An Energy Efficient Clustering Method for Wireless Sensor Networks

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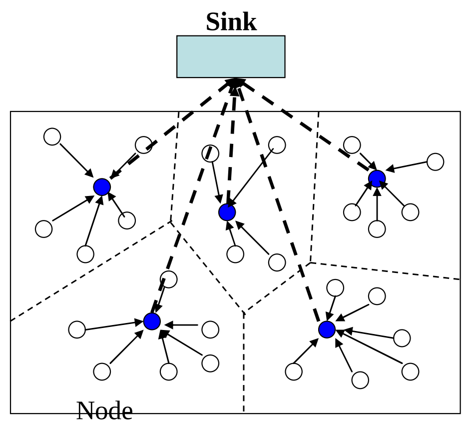
Abstract: Wireless sensor networks have many sensor nodes with a limited energy in a limited area. One of key issues in wireless sensor networks is to prolong the network lifetime. In this paper, we propose a scheme to construct an energy-efficient cluster structure in wireless sensor networks. Our scheme considers both the residual energy of sensor nodes and the number of neighbors around each node when selecting cluster heads. Simulation results show that our scheme can successfully prolong network lifetime by evenly distributing energy consumption over all sensor nodes.

Key-Words: wireless sensor networks, clustering, energy efficiency, energy-aware, neighbor-aware, network lifetime

1 Introduction

Wireless sensor network is a kind of the most essential technologies for implementation of ubiquitous computing [1]. Nodes in wireless sensor networks are typically less mobile, more limited in capabilities, and more densely deployed than those in mobile ad hoc networks. Sensors are generally equipped with data processing and communication capabilities. The sensors measure parameters which reveal some properties about objects located and/or events happening in the vicinity of the sensors. Typically the sensor sends such sensed data, usually via radio transmitter, to a sink, either periodically or based on events. The sink can be statically located in the vicinity of the sensors or it can be mobile so that it can move around the sensors and collect data. In either case, the sink cannot be reached efficiently by all sensors in the system. Therefore, we use a clustering method which groups sensors to form distinct clusters in the system. The method manages the network in the cluster, performs data fusion to correlate sensor reports, and organizes sensors by activating a subset relevant to required missions or tasks as shown in Fig. 1. Each sensor only belongs to one cluster and communicates with the sink only through the cluster header node in the cluster.



Node
○ Cluster-Header Node
● Cluster-Border
– – **Fig. 1** Clustered sensor network

One of the most important issues in sensor networks is the aspect of energy efficiency that is to say to prolong the lifetime of network. Keys to extend network lifetime are sensing schedules and ability to turn on/off a sensing unit. However, not much attention has been put into the method of cluster header selection. Most research works propose techniques to select cluster headers based on energy consumption. The primary objective is to extend the system lifetime. In this paper, we propose clustering scheme to improve energy efficiency of wireless sensor network.

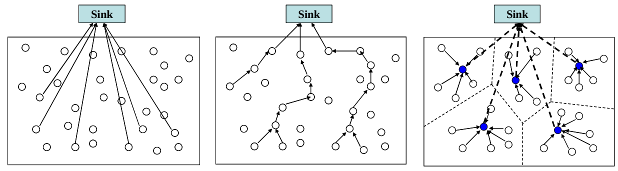
The remainder of this paper is organized as follows: In Section 2, we introduce hierarchical routing protocol in sensor networks and review the LEACH protocol. In Section 3, we present proposed clustering scheme for sensor networks. Section 4 contains the performance evaluation of our protocols through simulations. Finally, Section 5 is the conclusion.

2 Related Works

Recently, a number of energy efficient routing protocols designed for wireless sensor networks have been proposed. The existing routing protocols can be classified into two categories. The first category is a non-hierarchical routing protocol in which source node floods advertisement message to destination. When a destination receives an advertisement message from its neighbor, it sets up a route to send data to the neighbor as shown in Fig. 2.

