An Energy Efficient Fuzzy Cluster Head Selection Algorithm for WSNs

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***Abstract*— In wireless sensor networks (WSNs), tiny sensor nodes are randomly deployed with limited amount of energy to transmit massive data, like images and videos. Related information can be obtained when a CMOS camera is connected to a sensor node to capture images. Thus how to improve energy efficiency and prolong network lifetime is a challenging research issue. Recently, introducing mobile sinks to WSNs has been proved to be an efficient way to extend the network lifetime. However, many existing algorithms select the Cluster Head (CH) randomly based on a probabilistic threshold value or only consider the remaining energy parameter. In this work, we propose a fuzzy cluster head selection algorithm which takes three parameters into consideration, namely node's remaining energy, centrality of the clusters as well as the distance between node and the mobile sink. Simulation results show that our proposed algorithm is superior to other popular algorithms in terms of network lifetime and energy consumption.**

***Keywords*—Wireless sensor networks (WSNs); image sensor; cluster head; fuzzy logical; energy consumption.**

I. INTRODUCTION

Over the past fewer years, wireless sensor networks have been proved a promising technology in many applications. In particular, wireless image sensor networks, a usage of WSN where sensor nodes are equipped with tiny cameras to capture images, has been a good choice in applications like intrusion detection, weather monitoring, and disaster management etc. Based on WSNs system, we can detect particular environment parameters such as pressure, humidity, temperature, and gas in dangerous areas. Typically, wireless sensor networks consist of both base station and sensor nodes, the former unit is used to collect data information while the second one is used for environment monitoring. Besides, sensor nodes are equipped with limited battery power in most applications, and battery recharge seems impossible in most cases. There is no doubt energy efficiency has become the key point to extend the network lifetime.

Although compression of image or video can be done in WSNs, a compressed file is still quit large like several tens of kB. There have been lots of papers studying on image or multimedia sensors such as [1] and [2]. Finding appropriate methods to balance the network energy consumption is the main challenge. Among those existing works, cluster-based protocol is one of those most efficient ideas like [3]. Clustering algorithms divide the sensor nodes into groups named cluster, each cluster consists of Cluster Head (CH) and Cluster Members (CM). Data are collected by CM, and aggregated at the CH. Finally, each CH uploads their receiving information to the base station.

Low Energy Adaptive Clustering Hierarchy (LEACH) [4] is the earliest routing protocol using a probabilistic manner to elect CHs. In each rotation, clusters heads are selected to balance the network load. In spite of LEACH protocol's efficiency, its pitfalls should be noticed. It may happen in each rotation that no CH is selected. Besides, its cluster head election does not take the sensor nodes' distribution and nodes' remaining energy into consideration. Another efficient protocol is LEACH-C [5], which takes a centralized method to select CHs. Compared to LEACH protocol, it can select better number of CHs and distributes the cluster heads evenly among the clusters. Energy Aware Fuzzy Unequal Clustering Algorithm (EAUCF) [12] employ fuzzy logical-based method to select CHs. Its fuzzy system considers two parameters as inputs: remaining energy and distance to base station. The competition radius calculated to tentative cluster heads is its output. However, it does not consider sensor nodes' degree which may eventually select cluster head with fewer and distant neighbors.

In this work, we propose a new fuzzy CH selection method by considering three parameters, namely the residual energy of nodes, the centrality of each cluster and the distance of node to the mobile sink. Thus the selected CH has relatively higher remaining energy, being closer to the center of clusters and smaller communication distance to the mobile sink. Consequently, the network energy consumption can be reduced, thus increase the network lifetime. Details of those protocols will be discussed in the following section.

The rest of the paper is organized as follows. In section Ⅱ, related work is presented. Section Ⅲ shows system model and details the Fuzzy Cluster Head Selection Algorithm. Section Ⅳ shows the simulation results. Finally, we conclude this paper with future works in section Ⅴ.

II. RELATED WORK

In this part, some famous clustering algorithms proposed for WSNs are presented. Clusters heads are selected efficiently to gathering data from sensor nodes, and transmit the aggregated data to base station directly or in directly. Although various clustering algorithm have been developed for wireless sensor networks, we pay more attention to those methods that are related to our work, here very few of them are briefly described.

