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An Unequal Clustering Algorithm Based on Spacing and Residual Energy for Wireless Sensor Networks

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Abstract

The energy of a node in Wireless Sensor Networks (WSNs) is limited, so WSNs need energy saving algorithms. We propose an unequal clustering algorithm based on spacing and RE for WSNs (USRE). URSE prolong the lifetime from the two aspects. One is to select some appropriate nodes to become cluster heads (CHs), the other is to ensure the proper distribution of CHs. To reduce the energy consumption, CHs are selected in the nodes closed to the around nodes (ANs). Besides the spacing among the ANs, the residual energy (RE) and number of ANs are the condition for CHs selection. A node with higher RE and more ANs is more likely to be a CH. USRE calculates the minimum distance between two CHs. If a node is close to a selected CH, it won't be a CH. USRE is compared with other algorithms. The results show that the performance of USRE is better than other algorithms such as network lifetime.

Keywords: Wireless sensor networks; Energy efficiency; Clustering; Network lifetime

1. Introduction

Sensor nodes can monitor, perceive and gather information about the circumstance, and transmit the information to base station (BS). WSNs are made up of a number of such nodes in a self-organizing way, integrating a variety of technologies, such as sensors, embedded computing, distributed information processing, and modern networks and communications, so that WSNs have the ability to perceive, compute, and communicate [1]. WSN is a technology of

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information acquisition, processing and transmission. With the rapid growth of the demand for digital information, this convenient information acquisition technology has received more and more attention for its low cost, low power consumption and self-organization [2].

The network has a short survival time due to energy constraints, because each sensor node only relies on a battery that can't be replaced. The limited energy should be used for data acquisition, information processing, data fusion, communication between nodes and communication between nodes and BS. For some WSNs, we can use the charging technology to supplement the energy or replace the batteries, which, of course, can be easily affected by the environment and the cost is high. When sensor nodes are deployed in a remote or dangerous position, they are often unable to be recharged. This will lead to a short network life. WSNs need relevant rules for information processing and communication, that is, to design energy-efficient and effective protocols and structures to use network energy rationally to save energy [3].

We propose a new algorithm. Sect.2 to 5 are as follows: Sect.2 summed up the existing clustering algorithms. Sect.3 introduced the new algorithm in detail. Sect.4 compared the performance of the new algorithm and several related algorithms by simulation. Finally, the conclusion is given in Sect.5.

2. Related Research

Clustering can significantly reduce network energy consumption. A network is divided into multiple clusters. Each cluster is usually composed of multiple nodes and one of the nodes is selected to be a CH. The CHs gather, process and fuse the data collected by the cluster nodes, and sending the data to BS by multi-hop or single-hop. Clustering reduces the average distance of direct communication and the amount of communication data to save energy. The nodes in the cluster routing protocol are usually rotated to act as CHs.

LEACH is an early classical clustering algorithm. The operation is divided into rounds. A round has two stages: cluster stage and steady stage. In cluster stage, CHs are randomly selected from the nodes those have not been CHs in recent rounds. In steady stage, non CHs nodes collect information and send data to CHs. CHs send the data to BS after fusion.

Although the algorithm is simple and effective, the clustering is almost random, so that its network lifetime is not long [4]. When clustering, to reduce randomness we can consider some factors such as RE, the distribution of ANs, the distance from a node to BS, the distance from a node to the selected CHs and so on [5]. Multi-hop network can reduce the average distance of one wireless communication to reduce energy consumption.

A CH consumes more energy than a non CH node, so CHs should be select in the nodes with large RE to balance the load among nodes. Ref. 6 divides all nodes into general nodes and advanced nodes according to the initial energy. CHs are select only in the advanced nodes in the first phase and every node can become a CH in the second phase when the advanced nodes consume some energy.

Ref.7 calculates the probability of a node becoming a CH based on RE. A node with large RE is more likely to become CHs. The distance to the ANs is another annotation of selecting CH. The algorithm prefers to select the nodes with small average distance to be CHs.

i is a node and $d(i, \text{BS})$ is the distance between i and BS. Ref.8 proposes some new clustering algorithms based on RE, the number of ANs, and $d(i, \text{BS})$. Because the CHs closer to BS will consume more energy for data forwarding, these algorithms select more CHs near the BS.