The main problem of non-hierarchical routing protocol is that they have trouble to decide route. And it does not support scalability since the disturbing RREQ (Route REQuest) flooding over the whole network and considerable route setup delay become intolerable in the presence of both a large number of nodes.

The second category is a hierarchical (or clustering) routing protocol [2] which organizes sensor nodes into clusters based on the received signal strength and uses local cluster headers as routers to base station. LEACH [3, 4] is a typical example of the hierarchical routing protocols. The cluster structure provides several benefits. First, a cluster structure facilitates the spatial reuse of resources to increase the system capacity. With the non-overlapping multi-cluster structure, two clusters may deploy the same frequency or code set if they are not neighbor clusters. In addition, we can find another benefit in routing, because the set of cluster headers can normally form a virtual backbone for inter–cluster routing. Further, a cluster structure supports scalability and energy efficiency. The main problem of the hierarchical routing protocol is that it is not easy to elect cluster header. In this section, we briefly review some hierarchical routing protocols.



(a) single hop non-hierarchical routing protocol without clustering

(b) Multi-hop non-hierarchical routing protocol without clustering

(c) Single hop hierarchical routing protocol with clustering

Fig. 2 Routing protocols for sensor networks

LEACH [3, 4] is the most well known energy efficient clustering protocol. In LEACH, the nodes organize themselves into local clusters, with one node acting as the local base station or cluster header as shown in Fig. 2(c). The operation of LEACH is divided into rounds. Each round begins with a set-up phase when the cluster are organized, followed by a steady-state phase when data are transferred from the nodes to the cluster header and the SINK as shown in Fig. 3 LEACH forwards continuous sensed data to the sink at the region where nodes are randomly distributed. LEACH is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensors in the networks.

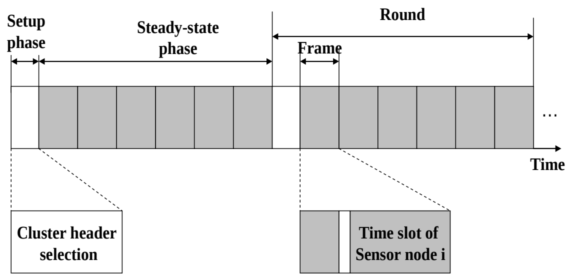


Fig. 3 Timeline of LEACH operation

While there are advantages to using distributed cluster formation algorithm, this does not guarantee the placement and number of cluster header nodes. Sometimes, LEACH may produce too many cluster headers. Even, it can produce no cluster header sometimes. Further, cluster headers may be concentrated in a specific area.

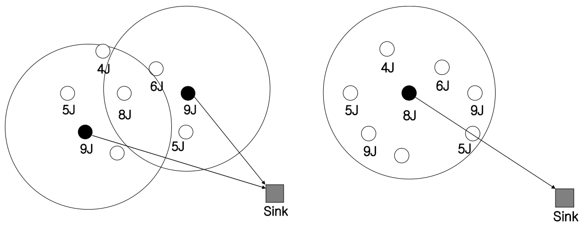
3 Proposed Scheme

As previously explained, the clustering method can provide an effective topology control to reduce energy consumption. Each node forwards sensing data to the nearest cluster header. And the cluster header conducts data fusion, and forwards the collected data to the sink.

Fig. 2 shows the basic concept of our clustering scheme. In energy-aware clustering method [5], as depicted in Fig. 4(a), two clusters can be made in a small area since it considers only reserved energy at each sensor node. So, each cluster header separately forwards its own data to the sink.

However, our scheme assumes neighbor awareness as well as energy awareness for clustering as shown in this figure. Our scheme elects the node with a more neighbors and a greater residual energy as the cluster head. Unlike energy-aware clustering method, our scheme can make only one cluster as illustrated in Fig. 4(b), since it considers both the reserved energy and the number of neighbor nodes at each sensor node. So, our method requires single data forwarding to the sink in this scenario.

