigned time-slot, the member node communicates with its cluster head directly via a single hop. The cluster-head node performs data fusion on all the data received, and the result will be sent to the base station.

2.2 LEACH IN WIRELESS COMMUNICATION MODEL

In wireless transmission, power (Watt) takes on exponential decay with the increase of transmission distance based on which the free space model and multi-path fading model can be defined, as shown in Figure 2 [6].

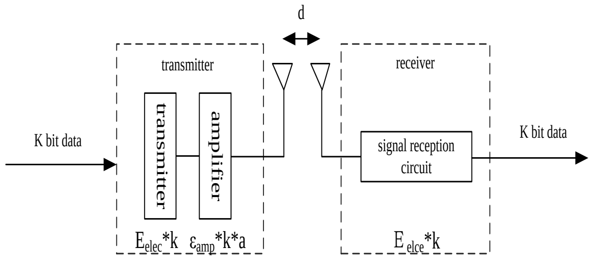

FIGURE 2 Energy Consumption Model for Wireless Communication

$E_{TX}(k,d)$ is wireless transceiver's energy consumption in data sending, including energy loss $E_{elec}(k)$ of the transmission circuit and the energy consumption $E_{amp}(k,d)$ of signal amplifier whose amplification factor is ε_{mp} , $E_{TX}(k,d)$ is wireless transceiver's energy consumption in data receiving.

Based on Equations (2) and (3), the energy consumption of sensor node in sending K bit data packet from transmitting circuit to receiving circuit is calculated: Equation (2) is the energy consumption in sending phase and Equation (3) is the energy consumption in receiving phase.

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

$$E_{Rx}(k)=E_{Rx-elec}(k)=E_{elec}*k \tag{3}$$

In Equation (2), d is the transmission distance of the signal. First calculate the transmission distance d between communication nodes; then compare it with the constant d_0, if $d\ge d_0$, the multi-path fading model is adopted, otherwise the free space model is adopted. The magnification ε_{amp} of power amplifier is determined by the transmission distance. Therefore, when the free space model is adopted, set $\varepsilon_{amp}=0.0013pj/bit/m^4$. The parameter values of the equations used in simulation in this paper are shown in Table 1.

TABLE 1 The parameters of WSN

Parameter	Energy Consumption
Transmission energy consumption $E_{TX}(k,d)$ and receive energy consumption $E_{Rx-elec}(k)$	$50nj/bit$
Transmit amplifier parameters ε_{amp}	$0.0013pj/bit/m^4$

As is shown in Table 1, the energy consumed by the transmitter and receiver in data transmitting is high. Therefore, we should try to minimized data bits number and the transmission distance.

3 The Improved algorithm ECHNL Based on LEACH protocol

We propose the ECHNL (Equal Cluster Head Distribution based on Network Level) algorithm to make effective usage of the sensor node energy and achieve maximal network lifetime.

By introducing the 1:1 dual-homed fault-tolerant routing technology and the notion of "hierarchical cluster heads probability" into the network, ECHNL algorithm modifies the cluster head election mechanism of LEACH protocol and optimizes information gathering process of the network in layered network area. The performances of ECHNL algorithm, LEACH protocol and RPUCDH algorithm [8] are compared in terms of network lifetime, total data received by the base station, and the global energy consumed by the network. With evenly distributed cluster head nodes, the above improvement aims to minimize energy consumption and prolong the lifetime of the network.

3.1 NETWORK TOPOLOGY

To avoid uneven distribution of excessive cluster-heads concentration, the RPUCDH-like improved algorithm is proposed in the network model, and hierarchy is introduced, as shown in Figure 3 and Figure 4.

1) N sensor nodes distribute evenly in the area of a square with a monitoring radius L.

2) Calculate the distances between the nodes and the base station, and then divide the results into layers. Let the radiuses of the layers be $r_1, r_2, ...r_i, r_n$ satisfying $0 < r_1 < r_2 < ... < r_i < r_n = L$. For the better data transmission of nodes as a cluster, let layer radius satisfy $r_i / r_n = 1/\sqrt{2}$, and set the layer of the node nearest to the base station as the first layer and the furthest as the nth layer, as shown in Figure 3.

3) Divide the whole sensor network into several cluster structures, let the ratio between k_i (the ideal number of cluster members in each layer) and N_i (the total number of nodes in this layer) be ideal cluster head percentage p_i; the greater the layer number is, the more network nodes there will be; the lower the percentage of cluster head is, and the greater the number of cluster member will be.

4) The communication method between cluster heads is different in the network. In the first layer, the cluster head nodes communicate directly with other nodes; the outer layer cluster head nodes, as relay nodes, communicate indirectly with the base station.

