Efficient Cluster Head Selection for Multimode Sensors in Wireless Sensor Network

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Abstract. It needs simple and effective network organization to improve the network lifetime in building practical wireless sensor networks (WSNs). As we know, clustering is a classical network model and has been widely used in WSNs, where cluster head (CH) is a manager to control its members and collect sensed data from them. However, in the most of the existing work, the number of cluster heads is stabilized so that the distribution of cluster heads is not reasonable. In addition, they did not consider the dynamic cooperative aware storage and transmission of the sensed data. Therefore, we propose an efficient cluster head selected approach for multimode sensors. First, we select the optimal number of cluster heads based on the approximate distance from the nodes to the sink and the network side length. Second, the nodes that are deployed in the range of cluster head competition radius broadcast their ID, residual energy, location information and distance to the sink node. In the proposed approach, each node competes cluster head according to the number of adjacent nodes and the distance to the sink. Simulation and data analysis show that the proposed approach can efficiently store data and significantly improve the network lifetime.

Keywords: Energy efficiency · Cluster head selection · Target tracking · WSN

1 Introduction

Wireless sensor networks (WSNs) have emerged as an attractive technology that can gather information by the collective effort of numerous sensor nodes [1]. Nowadays this field has attracted the significant attention of many researchers [2–4]. Since sensor nodes always deployed in an unattended environment and it is very difficult to replace their battery after deployed. As a result, energy efficiency is the most critical issues in WSN. It needs simple and effective network organization to improve the network lifetime in building practical wireless sensor networks (WSNs). As we know, clustering is a classical network model and has been widely used in WSNs, where cluster head (CH) is a manager to control its members and collect sensed data from them.

LEACH [5] is one of famous clustering protocols, in which CH is elected randomly and periodically. Cluster can keep only a portion of nodes CHs (cluster heads) active due to high node density in WSN. Except for achieving energy efficiency, clustering is

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also effective to solve the capacity and scalability problems so as to reduce channel contention and packet collisions, resulting in better network throughput under high load [6, 7]. However, in the most of the existing work, The number of cluster heads is stabilized so that the distribution of cluster heads is not reasonable. And they did not consider the dynamic cooperative aware storage and transmission of the sensed data. In the existing works, although CH is in active state, it can not detect the target on the edge of the cluster since CH always is located at the centre of the cluster. This way causes unnecessary energy consumption and much lower energy efficiency. Thus, it is important to consider the characters of application scenario to optimize the CH selection.

It is assumed that a static WSN and the network has one sink and some randomly distributed sensor nodes $\{Ni\}_{i=1}^{P}$ in an two dimensions field. There is an infinite power supply in the sink, which gathers the sensed data. The nodes are distributed mutually independent random variables and obey a Poisson distribution. The nodes are aware of their locations by GPS and other position algorithm. Let $X_i(x_i, y_i)$, $1 \leq i \leq P$ be the location of node Ni. The network is organized as clusters, as Fig. 1 shows.

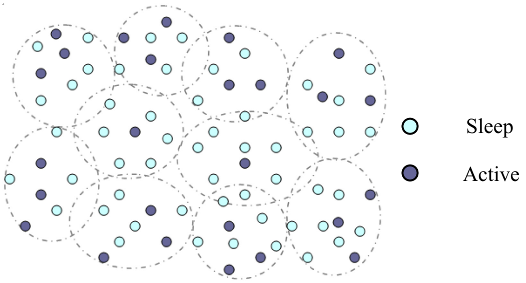

Fig. 1. Illustration of sleep intervals in the different cluster scheme

To solve these problems, we propose an efficient cluster head selected approach for multimode sensors. In the proposed approach, we dynamically choose nodes to play the roles of CHs. First, we select the optimal number of cluster heads based on the approximate distance from the nodes to the sink and the network side length. Second, the nodes that are deployed in the range of cluster head competition radius broadcast their ID, residual energy, location information and distance to the sink node. In the process of cluster head election, a comprehensive evaluation method is used. First, we should determine the weights for each factor. Then, the selected factors of cluster heads are obtained by weighted average with the weight values. In the proposed approach, each node competes cluster head according to the number of adjacent nodes and the distance to the sink. Using the way, the network can keep an optimal number of cluster head and active sensor nodes. Furthermore, in order to balance the energy consumption, an adaptive CH re-selection scheme is proposed to allow each node to take the role of CH different times according to its location and residual energy. As a result, it reduces the energy consumption of data transmitting so as to prolong the network lifetime.

