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Cluster-Head Election Mechanism for Wireless Sensor Networks

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Abstract: The energy consumption is a primary consideration factor in the Wireless Sensor Networks (WSN). To balance the energy consumption of each node and enhance the lifetime of the network, in this paper, a fuzzy logic approach to cluster-head election which is called FLCHE is proposed. This algorithm fully considers the residual energy of the node, the energy consumption rate, and the distribution density of the node. Simulation with Matlab shows, compared to the LEACH, FLCHE balance the energy consumption of the nodes more and prolong the network lifetime. The overall performance is better than LEACH. *Copyright © 2013 IFSA.*

Keywords: Wireless sensor networks, The energy consumption balancing, LEACH, FLCHE.

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1. Introduction

The wireless sensor network integrated the sensor technology, the computer technology and the communication technology for the sudden, temporary occasions, such as battlefield communications, disaster relief and public gatherings. With the development of communication technology, the Wireless Sensor Networks (WSNs) technology also has been widely used in medical monitoring, environmental detecting and intelligent smart home, etc. It consists of a large number of convenient and cheap sensor nodes that have limited energy storage, small memory size and computation capability. Among these three factors, the energy consumption is the most important one because the battery is not changeable if once the sensor nodes are deployed. The energy is also the major consideration in designing the routing of the WSNs. The traditional flat routing protocol is not suitable for applying to WSNs with limited energy because of the extremely unbalanced energy consumption. However, the clustering routing protocol balances the energy consumption more by dynamic replacing cluster heads [1]. It is very proper to WSNs. In clustering routing mechanism, several scholars from Massachusetts Institute of Technology (MIT) proposed a classic clustering algorithm LEACH [2] which is always throughout in the development of clustering mechanism. In LEACH, all sensor nodes evenly elect itself as a cluster head based on the probability model to distribute the energy consumption. However, in some cases, in-efficient cluster heads can be elected. Because LEACH is only depend on probability model, some cluster heads may be very close each other and can be located in the edge of the WSNs. These in-efficient cluster heads could not maximize the energy efficiency [3].

Appropriate cluster-head selection can significantly reduce energy consumption and prolong the lifetime of WSNs. Recently, the related researched have been done on the design of routing algorithm about WSNs using the fuzzy logic. Gupta et al. [3] proposed to use three fuzzy descriptors (residual energy, concentration, and centrality) during the cluster-head selection. The concentration means the number of nodes present in the vicinity, while the centrality indicates a value which classifies the nodes based on how central the node is to the cluster. In every round, each sensor node forwards its clustering information to the base station at which the CHs are centrally selected. However, this mechanism is a centralized approach. Kim et al. [4] proposed a similar approach (namely CHEF: Cluster Head Election mechanism using Fuzzy logic), but in a distributed manner by using two fuzzy descriptors (residual energy and local distance). The local distance is the total distance between the tentative CH and the nodes within predefined constant competition radius. Hence, the base station does not need to collect clustering information from all sensor nodes. Moreover, since selecting the cluster head is not easy in different environments which may have different characteristics, Anno et al. [5] employed different fuzzy descriptors, including the remaining battery power, number of neighbor nodes, distance from cluster centroid, and network traffics, and evaluated their performance. The sensor nodes closer to the base station consume much more energy due to the increased network traffic near the base station. Hence, the sensor nodes closer to the base station quickly run out of battery. Besides the residual energy, Bagci et al. [6] further considered a fuzzy descriptor, distance to the base station, during the cluster head selection. This unequal clustering approach is based on the idea of decreasing the cluster sizes when getting close to the base station.

There are also some different protocols were proposed to solve the energy consumption [7, 8]. But, most of the protocol did not fully consider the remaining energy, the rate of energy consumption and the density of the node [9-12]. To balance the energy consumption of the whole network better, this paper proposes a clustering routing algorithm based on fuzzy logic. So this paper introduces a cluster head election mechanism using fuzzy logic, it is called as FLCHE. It considers the remaining energy, the rate of energy consumption and the density of the node.

The rest of this paper is organized as follows. In section II, we define the base model of WSNs. In section III, LEACH will be briefly discussed. In section IV, the proposed cluster head election mechanism will be introduced. In section V, we evaluate our mechanism compared with LEACH by simulation. Finally, in section VI, we will summarize our paper and discuss about future research.