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LEACH [4] is a distributed algorithm which based on a probabilistic threshold value to elect cluster heads. It includes two phases, first is set up phase, during which each node chooses a random number between 0 and 1, if this number is less than the threshold value T(n), then the node becomes CH for the current round, else it may get its chance to be CH in the next round. The second phase is steady state phase, data are gathered and transmitted through cluster head to base station. T(n) is defined in equation 1.

$$T(n) = \begin{cases} \frac{p}{1-p*(r \ mod \ (1/p))}, & if \ n \in G \\ 0, & otherwise \end{cases} \quad (1)$$

G is a set of nodes which have never been cluster head in the last 1/p rounds. p is the probability of the nodes to be cluster head, and r is the round which already ended.

Although this protocol distributes the load equally on each cluster, we should notice its drawbacks. LEACH uses a probabilistic model to elect cluster head, it may happen that two cluster heads are selected closed to each other. Besides, LEACH protocol does not consider the nodes' remaining energy into consideration when elects a cluster head, which means the selected CH may have lower energy to transmit data. what's more, if the cluster head is elected near to the boundary of the sensor area, other nodes will dissipate much more energy to transmit data to CH, thus could accelerate the network energy consumption.

In CHEF [5], two parameters are considered to elect cluster heads. These are local distance of the sensor nodes and its remaining energy. The local distance is the sum of distance from all one-hop neighbors to a node. At the beginning of each round, candidate cluster heads are selected using the probability method as well as LEACH protocol. Then its fuzzy logical system takes two parameters as inputs, which are the nodes' remaining energy and local distance of each node. And the output variable namely the priority opportunity of CH is calculated. This protocol based on fuzzy method elects the node to be cluster head with high energy and locally optimal node. However, for CHEF, its fuzzy variable local distance is not always suitable for all kinds of network. If the network size is 200 x 200m, its .

In [6], researchers have proposed a new algorithm based on LEACH. It calculates the center point between the BS and the sensor node. Then those sensor nodes choose the closest cluster head to the center point to form clusters. Reference [7] pay more attention on selecting cluster head to make the network energy efficiency. It considers the node's remaining energy when selecting CH, and gives simulation results when the base station is located in or out the network area. An improvement over LEACH [14] consider three variables, energy of sensor node, distance between node and base station, distance between cluster head and base station, to redefine the threshold. Simulation results shows that in this way, it can balance the node energy consumption, also the network lifetime can be extended. Using fuzzy logic method on selecting proper cluster heads also attracts many researchers' attention. In [9]-[12] different ideas based fuzzy logic methods are proposed to select the efficient cluster head, so that the network lifetime can be prolonged.

Fuzzy based master cluster head election leach protocol (F-MCHEL) [11] is also a clustering algorithm that based on fuzzy logic method for wireless sensor networks. Its input variables include energy and proximity of distance. By taking these two parameters into consideration, it selects the nodes with maximum residual energy among the cluster heads, which named Master Cluster Heads(MCH), and sends the collected data to BS. Generally speaking, F-MCHEL is an improvement of CHEF. Although it provides more network stability compared to LEACH, it fuzzy input variables is not suitable for different sizes of WSNs.

While in [12], a fuzzy unequal clustering algorithm (EAUCF) considering the residual energy and the distance to the base station. When starting the round, tentative cluster heads are elected based on random number generation like CHEF algorithm. Its fuzzy method considers two input parameters: node's remaining energy and distance to the base station. The output variable is the competition radius which calculated to each tentative CH node. These tentative cluster head then broadcast its residual energy and check if there exists any other tentative CH node within its competition radius. However, during the cluster head election, an important parameter namely node degree is not considered which may result in the selected CH has fewer and distant neighbors, thus the intra cluster communication cost could be higher and the network lifetime is reduced.

III. Proposed Protocol

A.Energy Model

In our work, energy consumption model is just as the traditional LEACH. The transmitting energy consumption for sensor node is given in equation 2, and the receiving energy consumption is given in equation 3.

$$E_{Tx}(k,d) = \begin{cases} E_{elec} * k + \varepsilon_{fs} * k * d^2, if \ d < d_0 \\ E_{elec} * k + \varepsilon_{mp} * k * d^4, \ if \ d \geq d_0 \end{cases} \quad (2)$$

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

$$d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}} \quad (4)$$

For sensor node, E_{elec} represents the energy consumption while transmitting or receiving per bit information. Here *k* is the number of bits, $_{fs}$ is the transmit amplifier energy consumption in free space channel model, while $_{mp}$ is used in multipath fading channel model. Besides, the distance for transmitter to receiver is *d*.