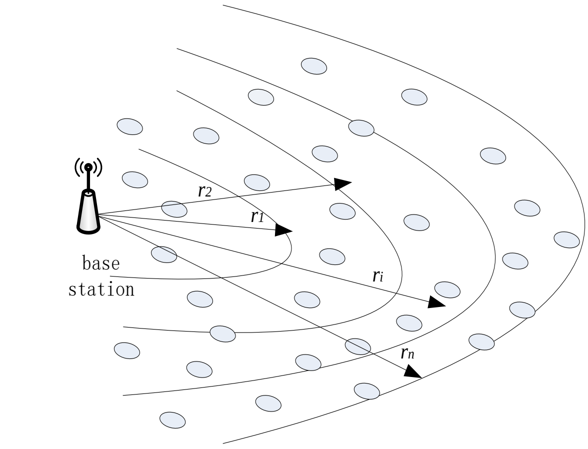

FIGURE 3 Network topology in Improved Algorithm ECHNL

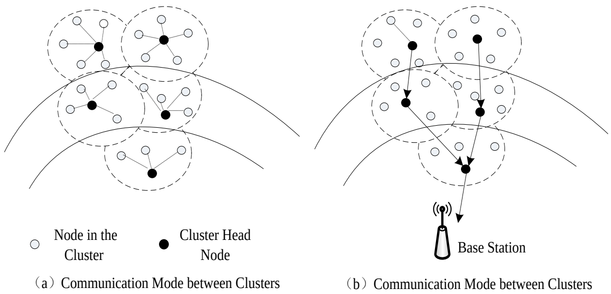

FIGURE 4 Nodes Communication Mode in Improved Algorithm ECHNL

3.2 THE IMPLEMENTATION OF IMPROVED ALGORITHM ECHNL

3.2.1 Network Node Initialization

Deploy sensor nodes randomly in the monitored area and initialize the WSN nodes via base station. The initialization message (*qur_msg)*) structure is shown in Table 2.

TABLE 2 Initialization Message Structure

Segment	Description
mes_type	Message Type
i	Number of Layers
R	Emission Radius of the Area
d_m	Distance Calculation Factor

3.2.2 Cluster Head Setup

After network nodes initialization, or at the beginning of a new round of cluster head election, the time when head number is 0, the election condition is met. The base station energy gain from global residual energy of the network is Equation (4); the number of living nodes is *j*; the current global energy of network nodes is Equation (5).

$$E_{total(r)\_energy} = \sum_{i=1}^{n} E_i' \quad (4)$$

$$E_{total(r)\_energy} = \sum_{i=1}^{j} E_i \quad (5)$$

Modify threshold selection of the LEACH protocol, as shown in Equation (6).

$$T'_{(n)} = \begin{cases} \dfrac{p_i}{1 - p_i \cdot (r \bmod 1/p_i)} \cdot \dfrac{E_{n\_current}}{E_{totzl(r)\_energy}} & n \in G \\ 0 & n \notin G \end{cases} \quad (6)$$

In the above equation, p_i is the cluster head node percentage in each layer in each round; and $p_i = k_i / N_i$, where k_i is the number of nodes that are cluster head in each layer and N_i is the total nodes number in each layer.

$E_{n\_current}$ is the current total energy of network nodes; $E_{total(r)\_energy}$ is the total initial energy of nodes that are alive at present; *G* is the set of nodes that have not been cluster-heads in the latest *r* round.

From $p_i = k_i / N_i$, we know p_i is the probability for nodes in a layer in the current round to become cluster node. The whole network can be divided into *i* layers, and $i = \dfrac{\sqrt{2}N^2}{A}$, where *N* is total number of nodes, *A* is the area monitored. To avoid multiple path fading phenomena in the communication among cluster heads, the free space model is adopted in this paper, and *i* satisfies $\forall i (i \in [1,n]) r_{i+1} - r_i \le d_0 / 2$.

The energy consumption of cluster nodes in different layers of the network is shown in Table 3 [9].

TABLE 3 Energy Consumption of Cluster Nodes in Different Layers

Layer	1	2	3	4	5	6	7	8	9	10
Energy Consumption（10^{-6}J）	730	653	576	499	422	346	269	192	115	38

In this case, the computing method of energy consumption rate ER_i can be defined, that is $ER_i = 2 \cdot (n - i + 1) - 1, i \in [1, n]$. In the improved algorithm ECHNL, setting the cluster member in each layer is k_i, we have Equation (7).

$$k_i = \left[\min\left(\frac{N}{\sum_{i=1}^{n} ER_i} \cdot ER_{(n-i+1)}, \frac{N}{n} \right) \right] \quad (7)$$

The flow chart of cluster set-up of improved algorithm ECHNL is shown in Figure 5.