2 Related Works

For cluster-based WSNs, a typical and classical approach is LEACH [5], in which the network is divided into a few clusters and only CHs send the aggregated data to the remote sink directly. The role of the cluster head randomly rotates among the nodes to increase the lifetime of the network. In [8], the authors formulate an optimization problem to maintain an acceptable system blocking probability. For every multicast group to be served, a dynamic cluster of cells is selected based on the minimization of a function that takes into account the traffic in every cell through some weights and the average SINR achieved by the group users. Hybrid Energy Efficient Distributed Clustering (HEED) [9] is a protocol that uses energy and communication cost to elect the cluster head. In [10], the authors proposed a method to decide the final probability of being a cluster head by both the equilibrium probability in a game and a node residual energy-dependent exponential function. In the process of computing the equilibrium probability, new payoff definitions related to energy consumption are adopted.

In [11], the authors propose a novel Raining Energy Cluster Head Selection (RECHS) protocol which is based on a simple Statistical Discrimination (SD) metric which detects collided packets before decoding as well as the Multi-Dimensional Slotted ALOHA (MDSA) MAC protocol which organizes the access to the communication channel. In [12], the tracking strategy is mainly divided into two stages: the cluster head establishes a “neighbor node set” within its communication range, and selects the neighbor node in the “neighbor node set” according to the distance between the node and the target to construct the “intra-cluster member set” to perform the target on the target. Tracking.

Hu et al. [13] focused on the problem of energy saving in moving target tracking scenario in WSN in order to transfer the sleep scheduling of nodes into the selection of the subset. The proposed algorithm uses the energy balance criterion to select a subset of cluster heads and sleep nodes to extend the lifetime of the WSN. However, the strategy only focuses on the “single target tracking” scenario and uses the tracking accuracy as the constraint, which optimization scope is small. At the same time, the limitations of the single life criterion (first node death) [14]. LokMan et al. In this paper, the authors proposed a task aware strategy combined power adaptive and sleep control methods. This strategy enables nodes to work efficiently in different domains and tasks. However, the protocol only verifies the effect in small-scale network, for medium-sized network the effect was not verified.

The above research from the balance of energy consumption, sleep scheduling, topology adjustment and so on. In order to improve the lifetime of WSN, there are still some shortcomings. In some sudden cases, performance and energy saving should be considered and flexible adjustment should be carried out. The above limitations can be summarized as follows: first, the adaptability of life criterion is not enough; second, it has insufficient activity and is not suitable for different application scenarios, such as unable to adjust and control the reliability and life index.

3 Efficient Cluster Head Selection Approach

3.1 Selection of the Optimal Number of Cluster Heads in the Network

In the network deployment phase, sink nodes broadcasts a signal to the monitoring area using a certain power. After the sensor nodes in the network receiving the signal, they calculate the approximate distance d_{sn} (sn is the node identified number) to the sink according to the strength of the received signal. After that, the network area side length l, the number of network nodes Q and the maximum (minimum) distance between the sensor node and sink node are aware. According to the reference [12], the optimal number of the cluster head p of a network is given as follow.

$$p = \sqrt{Q/2\pi} * l/d_{sn} * \sqrt{e/e_a} \tag{1}$$

Where e and e_a are the energy consumption of transmitting 1 bit data per unit distance in the free space mode and multi-channel attenuation mode respectively, the optimal number of cluster heads can be calculated by above formula. Then, the average area of one cluster H_c is approximately the ratio of the total area to the cluster head number.

$$H_c = \pi l/\sqrt{\pi p} = l^2/p \tag{2}$$

As a result, the nodes that are deployed in the area with radius $l/\sqrt{\pi p}$ campaign for cluster head.