B.System Model

Our proposed method mainly follows the principle of the well-known LEACH algorithm. Data is collected by CH, and aggregated inside each cluster. Then it is transmitted to the mobile sink. The system model is illustrated in Fig. 1.

The fuzzy cluster head selection algorithm is based on the Mamdani method. We take three input fuzzy variables, nodes' residual energy, centrality of cluster and distance between BS and node. The only output fuzzy variable is called priority opportunity. The fuzzy CH selection model is shown in Fig. 2.

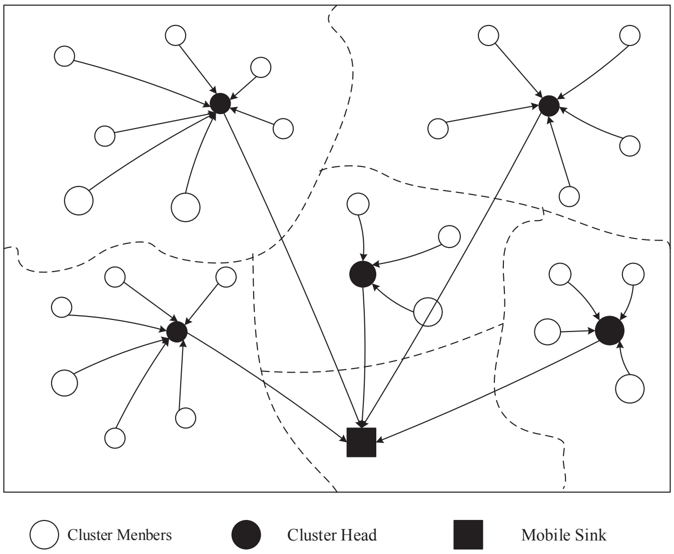

Fig 1. System model

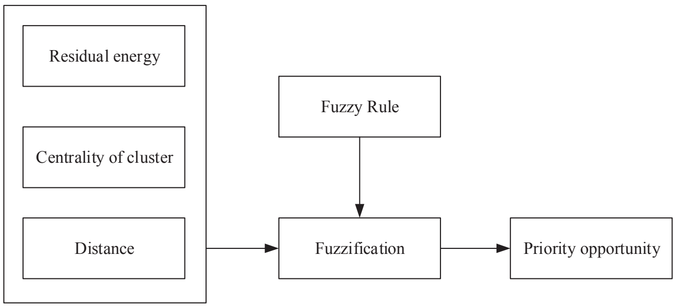

Fig 2. The fuzzy CH selection model

C.Fuzzy Cluster Head Selection Algorithm

In this section, we detail our proposed algorithm for selecting cluster head based on fuzzy logic method. As a matter of fact, we consider three parameters, remaining energy of sensor nodes, centrality of cluster and distance of node to mobile sink, to calculate the priority opportunity of becoming a cluster head. Actually, our algorithm is based on fuzzy logic method. Since we have three parameters to produce the cluster head, we simply classify three fuzzy input variables and one fuzzy output variable.

The first fuzzy input variable is residual energy, second input is centrality and the last input is the distance between node and mobile sink. Their fuzzy input linguistic variables are shown in Table I. The only fuzzy output variable is named priority opportunity. Its linguistic variables are: rather low, lower, low, medium, high, higher, rather high. The fuzzy rules and priority opportunity are depicted in Table II.

Table I Input Variables

Residual Energy	Centrality	Distance
Little	Near	Close
Medium	Medium	Adequate
Sufficient	Remote	Far

Table II Fuzzy Rules

Residual Energy	Centrality	Distance	Priority Opportunity
Little	Remote	Far	Rather low
Little	Remote	Adequate	Lower
Little	Remote	Close	Low
Little	Medium	Far	Lower
Little	Medium	Adequate	Low
Little	Medium	Close	Medium
Little	Near	Far	Low
Little	Near	Adequate	Medium
Little	Near	Close	High
Medium	Remote	Far	Lower
Medium	Remote	Adequate	Low
Medium	Remote	Close	Medium
Medium	Medium	Far	Low
Medium	Medium	Adequate	Medium
Medium	Medium	Close	High
Medium	Near	Far	Medium
Medium	Near	Adequate	High
Medium	Near	Close	Higher
Sufficient	Remote	Far	Low
Sufficient	Remote	Adequate	Medium
Sufficient	Remote	Close	High
Sufficient	Medium	Far	Medium
Sufficient	Medium	Adequate	High
Sufficient	Medium	Close	Higher
Sufficient	Near	Far	High
Sufficient	Near	Adequate	Higher
Sufficient	Near	Close	Rather high

IV. SIMULATION RESULTS AND ANALYSIS

In this part, our fuzzy logical method is simulated via Matlab software and the using parameters are listed in table III. Besides, simulation of related algorithms such as LEACH, CHEF as well as EAUCF is also performed in the same conditions. Then we could make a comparison to evaluate our proposed algorithm's efficiency.

