An Energy Efficient Dynamic Clustering Protocol based on Weight in Wireless Sensor Networks

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Abstract—Nodes in most wireless sensor networks (WSNs) are powered by batteries with limited energy. Prolonging network lifetime and saving energy are two critical issues for WSNs. Clustering is an effective technique to improve the energy efficiency and prolong network lifetime of wireless sensor networks. In this paper, an energy efficient dynamic clustering protocol (EEDCP) based on weight for wireless sensor networks is proposed, which is able to dramatically prolong network lifetime and save energy. In the EEDCP, we introduce the typical energy model to compute energy consumption, virtual grid technology to construct cluster and a long sleeping state to reduce energy consumption. In addition, we use the value of weight to measure the size of residual energy instead of voting, which can significantly reduce the voting times and the number of transmitting information. Further, simulation experiments are conducted to compare the EEDCP with some well-known clustering algorithms and simulation results show that the proposed method overcomes the existing methods in the aspects of energy consumption and network lifetime in wireless sensor networks.

Index Terms—Wireless sensor networks (WSNs), Energy efficient, Network lifetime, Dynamic clustering, Weight

I. INTRODUCTION

Wireless sensor networks (WSNs) have been blooming recently, which are being widely used in various areas such as reconnaissance, disaster relief, intelligent transportation, surveillance, environmental monitoring, healthcare, target tracking, and more. WSNs are extremely useful to collect information in harsh or hostile environment. A WSN has two important and interesting characteristics that are different from traditional wireless networks [1]. First, after the event occurs, multiple sensors nodes (denoted as data source nodes) around this event will sense the event, and then send the data back to one sensor node (denoted as sink node). Hence, communication mode in WSN occurs from multiple data source nodes to one data sink node. This is a type of multipoint-to-point, rather than the traditional point-to-multipoint communication in WSNs[2].

A wireless sensor network (WSN) is composed of a large number of sensor nodes that are densely deployed near an area of interest and are connected by a wireless interface. Since each sensor is limited in terms of processing capability, wireless bandwidth, battery power and storage space, in most applications, it is impossible to replenish power resources, a major constraint of WSN lifetime is energy consumption. Energy savings optimization is thus a major challenge for the success of WSNs. Typical tasks of a sensor node in a sensor network are to collect data, perform data aggregation, and then transmit data. Among these tasks, monitoring and transmitting data require much more energy than processing it [3]. Therefore, in wireless sensor network, a significant focus has been put on increasing energy efficiency [4]. Generally, there are two basic approaches to the problem of saving energy in WSN. The first one is scheduling some sensor nodes to go into an active mode while enabling the other sensor nodes to go into a low-power sleep mode [5,6]. The second approach is to select the optimization routing algorithm, eliminating redundant energy consumption.

Hence, proper energy efficient dynamic routing protocols should be designed to increase the lifetime of the network greatly. In this paper, an energy efficient dynamic clustering protocol (EEDCP) based on weight is proposed for wireless micro sensor networks to facilitate the achievement of low energy dissipation. From the simulation results, it is illustrated that the EEDCP achieves an order of magnitude increase in system lifetime when compared to the general – purpose approaches. Moreover, for a given quality, the overall residual is reduced by an order of magnitude.

The rest of this paper is organized as follows. Section II gives the detailed related work done. Section III presents the system model for our architecture, such as network model, energy model and node state transition model. Section IV gives the detailed description of the algorithm and structure. Section V gives the experimental results and section VI concludes the paper.

II. RELATED WORK

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There are many energy-saving routing algorithms used in wireless sensor networks, and new ideas for routing are announced in recent years. In this section, we review some of the most effective algorithm.

In low-energy adaptive clustering hierarchy LEACH) [7], the authors discuss an energy efficient algorithm. Various algorithms developed after that is based on this algorithm. In order to determine the cluster head, LEACH uses randomization technique Gossiping [8] is the improvements of flooding algorithm (Flooding), it can effective resolve the implosion and information overload problem which lead to energy loss, but it can not solve some of the data overlap and too much delay, but it can not balance the energy of nodes. Hybrid energy-efficient distributed clustering (HEED)[19] is based on LEACH thinking, the important difference is the choice of cluster head and cluster head formation. In PEGASIS (Power-Efficient Gathering in Sensor Information Systems), author tried to foster the past technique [10]. This new mechanism is a chain-based power efficient protocol based on LEACH [11]. It assumes that each node must know location information about all other nodes at first. PEGASIS starts with the farthest node from the base station. The chain can be constructed easily by using a greedy algorithm. The chain leader aggregates data and forwards it to the base station. In order to balance the overhead involved in communication between the chain leader and the base station, each node in the chain takes turn to be the leader.