Our scheme dynamically constructs clusters based on the amount of remained energy and the number of neighbor nodes at each node. For this, each node computes its own priority weight depending on its residual energy and the number of neighbor nodes. The node with the highest weight among one-hop neighbors is elected as cluster header. Our scheme intends to prolong the network lifetime by selecting cluster header fairly over all sensor nodes.



(a) Energy aware clustering (b) Energy and neighbor aware clustering

Fig. 4 Concept of our clustering scheme

3.1 Priority weight for selecting cluster head

When a node forwards a *k-bit* data, its energy consumption is given by:

$$E_{Tx}(k) = (E_{Tx-elec} \times k) + (E_{amp} \times k \times d^2) \qquad (1)$$

where $E_{Tx\text{-}elec}$ is 50 *nJ/bit*, E_{amp} is 100 $pJ/bit/m^2$, and d is corresponded cluster radius as transmission range of each node. In general, energy consumption for receiving data is less than energy consumption for transmitting data.

The priority weight, denoted by ρ, for cluster header selection is calculated by

$$\rho = \frac{E_r}{E_i} + (\alpha \times \frac{N_n}{N_i}), \quad 0 < \alpha < 1, \qquad (2)$$

where E_i is an average of the residual energies of neighbor nodes and E_r is the residual energy of the node itself. N_i is an average of the number of neighbor nodes and N_n is the number of neighbor nodes within one-hop from the node itself. α is a tuning factor which controls the possibility of being selected as cluster head based on the number of neighbor nodes.

If N_n is greater than N_i, the node will be again selected as cluster header in the next round. To prevent this, the value of α should be decreased once the node is selected as cluster header.

If we want as many cluster headers as approximately 5% of the total number of nodes, about 20 rounds are necessary for all nodes to be selected as cluster header one time on an average. So, α of each node is initialized by 1 after every twenty rounds.

3.2 Clustering method

Each node exchanges its status nodes at the end of each round, including its residual energy and the number of neighbor nodes through HELLO message. With this information, each node calculates the priority weights of its neighbors. If its own priority weight value is greater than those of neighbors, it elects itself as a cluster header and sends an advertisement message to its neighbor nodes within one hop. And it aggregates data and forwards only one message to the sink.

On receiving the advertisement message, each neighbor node knows that a node around it has been elected as cluster head. And it sends a join message to the cluster header to belong to the cluster. However, if its own priority weight value is less than that of any neighbor node, it does not send advertisement message [6]. When some neighbor node has the same priority weight value as its own priority value, the node with the lowest-ID [7] is elected as cluster header. Also, if a node does not have any neighbor nodes around it, the node becomes cluster header.

As described so far, our clustering method considers the number of neighbors as well as the residual energy when selecting cluster headers. So, there is possibility that a big cluster with a large number of neighbors can be formed. In this case, the cluster header in the big cluster collects an extremely large data and consumes huge energy, which results in a short network lifetime. To avoid this problem, when a node hears multiple advertisement messages from more than two cluster headers, it joins the cluster which has less neighbors. Fig. 5 and 6 illustrate operation of our scheme described so far.