2. System Model

2.1. System Model

The system model of this paper is described in Fig. 1. Both non-cluster head and cluster head are sensor nodes. Each sensor node sends the source data to its cluster head. The cluster head aggregates the collected data and transmits the aggregated information to the base station. Based on this system model, here are some assumptions for our mechanism:

Each node has a routing function and can be the cluster head node by LEACH algorithm. The cluster head node has relatively strong communication ability, a wide range of communication, mean while nodes in the subnet of the cluster head node within its communication range

The base station is located far from the sensor nodes and is immobile;

All nodes in the network are homogeneous, energy constrained and the same initial energy;

Symmetric propagation channel.

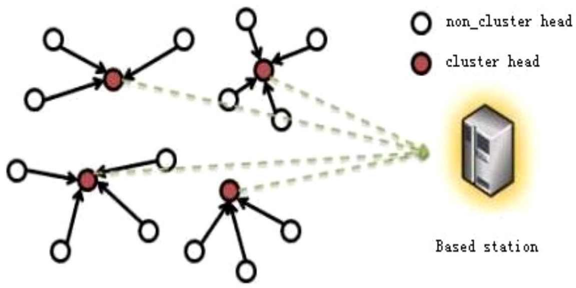

Fig. 1. System model.

2.2. Radio Model

For the realistic, the first order radio model that is shown in [13, 14] will be used as a communication model between sensor nodes. Equation (1) and (2) represents the amount of energy consumption in transmitting a packet with l bits over d distance according to the first order radio model. Eelec is the amount of energy consumption per bit to run the transmitter or receiver circuitry. Efs and Empis the amount of energy per bit dissipated in the RF amplifier according to the distance d_0.which can be obtained from Equation (3).

$$E_{tx} = l \times (E_{elec} + E_{fs} \times d^2),\ \ if\ d \le d_0 \qquad (1)$$

$$E_{tx} = l \times (E_{elec} + E_{mp} \times d^4),\ \ if\ d > d_0 \qquad (2)$$

$$d_0 = \sqrt{E_{fs} / E_{mp}}\ , \qquad (3)$$

The amount of energy consumption in receiving a packet with l bits can be calculated like follow.

$$E_{rx} = l \times E_{elec}, \quad (3)$$

3. Leach

LEACH is a Low-Energy Adaptive Clustering Hierarchy which proposed by Wendi Rabiner Heinzelman. In this protocol, every sensor node has equal probability to be elected as cluster head. Each round, when electing the cluster heads, each node chooses a random number between 0 and 1. If the random number is less than the threshold T(n), the node becomes the cluster-head for the current round. The threshold is set at:

$$T(n) = \frac{p}{1 - p(r \bmod 1/p)}, \quad if\ n \in G, \quad (5)$$

$$T(n) = 0, \qquad other, \quad (6)$$

where p is the cluster-head probability, r is the number of the current round and G is the set of nodes that have not been cluster-heads in the last 1/p rounds. This method ensures all nodes to be cluster head once inner 1/p. It can balance the energy consumption of the whole network and prolong the lifetime of the WSNs.

However, several disadvantages are there for selecting the cluster-head using only the local information in the nodes. Firstly, it does not consider the residual energy of each node so the nodes that have relatively small residual energy can be the cluster heads. Secondly, the cluster head may be located in the place where the node density is very low. In this case, many nodes in that cluster inefficiently consume energy in communicating with the cluster head. Finally, it does not consider the rate of energy consumption.

LEACH-C uses a centralized algorithm and provides another approach to form clusters as well as selecting the cluster-heads using the simulated annealing technique.

4. Clustering Algorithm Based on Fuzzy Logic

To solve the defects of LEACH, we propose the FLCHE which uses fuzzy logic to optimize the selection of the cluster head. Similar to LEACH, FLCHE algorithm re-elects a cluster head every round, but it does not require that each sensor node to act as a cluster head in each 1/p round. The central idea of FLCHE is based on the remaining energy, the rate of energy consumption and the density of the node, through the fuzzy logic controller, to calculate a proper value instead of the random number at LEACH. Then, according the fuzzy results to elect cluster head, balance the energy consumption of WSNs purposefully. After the end of electing cluster, the base station broadcasts information to inform each node whether or not itself is elected as the cluster head. Cluster organizations and data transfer use the same mechanism with LEACH algorithm.