A clustering-based routing protocol called base station controlled dynamic clustering protocol (BCDCP)[12], which utilizes a high energy base station to set up cluster heads and perform other energy-intensive tasks, can noticeably enhance the lifetime of a network. United voting dynamic cluster routing algorithm based on residual-energy in wireless sensor networks (UVDC)[13], which periodically selected cluster head according to residual energy among the nodes located in the event area, so the voting cost of UVDC is gigantic and the large redundant nodes will waste limited energy. Sensor protocols for information via negotiation (SPIN)[14] is also improved the flooding algorithm, before transferring data, it only transmit data to needed neighbor nodes which using meta-data to reduce redundant information to save energy consumption. Directed diffusion (DD)[11] periodic automatic forms the enhanced path, because of node energy and topology changes, the enhanced path will be different in different period, the most of data from the source to the cluster is transmitted by the enhanced path, thus reduce the energy consumption of non-enhanced nodes. And GBR (Gradient-Based Routing) is also proposed as a variant of directed diffusion [15]. The key idea in GBR is to memorize the number of hops when the interest in diffused through the whole network. In GBR, three different data dissemination techniques have been discussed [11] (i) Stochastic Scheme, where a node picks one gradient at random when there are two or more next hops that have the same gradient, (ii) Energy-based scheme, where a node increases its height when its energy drops below a certain threshold, so that other sensors are discouraged from sending data to that node, and (iii) Stream-based scheme, where new streams are not routed through nodes that are currently part of the path of other streams. The main objective of these schemes is to obtain a balanced distribution of the traffic in the network, thus increasing the network lifetime.

Threshold sensitive energy efficient sensor network protocol (TEEN)[16] is designed for responsive applications, it determine whether to send data by setting up a reasonable soft and hard threshold to compare with the monitoring data. It only transmit the interest information to users to effectively reduces the network traffic and thus reduce network energy consumption.

Guojun Wang, et al., have proposed a local update-based routing protocol in WSNs with a mobile sink [17]. The protocol proposed by the authors saves the energy for sensor networks and makes the sink keep continuous communications to sensors by confining the destination area into a local area for updating the sink location information as the sink moves. Hayoung Oh and Kijoon Chae have presented a sensor routing scheme [18], EESR (Energy-Efficient Sensor Routing) that provides energy-efficient data delivery from sensors to the base station. Their scheme divides the area into sectors and locates a manager node to each sector.

Besides these algorithms mentioned above, there exist several other algorithms [19], such as: Soro et al. [20] proposed an unequal clustering size model for network organization, which can lead to more uniform energy dissipation among cluster head nodes, thus increasing network lifetime. Ye et al. [21] proposed a clustering algorithm, which achieves good cluster head distribution with no iteration and introduces a weighted function for the plain node to make a decision for joining a proper cluster.

III. System model

A. Network model

In this paper, we consider the wireless sensor networks where N nodes in field A are homogenous and energy constrained and the sensor network has the following properties [22]:

1) This network is a static densely deployed network. It means a large number of sensor nodes are densely deployed in a two-dimensional geographic space, forming a network and these nodes do not move any more after deployment.

2) There exists only one Sink node, which is deployed at a fixed place outside the WSNs.

3) The energy of sensor nodes cannot be recharged. It means sensor node will die if its energy be exhausted.

4) Sensor nodes are location-aware, i.e. sensor node can get its location information through other mechanisms such as GPS or position algorithms (in order to describe the position of node uses (Xi,Yi) , the Sink node as (Xsink,Ysink)).