ACCA is based upon competition and the distances among the CHs [9]. Usually, the uniform distribution of CHs can reduces the energy consumption of inter-cluster communication. ACCA is an unequal multiple hops algorithm and specifies that the distance between two CH can't be too small.

CAST-WSN divides the whole network into some grids of different sizes and selects a CH in each grid by the RE, the nodes distribution in a grid and the size of the grid [10]. Because a node near the grid center is more likely to become a CH, the distance between two CHs is appropriate.

These algorithms all have their own disadvantages.

3. Propose Algorithm

3.1. The net model

The WSNs adopted in this paper is as follow: N nodes are randomly installed in a square area whose side length is S. All nodes are immovable and the energy of a node is limited. A node can change the transmission power. A receiver can perceive the received signal intensity to estimate the distance to the sender.

We use Eq.1 to calculate the energy consumption [10].

$$E_{Tx}(l,d) = \begin{cases} l \times E_{elec} + l \times \varepsilon_{fs} d^2, d < d_{corssover} \\ l \times E_{elec} + l \times \varepsilon_{mp} d^4, d \geq d_{corssover} \end{cases}$$
$$E_{Rx}(l) = l \times E_{elec} \tag{1}$$

Where, l is the data whose unit is bit, d is communication distance. E_{elec} , ε_{fs}, ε_{mp} and $d_{corssover}$ are constants.

3.2. CHs selection

At the beginning, each node sends its initial energy at a specific signal intensity. A node receives these messages and calculates the distance to each other node. BS also receives these messages, then calculates and broadcasts E_{ave} . E_{ave} is the average RE of living nodes.

CHs are selected by competition radius (R_c) and reject radius (R_j).

The formula of R_c is shown as Eq. 2

$$R_c = \left(1 - 0.3 \times \frac{d_{max} - d(i, BS)}{d_{max} - d_{min}}\right) \times R_{max} \tag{2}$$

In Eq. 2, R_{max} is the maximum R_c which is predefined. d_{max} and d_{min} are the maximum and minimum of $d(i, BS)$.

R_c reflects the influence of $d(i, BS)$ on clustering. When $d(i, BS)$ is small, the inter-cluster communication load is heavy. We reduce the cluster size to reduce the energy consumption of intra-cluster communication, and keep the energy consumption of each CH similar.

The formula of R_c is Eq. 3.

$$R_j = \alpha \times \beta \times R_c \tag{3}$$

In Eq.3, α and β are variables. α is used to reflect the influence of RE. A node with larger RE is smaller in α. E_i is the RE of node i.

$$\alpha = \begin{cases} \mathrm{MAX}\left[\frac{1}{2}, \left(1 + \frac{E_{ave} - E_i}{E_{ave}}\right)\right], E_i \geq E_{ave} \\ \mathrm{MIN}\left[\frac{3}{2}, \left(1 + \frac{E_{ave} - E_i}{E_{ave}}\right)\right], E_i < E_{ave} \end{cases} \tag{4}$$

β reflects the influence of the number of ANs. A node with more ANs is smaller in β.

$$\beta = \begin{cases} \mathrm{MAX}\left[\frac{1}{2}, \left(1 + \frac{N_{ave} - N_i}{N_{ave}}\right)\right], N_i \geq N_{ave} \\ \mathrm{MIN}\left[\frac{3}{2}, \left(1 + \frac{N_{ave} - N_i}{N_{ave}}\right)\right], N_i < N_{ave} \end{cases} \tag{5}$$

N_{ave} is the average number of nodes in the circle whose radius is R_c that is calculated as Eq.6. N_i is the number of nodes in the circle whose center is i, and radius is R_c and $d(i, \mathrm{RNs})$ is the average distance from i to these nodes.

$$N_{ave} = \frac{\pi \times N \times R_c^2}{S^2} \tag{6}$$

t_i is used to reflect the influence of $d(i, \mathrm{RNs})$. A node with less $d(i, \mathrm{RNs})$ is smaller in t_i.

$$t_i = \frac{d(i, \mathrm{RNs})}{R_c} \times t_0 \tag{7}$$

t_0 is a time constant. The node that has the chance to be a CH is named CH candidate (CHC). At the beginning of the CHs selection, each node is CHC and begins to wait for t_i. When waiting, a node keeps on receiving messages. If node i receives a cluster-built message from node q, it calculates the distance to q according to Eq.1. If the distance is less than the sum of q' R_c and i' R_j, i will become non-CHC. After waiting, if i is still a CHC, it becomes a CH and broadcast a cluster-built message with the R_c of i. Obviously, the smaller the R_j, the greater the possibility that nodes will become CH.

k is the optimum number of CHs. The formula of k is given in Ref.10. If k CHs have been select or the waiting time is over t_0, the CHs selection is over. A non-CH node selects the closest CH to join its cluster.