4.1. Fuzzy Logic Controller

Fuzzy logic controller uses fuzzy logic to simulate system that human thinking is difficult to establish the mathematical model. The fuzzy logic mainly lies in the fuzzy controller design. The fuzzy logic controller shows in Fig. 2. It is basic elements consisting of membership functions, rule base and defuzzification unit [15].

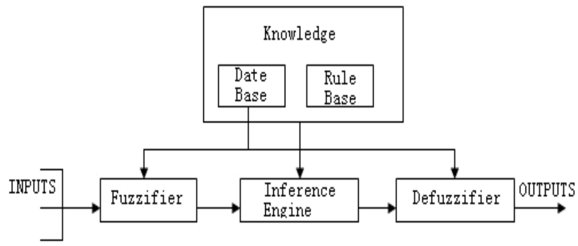

Fig. 2. Fuzzy Logic Controller Model.

In the area of fuzzy logic, it expresses digital data into linguistic variable. Obviously, we can know as membership function of differences of variables as shown in Fig. 3 - Fig. 6. The values of Linguistic variables are words or sentences in a natural language, such as VH, VL, etc.

There are two inference systems for fuzzy logic, there are Mamdani and Sugeno. The algorithm we proposed has used Mamdani Fuzzy Inference system. It has widespread acceptance, and well suited for human inputs. Seeing the name of the fuzzy logic, it naturally does not require precise, noise-free inputs and can be programmed quite safely. As the fuzzy logic controller uses custom rules to govern the target control system, it can be modified easily to improve or drastically alter system performance. The defuzzifier values are processed by the inference engine, which consists of a rule base and various methods for inferring the rules. All the rules in the rule-base are processed in a manner by the fuzzy inference engine.

Any rule that fires contributes to the final fuzzy solution space. The inference rules govern the manner in which the consequent fuzzy sets are copied to the final fuzzy solution space. Example, techniques are MIN-MAX and fuzzy adaptive method. The defuzzifier performs defuzzification on the fuzzy solution space. That is, it finds a single crisp output value from the fuzzy space solution. Common defuzzification techniques are centroid, composite maximum, composite mass, etc. The design process of fuzzy controller will be described in detail below [16].

4.2. Membership Functions

Remaining energy – the remaining energy of the node. We described it as RE.

Neighbors – the number of other node which is still alive within the neighborhood. The neighborhood described as other nodes within the area of 20 X 20 meters, with that node in the center. We described it as NBs.

The rate of energy consumption – The ratio of consumed energy of node in the r +1 round of and that in the r round. We described it as REC.

The fuzzy logic uses the linguistic variables to represent the fuzzy set. The RE are divided into seven levels: very low, low, rather low, medium, rather high, high, very high, which are abbreviated as VL, L, RL, M, RH, H, VH. Very low uses the right trapezoidal membership functions, very high uses the left trapezoidal membership functions and other use the triangular membership function. The NBs are divided into three levels: low, medium, high, which are abbreviated as L, M, RH. Low uses the right trapezoidal membership functions, high uses the left trapezoidal membership functions and medium uses the triangular membership function. The REC is divided into one level: medium, and abbreviate it to M. Medium use the left trapezoidal membership functions. The CH are divided into seven levels: very low, low, rather low, medium, rather high, high, very high, which are abbreviated as VL, L, RL, M, RH, H, VH. All of them use the triangular membership function. They are described in Fig. 3, Fig. 4, Fig. 5, and Fig. 6.

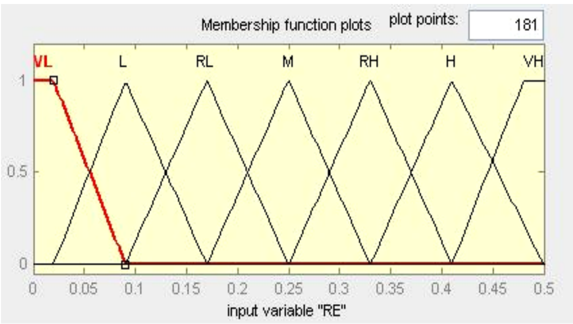

Fig. 3. RE membership function.