5) The radio power can be controlled, i.e., a node can vary its transmission power depending on the distance to the receiver [23].
In Table 1, we give the symbols definition in this paper.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>N</td>
<td>The set of sensor nodes</td>
</tr>
<tr>
<td>x,y</td>
<td>Coordinates of the node</td>
</tr>
<tr>
<td>d_{ij}</td>
<td>The distance of node i and node j</td>
</tr>
<tr>
<td>E_{tx}</td>
<td>The consumption energy of node i transmitted a packet.</td>
</tr>
<tr>
<td>E_{rx}</td>
<td>The consumption energy of node i receive a packet.</td>
</tr>
<tr>
<td>E_{r(i)}</td>
<td>The residual energy of node i</td>
</tr>
<tr>
<td>E_p</td>
<td>The consumption of processing in cluster head</td>
</tr>
<tr>
<td>T_l</td>
<td>Listening timer</td>
</tr>
<tr>
<td>T_s</td>
<td>Sleeping timer</td>
</tr>
<tr>
<td>T_j</td>
<td>Sensing timer</td>
</tr>
<tr>
<td>r(i)</td>
<td>The number of active node i receives voting information</td>
</tr>
<tr>
<td>s(i)</td>
<td>The number of active node i sends voting information</td>
</tr>
<tr>
<td>v(t)</td>
<td>The number of total sending and receiving voting information in head</td>
</tr>
<tr>
<td>G_i</td>
<td>The ith virtual grid in a cluster</td>
</tr>
<tr>
<td>k</td>
<td>The size of a packet</td>
</tr>
<tr>
<td>Weight</td>
<td>The value of residual energy divided by Er(i) for each active node</td>
</tr>
<tr>
<td>M,N</td>
<td>The number of virtual grid in a cluster</td>
</tr>
</tbody>
</table>

Table 1. NOTATION

First, we use the virtual grid ideas to divide the field A into many same square, namely, there are many clusters, and each node can directly communicate with other nodes in a cluster. Then the cluster was divided into M×N small area (the value of M, N are determined by the cluster’s size, assume that there are M×N grid in a cluster, each grid is named G_k(k=1.. M×N).

Fig. 1 shows the virtual grid ideas, in order to conveniently describe, we suppose that the value of M and N are equal to three, each small square call as a virtual grid, nodes are randomly distributed into this virtual grid, such as CH1 has 9 virtual grid, namely, G1, G2, G3, G4, G5, G6, G7, G8 and G9, we suppose virtual grid G5 as a cluster head grid, and the red pentagram as the cluster head., for arbitrary adjacent virtual grid G1 and G2, each node in G1 can communicate with all nodes in G2, and vice versa. In a cluster, the red dot as the working node in each grid and each node can communicate with cluster head, and we suppose the number of simultaneous working node is one in a virtual grid (red dot), other nodes are sleeping (black dot). In order to guarantee the network normal working and prolong network lifetime, one sleeping node in a virtual grid will be awakened at the right time so as to instead of the energy-exhausted node or disabled node [24].

B. Energy model

We adopt a simplified power model of radio communication in document [25], namely, in order to send a k-bit packet information and the sending distance is \(d_{ij}\), the sending energy consumption is

\[
E_{tx}(k,d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d \times d
\]  

(1)

The distance of node i and node j is \(d_{ij}\):

\[
d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}
\]  

(2)

The receiving energy consumption is

\[
E_{rx}(k) = E_{elec} \times k
\]  

(3)

Where \(E_{elec}\) is the energy/bit consumed by the sender and receiver electronics, J/bit, \(E_{elec} = 50 nJ J / bit\), \(\varepsilon_{amp}\) is the J/(bit × m²), \(\varepsilon_{amp} = 100 pJ J / bit m^2\). we commonly assume that the sending distance and \(d_2\) is directly proportional for shorter distance, while the sending distance and \(d_4\) is directly proportional for longer distance, so we can see the directly sending to long distance is consumed more energy than multi-hop sending.