After that, the nodes that are deployed in the range of cluster head competition radius broadcast their ID, residual energy, location information and distance to the sink node. All the neighbor nodes within the competition radius will receive this information and establish a neighborhood table. The node calculates the distance to all neighbor nodes and the mean distance.

3.2 Selection of Cluster Heads in the Network

In the process of cluster head election, a comprehensive evaluation method is used. First, we should determine the weights for each factor. Then, the selected factors of cluster heads are obtained by weighted average with the weight values. First, the weights for each factor are calculated as follows.

Through the analysis, we should select the nodes that have more residual energy and shorter distance between them and sink as cluster heads. In this paper, the following method is used to calculate weights for each node. The values of the weights are from 0 to 1. The weight of the residual energy is calculated as follow.

$$E_w(sn) = E_r(sn)/E_i(sn) \tag{3}$$

Where $E_r(sn)$ is the residual energy of the node sn, is the initial energy of the node sn. The weight of the distance is calculated as follow.

$$S_w(sn) = \frac{1/d_{sn} - \min 1/d_{sn}}{\max 1/d_{sn} - \min 1/d_{sn}} \tag{4}$$

Where $\max 1/d_{sn}$ and $\min 1/d_{sn}$ are the maximum and minimum value of the reciprocals of the distance from node *sn* to the sink. The weight of the average distance to neighbor nodes is calculated as follow.

$$S_w(sn{-}n) = \frac{1/d_{sn-n} - \min 1/d_{sn-n}}{\max 1/d_{sn-n} - \min 1/d_{sn-n}} \tag{5}$$

Where d_{sn-n} is the average distance between the node sn and its neighbors, $\min 1/d_{sn-n}$ and $\max 1/d_{sn-n}$ are the maximum and minimum value of the reciprocals of the average distance from node *sn* to its neighbors.

Combining the above factors, the comprehensive weight of node *sn* is obtained as follow.

$$ES(sn) = \begin{bmatrix} E_w(sn) \\ S_w(sn) \\ S_w(sn{-}n) \end{bmatrix} \tag{6}$$

3.3 The Comprehensive Evaluation Method

$A = (a_1, \ldots a_n)$ is a comprehensive evaluation standard for cluster head election. $B{=}(b_1, b_2, b_3)$ is the weight set of three parameters. Using the weighted average model, we can obtain the value of A.

$$A = (a_1, \ldots a_n) = B \cdot ES(sn) = (b_1, b_2, b_3) \cdot \begin{bmatrix} E_w(sn) \ldots E_w(sx) \\ S_w(sn) \ldots S_w(sx) \\ S_w(sn{-}n) \ldots S_w(sx{-}n) \end{bmatrix} \tag{7}$$

Then the weighted average method is used to get the value of the comprehensive evaluation for each node $\left(a'_1, \ldots a'_n\right)$. If a node within the competing diameter has is highest comprehensive evaluation value, it is selected as a cluster head.

3.4 Dynamic Cooperative Aware Storage Method

The method is mainly divided into two parts, dynamic cooperative sensing data and data backup and storage. In the first part, the cluster partition and cluster head selection are used to divide the whole sensing area. The network is divided into several clusters centered on events (see Fig. 2) in order to ensure that the nodes that in each cluster are closest to the event are used to backup and storage data. Then, the nodes in the same cluster can communicate with each other. The nodes who will be able to sense the event are composed a set Ai1 in which all nodes adopt time division collaboration technology to record event data in turn. Since the dynamic change of network topology, the nodes in each set periodically interact with each other. Thus, the added or dead nodes can be added or deleted. Then, we select a new cluster head node based on the principle of maximum residual energy. Finally, the head node redistributes the monitoring sequence and time slot to its member nodes. Using the proposed method, the scalability of the network is enhanced and the memory space of nodes is saved.