4. Simulation Results

USRE is compare with LEACH, ACCA and CAST-WSN by simulation in NS2. The network is square whose length is 400m and has 300 nodes. BS is at the center. Fig.1 shows the distribution of the nodes.

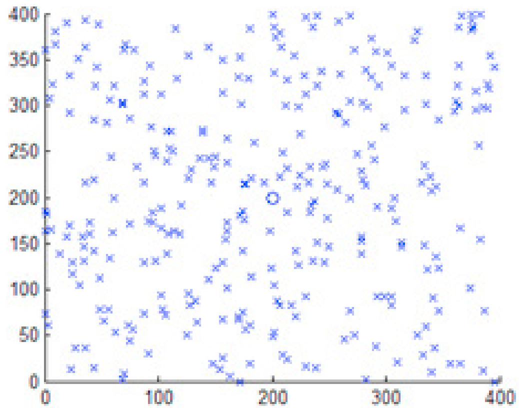

Figure. 1 Distribution of the nodes

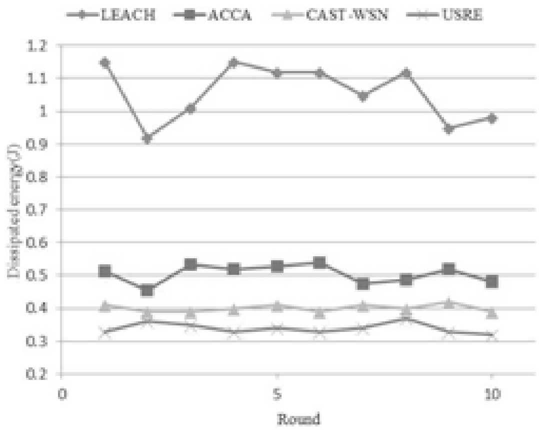

Figure.2 Energy consumption

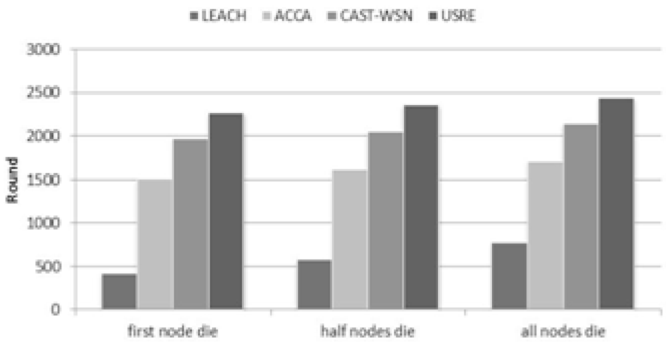

Figure.3 Network lifetime

Fig.2 shows the energy consumption of the whole network for several rounds. The energy consumption of LEACH and the fluctuation of the curve is larger. These show that LEACH has large randomness in the distribution and quantity of CHs, so it can't cluster the nodes well. The minimum distance between two CHs is fixed by ACCA and CAST-WSN, so the CHs won't be too dense. Because the distribution of CHs is more reasonable, the two algorithms have less energy consumption and the curves are smoother. Because the minimum distance between two CHs is fixed, there are not more CHs in the nodes dense area and the loads of the CHs may be very different. USRE adjusts the minimum distance according to the energy and distance, so the energy consumption is minimum.

Fig.3 shows the network lifetime. The lifetime of LEACH is the shortest because of the high energy consumption. The other three algorithms have longer lifetime and URSE has the longest lifetime.

5. Conclusion

A clustering algorithm is proposed. A node that is in the node intensive area and has high RE is likely to be a CH and all nodes are divided into clusters of different size. URSE calculates Rc by the distance to BS and Rj by the number of ANs and RE. New CH is selected according to the Rj of a CHC and the Rc of a selected CH. URSE can prolong the network lifetime by selecting appropriate CHs. We think that the algorithm is suitable for the network with large size, many nodes which are uneven distributed and have different initial energy. Further work may be carried out on the selection of CHs by the location of nodes and so on.

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