As described in Table III, 100 sensor nodes are randomly deployed in $100x100m^2$ field. At the beginning, each node is normal node and has the same initial energy. During the simulation process, we mainly focused on the number of alive nodes and total residual energy after each round. Finally they are depicted respectively in figures 3 and 4.

Fig.3 shows the alive node's number in each round. Compared to LEACH, CHEF and EAUCF, the first dead node in our algorithm appears lastly. From this figure, we know that our method extends the network lifetime longer than other algorithms.

Fig.4 shows the energy decreasing per round. LEACH consumed much more energy and its network dead earliest since it elects the CH relay on a probabilistic threshold value. When considering the remaining energy of sensor node, centrality and distance for node to mobile sink, it is visible our proposed algorithm performed better in extending the network lifetime and balance the energy consumption.

Table III Parameters list

Network size	100 x 100m^2
Number of sensor nodes	100
Number of rounds	1500
Initial energy	1 J
Expected percentage of CH	10%
E_{elec}	50 nJ/bit
$_{fs}$	10 pJ/bit/m^2
$_{mp}$	0.0013 pJ/bit/m^4

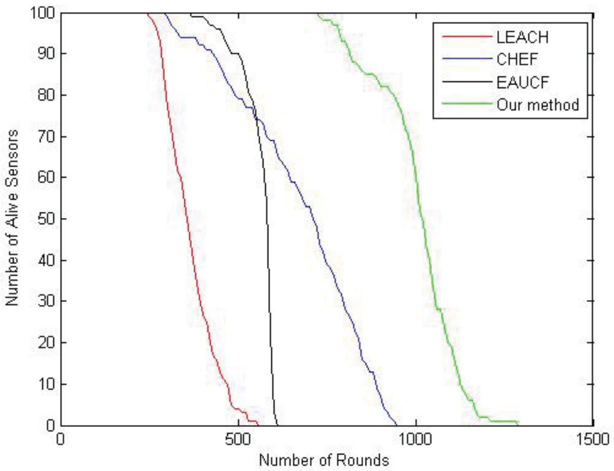

Fig. 3. The number of alive nodes each round

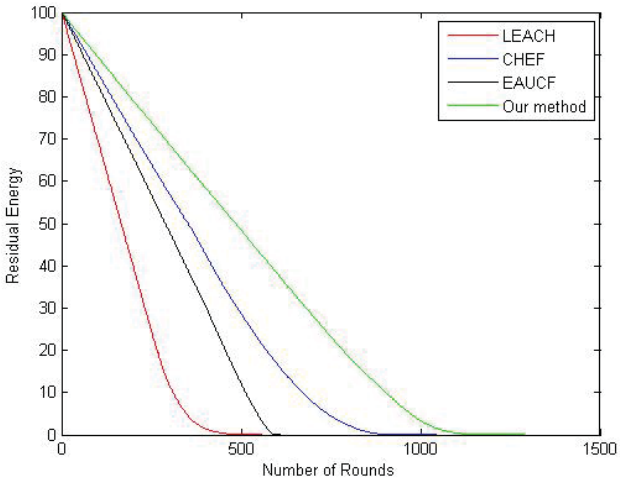

Fig.4. Total residual energy each round

V. CONCLUSION

In wireless image sensor networks, multimedia information is compressed in image or sensors, this process consumes more energy. Thus finding appropriate methods becomes the key point to increase networks' efficiency. Although LEACH protocol performed well in this aspect, improvements still exist to make this protocol perform better. In this paper, we take three important parameters into consideration, namely residual energy, centrality of cluster and distance between node and mobile sink. Our fuzzy method in selecting CH can balance network energy consumption well. For image networks' applications, it would be more useful. Simulation results have also proved that our approach performs much better than LEACH, CHEF and EAUCF in terms of energy consumption and network lifetime extending. The future work of this paper is to improve the performance of Wireless sensor network in terms of scalability and robustness.

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