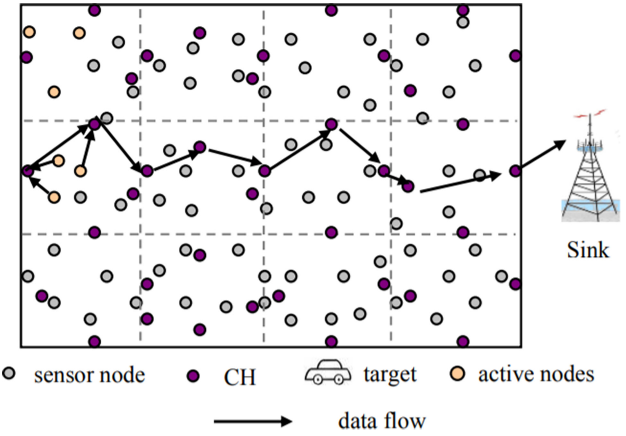

Fig. 2. Data transmitting and storage in the proposed approach

In the latter part, the storage data failure caused by node failure is considered. When the monitoring event occurs the source node will first record the event data on the current time slot as independent data blocks. And the event data need to be backup and storage. Then, according to the estimated failure probability of the node, the total number of the data backup is calculated to manage data backup storage.

According to the above discussions, the fault probability of all nodes in the network is assumed as P_n. If the rate P_n is the same for each node, the effective number of backups per data block is b, then the average number of available backups for data blocks is,

$$N_a = \sum_{j=0}^{b} \binom{b}{j} \cdot j \cdot (1 - P_n)^j \cdot P_n^{b-j} = b(1 - P_n) \tag{8}$$

If each piece of data has at least one available data backup, $b(1 - P_n) \geq 1$. Therefore, the optimization model is established to minimize the communication energy consumption of data backup storage. The model can be described as follow,

$$\min Een_r = \sum_{i=1}^{b} H(u, v) \cdot Bp(u, i) \cdot (C_s + C_r) \tag{9}$$

Where *H (u, v)* is the communication hop from node *u* to node *v*, *Bp (u, i)* is the *i*-th data copy of node *u*. Where $b(1 - P_n) \geq 1$ and $bNC_e < nM$, C_e is the total data capacity of each monitoring event. *M* is the storage space of each node.

Assuming that *H (u, v)* is a constant, from the above model we can obtain the minimum total energy consumption Een_r of data backup, when the following formula holds,

$$\begin{cases} b = 1/(1 - P_n) \\ P_n < 1 - NC_e/nM \end{cases} \tag{10}$$

In addition, the node is allowed to select the free neighbor in the range of three hops in order to carry the data backup storage. As a result, the delay and energy consumption of data backup are reduced.

4 Performance Evaluation

4.1 Experiment Environment

We assume that there are 200 sensor nodes distributed randomly over an area of 100 m by 100 m. And the sensing range of each sensor node is $r = 12$ m. We also assume each node has an initial energy of 100 J (Joules). Moreover, the position of the sink node is (0, 0) in the network. We also compare our simulation results with LEACH in [5] and RECHS in [11] in terms of total energy consumption, average data collection delay, and network lifetime (Table 1).

Table 1. Parameters

Parameters	Values
Field size	100 m × 100 m
The number of nodes	200
Sensing range	12 m
Data collected frequency	Every 0.6 s
Data packet size	256 bytes
Control message size	8 bytes
Processing data energy	50 nJ/bit/signal
Date storage energy	50 nJ/bit
Amplification coefficients ε_{amp}	100 pJ/(bm^2)
Amplification coefficients ε_{fs}	10 pJ/bit/m^2
The threshold distance d_0	75 m
Initial energy of nodes	10 J
Duty cycle of cluster members	10%
Wireless channel bandwidth	250 kbps
The distance weight	0.3

4.2 Simulation Results

Figure 3 compares the energy consumption of each of the three algorithms in 10 randomly selected rounds through simulation data. LEACH has great randomness in the number and location of cluster heads, and does not consider the residual energy. Therefore, the energy consumption is the largest and the energy consumption of different rounds varies greatly. RECHS gives priority to the nodes with high residual energy as cluster heads, which can achieve the uniform energy consumption among nodes to a certain extent, but this algorithm cannot reduce the energy consumption. The proposed method (TPM) can ensure the appropriate number of cluster heads, thus reducing the energy consumption. According to the residual energy, the number of adjacent nodes, cluster head position and other factors, the proposed algorithm achieves the uniform distribution of cluster heads to a certain extent, so it consumes less energy.