But the differentiation from the document [26], we consider the processing consumption in order to proximity real scene, the energy consumption of cluster head is \(E_p\)

\[
E_p(k,m) = \sum_{i=1}^{3} 1/3 \times E_{elec} \times k_i
\]  

(4)

So the residual energy of cluster head is:

\[
E_{r}(i) = E_{r}(i) - \sum_{n=1}^{n} E_{r}(k_{\alpha}, d_{\alpha}) - \sum_{n=2}^{n} E_{r}(k_{\beta}, d_{\beta}) - E_p(k,m), n_1, n_2 \in N
\]  

(5)

Where \(n_1, n_2\) are the cluster head respectively sending and receiving times before time \(T_i\).

The residual energy of ordinary node is:

\[
E_{r}(i) = E_{r}(i) - E_{r}(k_{\gamma}, d_{\gamma}) - E_{r}(k)
\]  

(6)

C. Node state transition model

The energy dissipation in wireless sensor networks has three models: sensor model; procession model; wireless radio model [27]. In order to maximum lifetime and minimum routing, nodes in the EE-MLMR have various operation modes with different levels of activation and, thus, different levels of energy consumption. We put forward the new state conversion model which have flag
of valve which depend on the EPGR state model. In this model, each node has six operation modes [28]: mode 1: sleeping-sensing off and radio off; mode 2: sensing - sensing on and radio off; mode 3: receiving sensing on and radio receiving; mode 4: transmitting -sensing on and radio transmitting; mode 5: listening - sensing on; mode 6:long sleeping- sensing off and radio off forever, no responding.

Figure 2. The transition model os sensor nodes

Where Ts is a sleeping timer, Ti is listening timer, Tj is sensing timer.

The Fig. 2 shows the “commands” performed along the path (state transition) between states [29]. It means that whenever a node changes its state-based energy dissipation model to current state it performs tests and actions until the new state is reached. “sleeping” determines whether the node will sleep or not; The “receiving” test depends also on the characteristics of the event. Its value is influenced by the degree of cooperation needed by the application. The “sensing” test is called only if there is no event in the area of the node. If no event happens, this test will depend on the degree of coverage needed by the application. In the “transmitting” state, if flag=0, then sensing off and radio off and node convert to long sleeping; if flag=1, then convert to the transmitting. The “listening” test determines whether a new sensing event is present; the long sleeping denotes the node never respond any event. “Timer” is an action that starts a timer. The outcome of each test depends on a probabilistic parameter associated with the test. These transitions try to capture the behavior of a sensor node, specially in terms of energy consumption.

IV. ENERGY EFFICIENT DYNAMIC CLUSTERING PROTOCOL BASED ON WEIGHT

At any time, only one node within a virtual grid stays active to be a coordinator, while the others fall into sleeping mode. Doing this significantly reduces the energy consumption because nodes in the idle state spend much more energy as compared with the sleeping state.

In our protocol, we use weight as the selection criteria for new cluster head, when the residual energy of the cluster head is lower than threshold, the EEDCP will be implemented. First, it compute the total residual energy(Et) of all active nodes from the cluster head member table, then respectively compute the weight of all active nodes as shown in formula (7). Second, we select the minimal weight active node as the new cluster head and inform all member nodes and the cluster head neighbor. All received information nodes will reply related information and update its table. Lastly, the old cluster head will select a new active node replace him and then goto long sleeping.

\[
\text{weight}(i) = \frac{\sum E_r(i)}{E_r(i)}
\]

Where k is the number of active nodes in the cluster, Er(i) is the residual energy of active node.

The energy efficient dynamic voting cluster (EEDCP) based on weight has four steps: Initialization, active node selection, dynamic clustering based on weight phase, sensing and sending. When the residual energy of cluster head is lower than threshold, dynamic clustering based on weight will happens, namely, cluster head will initiate clustering process from the active node. If new cluster head is come into being, clustering is formed. The detailed process described in the followings:

Step1: Initialization: the whole area was divided into many same squares, namely, there are many clusters, and each node can directly communicate with other nodes in a cluster. Then the cluster was divided into M×N small area (the value of M,N are determine by the cluster’s size, there are M×N grid in a cluster, each grid is named Gk(k=1.. M×N). The first cluster head is randomly selected from the active nodes and each active node has a neighbor table (as shown in table 2.) to record its member information and all directly connect active node ID and energy information, then cluster head will send information to other cluster head, so as to form a cluster neighbor table (as shown in table 3.).