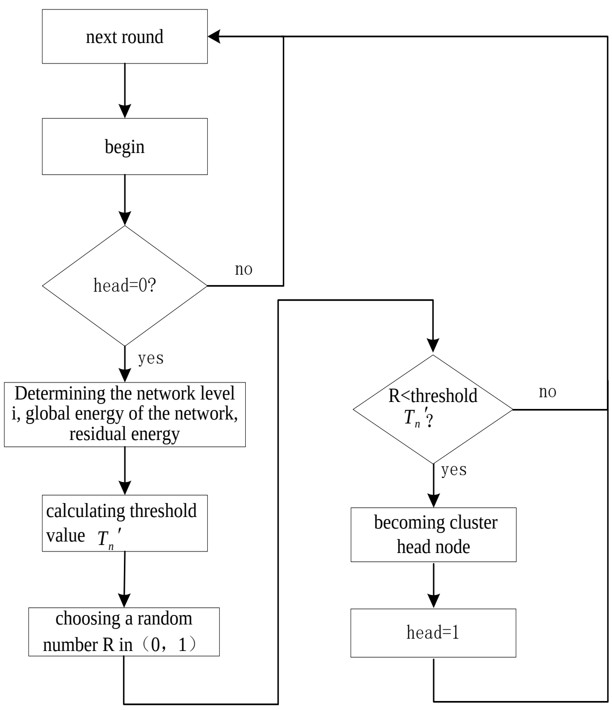

FIGURE 5 Cluster head election process

3.2.3 Cluster structure setup

After receiving ADV message, normal nodes need to update the nodes structure table, add information received from all cluster heads, and choose cluster heads based on the strength of received message. Detailed process is shown in Figure 6, and Table 4 is the ref format.

TABLE 4 Ref structure format

Segment	**Description**
Member_id	Member node *id*
Member_E_id	*Residual energy of member node*

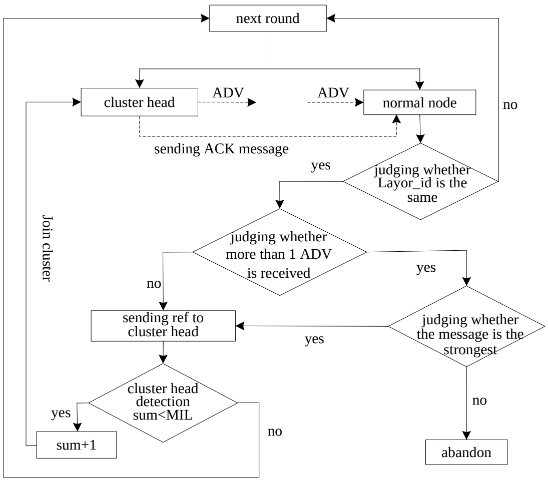

FIGURE 6 Detailed process of cluster structure setup

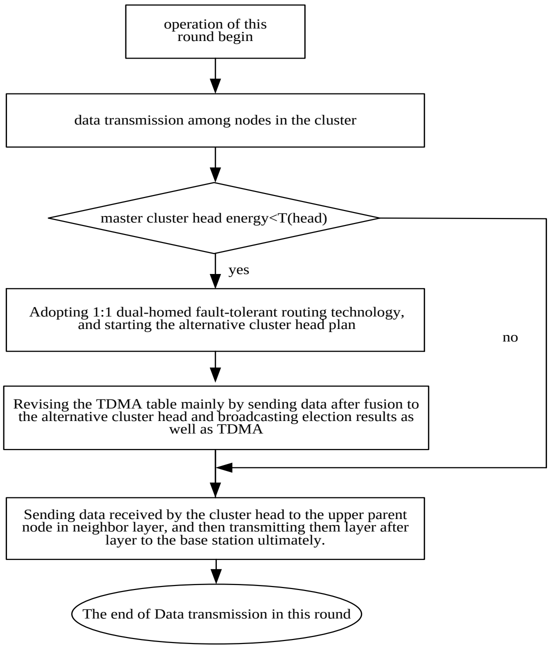

FIGURE 7 Flow Chart of Steady Data Transmission Phase

3.2.4 Routing building phase

After cluster structure is built, each node will have a table of neighbor cluster heads, which will be updated as more information is received from neighbor cluster head. Based on the table, the communication routing between cluster head and base station is set up. Detailed process is as follows:

1) When cluster head node is in the first layer, nodes communicate with the base station via hop, otherwise come into next step.

2) If there is *Layer_id* information of upper-layer nodes, the head node chooses node in the neighbor layer to perform the next hop data transmission, otherwise comes into next step.

3) Going through step 1 and 2, cluster head comes to the base station after the last hop, thereby completing routing setup among clusters.