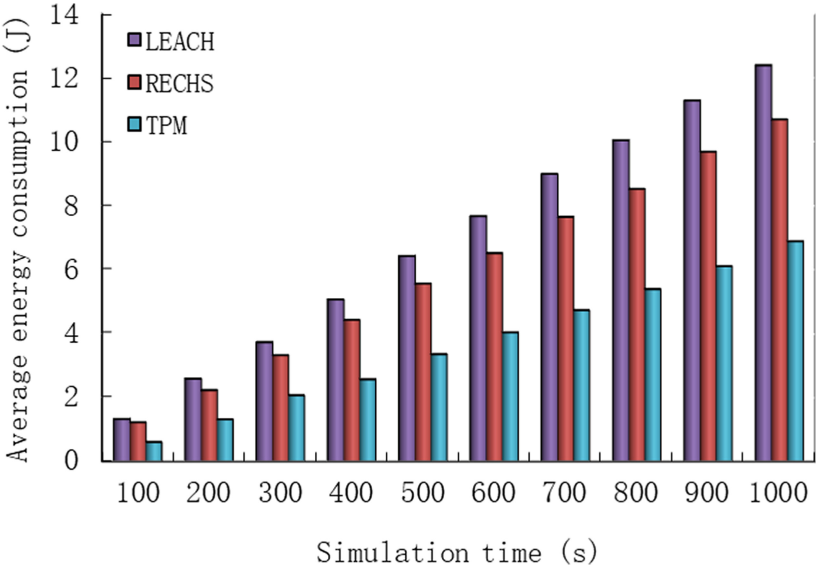

Fig. 3. The average energy comparison

Then, we changed the node number of the network. Figure 4 shows the average residual energy with different node density. From that, we can see the proposed method performs better than the other methods. Clearly, all they tend to decrease, since more nodes can sleep to save energy when the node density is higher. It can be seen that the proposed method can save approximately 25% more energy compared to RECHS because the CH in our algorithm has the most high-energy efficiency. In RECHS, the CH discovery process needs to be executed frequently when the number of nodes increased. Nevertheless, the proposed method transferred the long distance data transmitting into the relative short distance transmitting to save the energy. Unfortunately, in LEACH, the CH has lower energy efficiency. We can see that LEACH approach consumes the most energy since it has a lot of data packets transmitted by long distance.

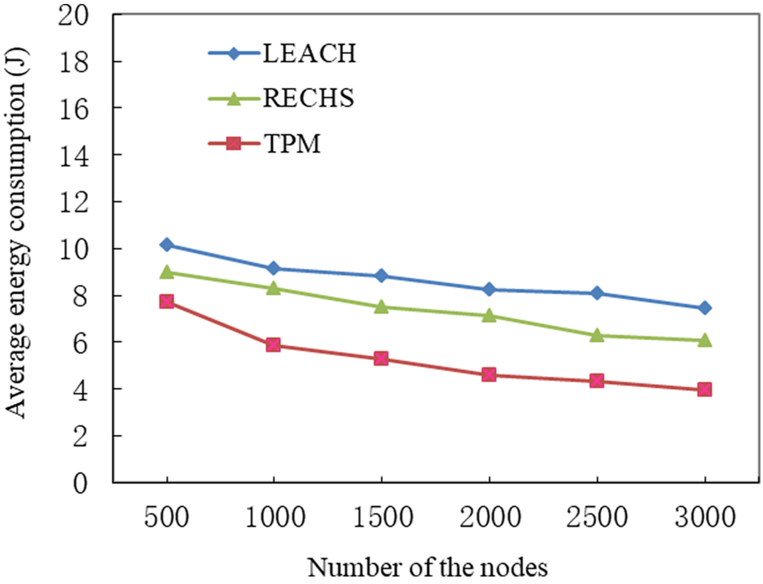

Fig. 4. The average energy after 100 s with different target velocity

Figure 5 shows the average transmission delay comparison of three approaches in our simulation. From that we can see RECHS approach have the longest average transmission delay because it needs to execute the procedure of CH selection and consider many factors inside the network. The proposed method has shorter delay than the other two approaches since it efficiently manages data backup storage and the CHs in the data transmitting chain keep active for the sensed data transmission and the transmitting distance among the CHs is shorter than that in the other approaches. Moreover, the proposed method can reduce the frequency of reconstructing the cluster.