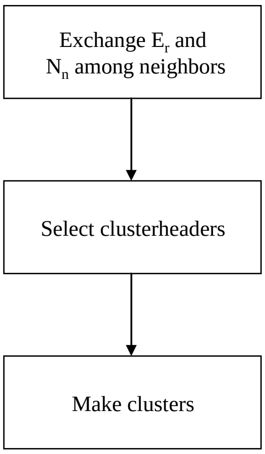


Fig. 5 Procedure for clustering

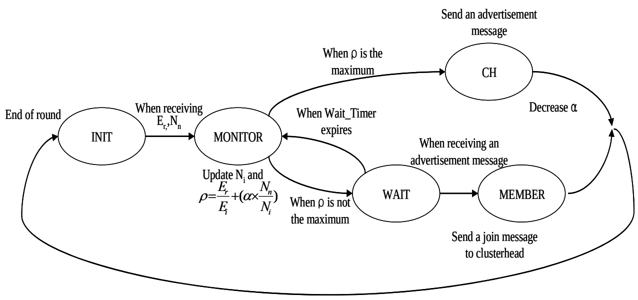


Fig. 6 State transition diagram at node

4 Performance evaluation

In this section, we evaluate the performance of the proposed scheme via computer simulation. We compare our proposed scheme to LEACH. We assume that nodes are uniformly distributed in a field with *100m *100m*, and the sink is located at the point *(50,175)*. The parameters for simulation are listed in Table 1 [8].

Table 1. Parameters for simulation

Type	Parameter	Value
Network	Network grid Sink Initial energy	From (0,0) to (100,100) At (50, 175) 1 *J / battery*
Application	Cluster radius Data packet size Broadcast packet size Packet header size	Variable radius 100 *bytes* 50 *bytes* 25 *bytes*
Radio model	E_{elec} E_{fs} E_{mp} E_{fusion} Threshold distance (d_0)	50 *nJ/bit* 100 *pJ/bit* m^2 0.0013 *pJ/bit* m^4 5 *nJ/bit/signal* 75 m

First, we try to find out the cluster radius to choose as many cluster headers as approximately 5% of total nodes by

$$R = \frac{(N \times M)\times 19}{(N_0 - 1)\times \pi} \times \beta, \qquad \beta = 1.7 \qquad \textbf{(3)}$$

where R is cluster radius, N_0 is the number of deployed nodes in $N * M$ map, and β is a constant value which is used to yield as many cluster headers as 5% of total nodes in the sensing field, and will be derived from simulation.

Fig. 7 shows the cluster radius which can select as many cluster headers as approximately 5% of total nodes when the network size is varied. We can see that the experimental and theoretical results are almost the same and the cluster radius depends on the number of nodes.

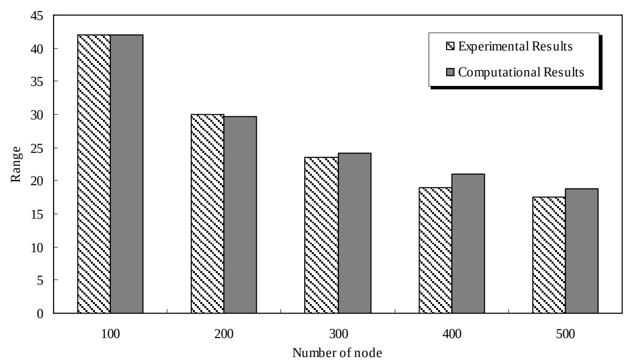


Fig. 7 The cluster radius needed to select as many cluster heads as 5% of total nodes (obtained experimentally and computationally)

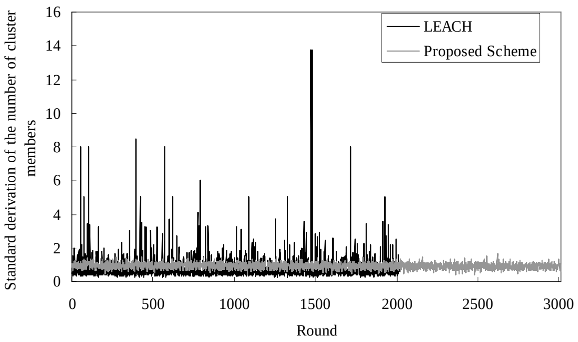


Fig. 8 Standard deviation of the number of cluster members

Fig. 8 shows the standard deviation of the number of cluster members per round. We can see that the proposed scheme has a smaller variance, which means that every cluster has a similar number of sensor nodes. However, LEACH has a variation for each round, which indicates that the number of sensor nodes in each cluster shows a big change as the time goes on.