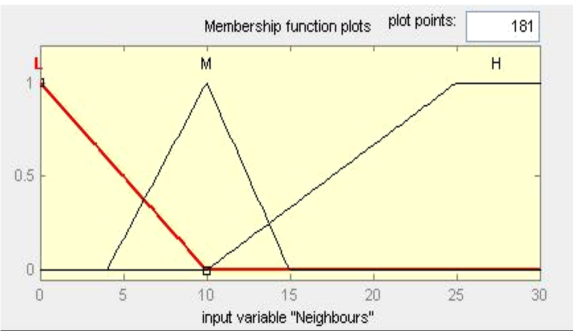

Fig. 4. NBs membership function.

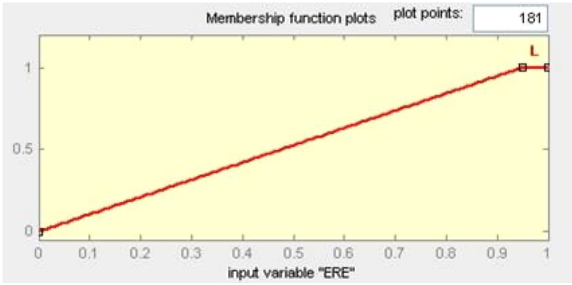

Fig. 5. REC membership function.

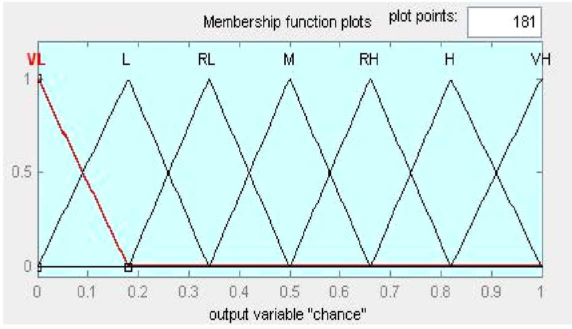

Fig. 6. CH membership function.

4.3. Rule Base

We used 3×7 = 21 rules for the fuzzy rule base. The rule base is shown in Table 1.

Table 1. Rule Base.

Number	RE	NBs	REC	CH
1	VH	H	L	VH
2	VH	M	L	VH
3	VH	L	L	H
4	H	H	L	VH
5	H	M	L	H
6	H	L	L	RH
7	RH	H	L	H
8	RH	M	L	RH
9	RH	L	L	M
10	M	H	L	RH
11	M	M	L	M
12	M	L	L	RL
13	RL	H	L	M
14	RL	M	L	RL
15	RL	L	L	L
16	L	H	L	RL
17	L	M	L	L
18	L	L	L	VL
19	VL	H	L	L
20	VL	M	L	VL
21	VL	L	L	VL

In Table 1, we can see that the more remaining energy node has the larger chance to be a cluster head it has. The more density of node around, the larger chance to be a cluster head it also has. Besides, we also consider the rate of the energy consumption. The higher speed of energy consumption, the lower chance to be a cluster head it has. In summary, FLCHE can choose the optimal cluster head and prolong the network lifetime.

4.4. Defuzzification

Obviously, the output of the fuzzy controller does not work to control the execution unit. So it is necessary to determine a most representative values as the real output to control execution unit. This is defuzzification's duty. We often use the centroid, which can be expressed as:

$$z^* = \int \mu_c(z) z dz / \mu_c(z) dz \qquad (7)$$

4.5. Clustering Algorithm

The clustering algorithm is shown in below. In every round, sensor nodes calculates the chance using fuzzy if-then rule. And advertises an Applying Message with the chance. This message means that the sensor node is an Application for the cluster head with the value of chance.

Once a node advertises an Applying Message, the node waits Applying Messages from other nodes. If the chance of itself is bigger than every chance from other nodes, the sensor node advertises a CH Message which means that the sensor node itself is elected as the cluster head. If a node which is not a cluster head receives the CH message, the node selects the closest cluster head as s cluster head and sends a Cluster Join Message to the closest CH.

Clustering Algorithm

```
Create Fuzzy Inference System
Initialized Network Parameters
Estimate Total cluster leader
Calculate local level parameters
 /* for every round */
Each node computes the chance using Fuzzy if-then rule itself;
Adv Applying Message(m_chance);
m_CH= myself;
 while receiving Applying Messagefrom node N
   if m_chance<N_chance  then
     m_CH = N;
  end if
 end while
  if m_CH == myself  then
      Adv CH Message;
      Wait join Message from nodes
  else
    On receiving CH message
    Selectthe closest CH;
    Send Cluster Join Message to the closest CH;
  end if
```

5. Simulation and Analysis

To test and analyze the algorithm, experimental studies were performed. The simulator was programmed using MATLAB. In more cases, we often use the First Node Dies (FND), the Half Node Die (HND) and the Final Node Die (FND), to evaluate the properties of clustering routing algorithm. But it is meaningless when all nodes died, so we use 85 % Node Die (END) instead of that of final node die. The reference network consists of some nodes randomly distributed over an area of 100 X 100 meters. The base station is located at 50, 200. And other parameters are shown in Table 2.