Figure 6 shows the simulation results of the network life cycle of the four algorithms. From the diagram, it is seen that LEACH algorithm has the shortest life cycle. The RECHS algorithm selects CHs from the nodes with more residual energy, and preferentially selects the nodes with more adjacent nodes and the appropriate distance from the selected CH to become the new CHs, which improves the network lifetime. However, because the algorithm cannot reduce energy consumption, due to the uneven distribution of CHs, the improvement of network lifetime is limited. Our proposed method takes into account the uniformity of energy consumption of nodes, which stabilizes the number of CHs and reduces the energy consumption so that it delays the time when nodes begin to die to a certain extent.

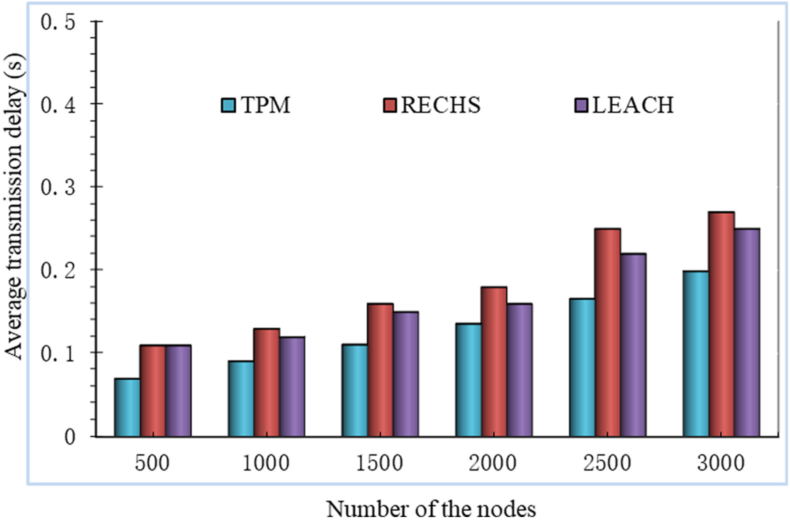

Fig. 5. The data transmitting delay with different number of detecting nodes

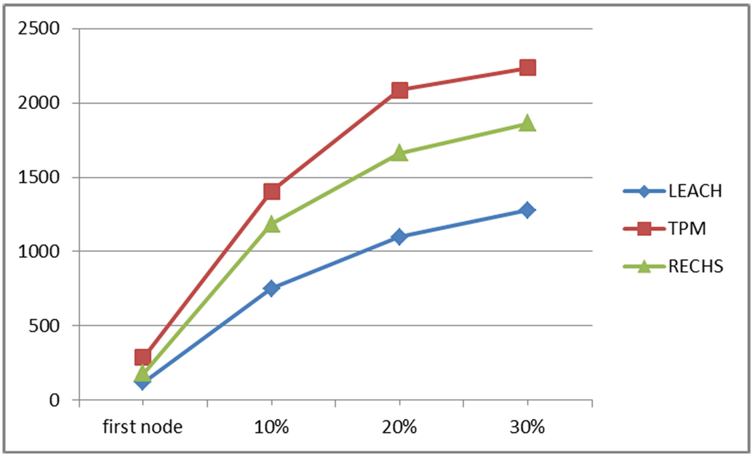

Fig. 6. The lifetime comparison

5 Conclusion

This paper proposed an efficient cluster head selected approach for multimode sensors. We select the optimal number of cluster heads based on the approximate distance from the nodes to the sink and the network side length. Second, the nodes that are deployed in the range of cluster head competition radius broadcast their ID, residual energy, location information and distance to the sink node. In the proposed approach, each node competes cluster head according to the number of adjacent nodes and the distance to the sink. Simulation and data analysis show that the proposed approach can efficiently store data and significantly improve the network lifetime. In addition, each node takes the role of CH different times based on the residual energy of the node. The experiments proved that the proposed approach outperformed the state-of-the-art works by improving the energy cost as well as extending the network lifetime.

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