We examine the effect of priority weight value on the performance of network lifetime. We vary the weight value from 0 to 20 to observe how the protocol works. This figure shows that the constant weight value without considering the number of nodes produces the worst performance. We can see that the network lifetime can be highly prolonged when a proper weight value is used. This figure also indicates that each node can fairly consume its energy by adjusting the probability of being selected as cluster header at each node.

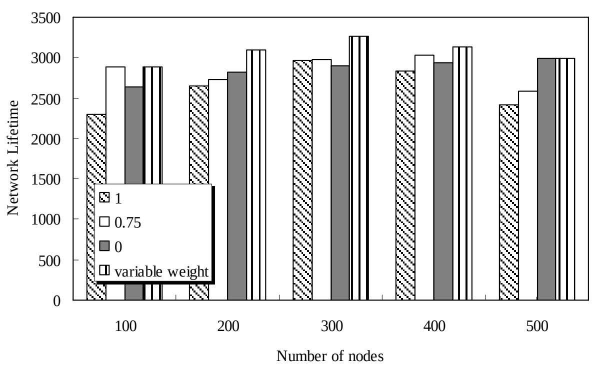


Fig. 9 Network lifetime with different values of the priority weight

We vary the number of nodes from 100 to 500 to measure how the network lifetime changes. In simulation, lifetime is measured as the time until the first node dies among nodes. A node is considered to "die" if it has lost 99.9 percent of its initial energy [9][10]. Fig. 10 shows the average energy consumption over all nodes per round. We can see that the proposed scheme clearly improves network lifetime over LEACH. This is because LEACH randomly selects cluster headers, which may result in a faster death of some nodes. This is avoided in the proposed scheme because cluster headers are selected in such a way that it considers the number of neighbors as well as the residual energy. Similar results are obtained when lifetime is measured as the time until the last node dies among nodes as shown in Fig. 11.

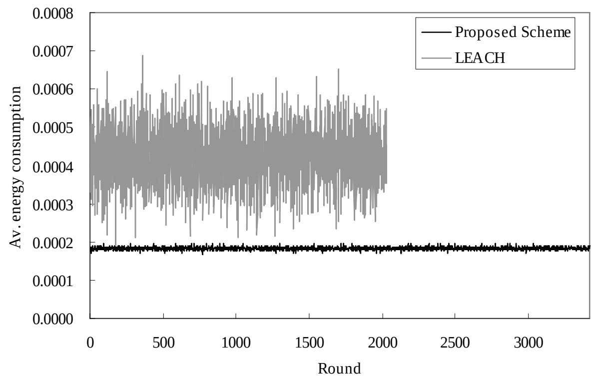
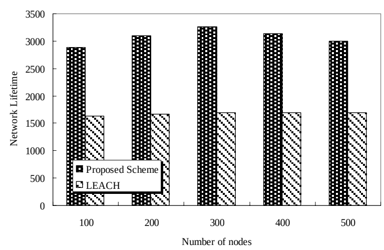
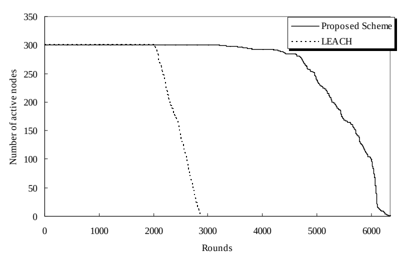


Fig. 10 The average energy consumption per round



(a) The number of rounds until the first node dies



(b) The number of rounds until the last node dies

Fig. 11 Network Lifetime

4 Conclusion

In this paper, we have proposed a distributed and energy efficient clustering algorithm for wireless sensor network. Our scheme selects cluster header based on the residual energy and the number of neighbors at each node. Simulation results demonstrate that our scheme equally distributes energy consumption, and thus prolongs network lifetime. In the future, we will extend our scheme to multi-hop routing environments in wireless sensor networks.

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