3.2.5 Steady phrase of data transmission

Based on the idea of double cluster heads, the 1:1 dual-homed fault-tolerant routing technology, where there is an alternative cluster head fault tolerant enabling reliable data transmission, is adopted, as shown in Figure 7.

4 Simulations and result analysis

4.1 SIMULATION SCENARIO AND PARAMETER SETTING

In this paper, Cygwin+NS2.27 is installed in Windows XP, and simulation is made using NS2.27. The based station is located at （0,0）, and 100 sensor nodes distribute randomly within the 100×100 area. The simulation parameters needed are shown in Table 5. With the simulation running for 50 times and the average value derived from the experiment as the simulation result, compare the performance of improved algorithm ECHNL, LEACH protocol and RPUCDH algorithm.

TABLE 5 Simulation parameter table

Name	**Symbolic Representation**	**Parameter**
Nodes Number	N	100
Node Initial Energy	$E_{initial}$	2j
Monitored Area	$L\times L$	100×100
Transmission Amplifier Energy Consumption	E_{fs}	10$pj / bit / m^2/$
1bit Transmit/receive Energy Consumption	E_{elec}	50nj / bit
Data Fusion Energy Consumption	E_{da}	5$nj / bit / signal$
Packet Size	k	100 bytes

4.2 PERFORMANCE ANALYSIS OF IMPROVED ALGORITHM ECHNL

Comparison of the Simulation results of ECHNL algorithm, LEACH protocol, and RPUCDH algorithm is shown in Figure 8, Figure 9 and Figure 10.

From Figure 8, the comparison of the three algorithms in terms of death of the first node and all nodes in the network is shown in Table 6.

From Figure 9, we know the network flight time of ECHNL is longer than that of LEACH and RPUCDH, and so is the case in terms of the amount of data received; From Figure 10, we know, from 48s onwards, the energy consumption of the model based on ECHNL is always lower than the model based on LEACH protocol, and is lower than the model based on RPUCDH from 120s onwards.

TABLE 6 Network node death comparison

Node Statistics / Algorithm Type	Death of the First Node	Death of All Nodes in the Network
LEACH	400	580
ECHNL	420	730
RPUCDH	420	675

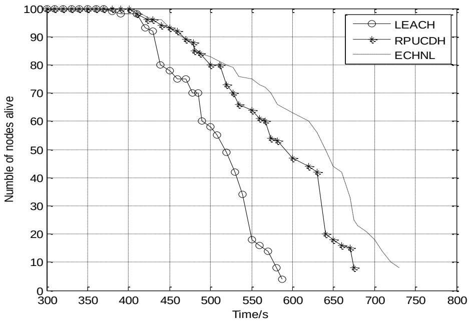

FIGURE 8 Living Node Number Comparison (ECHNL, LEACH and RPUCDH Protocol)

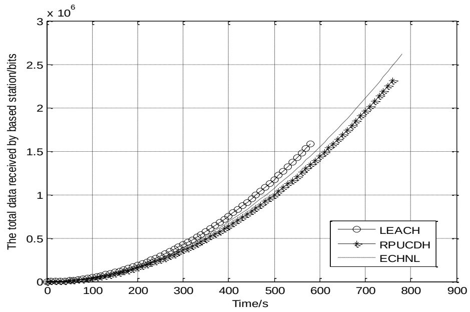

FIGURE 9 The Comparison (ECHNL, LEACH and RPUCDH Protocol) of Total Amount of Data Received by Base Station

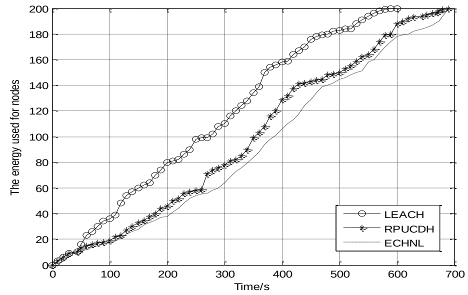

FIGURE 10 Nodes Energy Consumption Comparison (ECHNL, LEACH and RPUCDH Protocol)

Conclusions

In this paper, based on the “1:1 dual-homed fault-tolerant routing technology” and the notion of “hierarchical cluster heads probability”, the cluster head election mechanism in LEACH protocol is modified, and the ECHNL (Equal Cluster Head Distribution based on Network Level) algorithm is proposed solving the problem of imperfect cluster head election mechanism in LEACH protocol, the uneven distribution of cluster heads, and limited fault tolerant mechanism. The simulation shows that the improved algorithm ECHNL optimizes cluster head election mechanism, balance the network nodes energy consumption, and ultimately prolong the network lifetime.

Acknowledgments

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