Table 2. Experiment Parameter of FLCHE.

Parameter	Value
Nodes	dynamic
Energy consumption per bit	50 nJ/bit
Data aggregated energy	50 nJ/bit
Efs	10 pJ/bit/m2
Emp	0.0013 pJ/bit/m4
Control packet	100 bit
Data packet	4000 bit

Table 3 is one result of experiment. Compared with LEACH, FND of FLCHE delays 276 rounds, HND delays 199 rounds and END delays 72 rounds. Fig. 7 shows number of alive nodes for every round in WSNs. In the case of LEACH, the number of alive nodes is decreased after about 670th round. In FLCHE, the number of alive nodes is decreased after about 860th round. The reason of this decrement is that LEACH selected the clusters only depends on the randomly probability of each cluster but FLCHE uses the appropriate method that selected the clusters with considering the residual energy of the node, the energy consumption rate, and the distribution density of the node. So we can see FLCHE is better than LEACH. FLCHE have more effective than LEACH. It not only enhances the whole network stability and reliability, but also prolongs the network lifetime.

Table 3. n=100.

	FND	HNA	END
LEACH	498	669	829
FLCHE	765	868	901

Then, we study the stability phase between the LEACH and FLCHE. Stability phase means the time from the first round to the first node die (FND). From Fig. 8, with the increase of numbers of nodes, the stability phase of LEACH seems almost steadily, even get down. However, FLCHE is contrary. So FLCHE have the better performance.

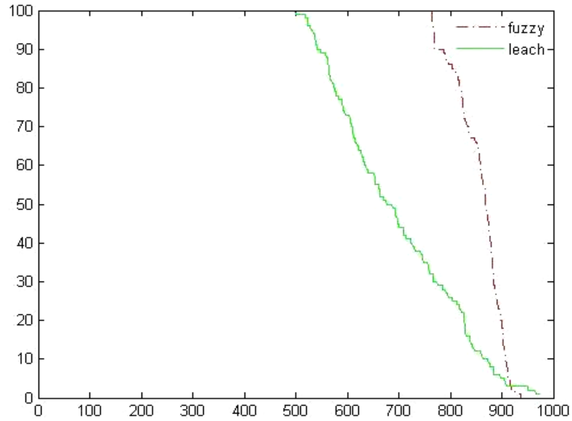

Fig. 7. Number of alive nodes for every round.

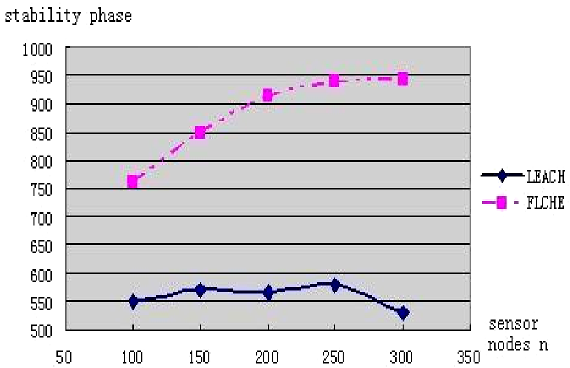

Fig. 8. Stability phase of WSNs.

6. Conclusion

The energy is the major factor in designing the WSNs. We should achieve the energy efficiency. In this paper, we proposed a cluster head election mechanism – FLCHE. This algorithm fully considers the residual energy of the node, the energy consumption rate, and the distribution density of the node. It makes the network optimally more. Simulation with Matlab shows the algorithm we proposed evidently enhance stability and reliability to WSNs, prolong the network lifetime effectively. Although we compared FLCHE with LEACH, on the one hand, there are also many clustering routing algorithms that have to be compared. On the other hand, there are many factors that can affect the network lifetime. A further direction of this study will be to find the optimal fuzzy set and to compare the enhanced version of FLCHE with other clustering algorithms.

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