Step2: Sensing and sending: when there is a event, the active node will collect event information, then compute its residual energy, if Er is lower than threshold then goto active node selection; else it will send event information and the residual energy to the cluster head.

Step3: Active node selection: for each grid, if its active node residual energy is lower than threshold, the active node will select a new node as the new active node from its neighbor table which has maximum residual energy, and send the new active node ID and energy information to cluster head and its directly connect active nodes.

Step4: Dynamic clustering based on weight: Cluster head is responsible for receiving data, gathering data, sending data to next top, computing its residual energy and maintaining its all table. After some time, if the residual energy of cluster head is lower than threshold, the cluster head will implement the dynamic clustering process. First, it compute the total residual energy of all active nodes and the weight (is equal to the total residual energy of all active nodes in the cluster divided by the residual energy of each active node.) of each active nodes; Second, old head will use active node selection and select a new active node and update its member table; Third, old head will select a minimal weight active node as the new
cluster, if there are more than one active node has the same weight, it will randomly select one as the new cluster head, then, the cluster head will inform its member nodes and neighbor nodes about the new cluster head, such as: ID,(xi,yi) etc, all active node in this cluster and the neighbor nodes received this active node will update its table and record the new cluster head and replay a ACK to old head. Fourth, the old head will send the information to the new cluster head, including its member table and neighbor table. Lastly, the old cluster head goes to sleep.

TABLE 2.
THE ACTIVE NODE STRUCTURE

<table>
<thead>
<tr>
<th>Name</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>Identification of nodes</td>
</tr>
<tr>
<td>xi,yi</td>
<td>Position of node i</td>
</tr>
<tr>
<td>Er(i)</td>
<td>Residual energy of node i</td>
</tr>
<tr>
<td>flag</td>
<td>0-cluster head;1-node itself;2-member node;3-neighbor node</td>
</tr>
<tr>
<td>state</td>
<td>0-active;1-sleeping</td>
</tr>
</tbody>
</table>

For example, at a time, if cluster head (such as G5) residual energy is lower than threshold in CH1 and other active node residual energy is show as Fig.3.

But using our proposed method, we can use minimal times to generate the new cluster head, significantly save energy and ensure the residual energy active node as the new cluster head, for example, for the same case as shown in Fig.3, the total computing times is 10 times (one is compute the total energy, the others are compute the weight of each active node) and each active nodes does not require any messages to send and receive in this process, the old head can choose a new cluster head G2 as shown in Fig.7, and we can see that the w(2) is the minimum, namely, G2 is the maximum energy active node. At the same circumstances in Fig.5, using our method, we can see from the Fig.8 that the minimal weight active node(G8) is the only new cluster head, so

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we can reduce the energy consumption in the new cluster head generation, always select the maximum active node as the new head and extend the network lifetime.

Ⅴ. SIMULATION RESULTS

A. Simulation Parameters:

We have implemented our proposed protocol in NS-2 (ver. 2.31). We considered a 600 node random network deployed in an area of 360 X 360 m. Initially the nodes are placed randomly in the specified area. The only Sink node is assumed to be situated 100 meters away from the above specified area. At the same time, we considered specified area is divided into 90 X 90 m square area called cluster and each cluster is divided into 30 X 30 m area called virtual grid. Obviously, the first set of cluster heads are taken randomly. The initial energy of all the nodes assumed as 5 joules. The radio range is varies from 30m to 120m. Each data packet has 64 bytes, and the others are 32 bytes long. Summary of parameters and defined values are shown in Table 4.

B. Experimental results and analysis

From the diagram of Fig.9, we can see that there are considerable differences on the average energy consumption among the three algorithms. EEDCP has the minimum energy consumption, and with the increase of number nodes in each cluster, the consumption is slowly increase, For UVDC, because of there are large redundant nodes and the consumption of voting is gigantic, so the average energy consumption is rapidly increase. For LEACH, because of randomly rotating the role of a cluster head among all the nodes, the average energy consumption is approximate linear increase.

<p>| TABLE 4. SIMULATION PARAMETERS AND VALUES |</p>
<table>
<thead>
<tr>
<th>Simulation parameters</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N(total nodes)</td>
<td>600nodes</td>
</tr>
<tr>
<td>A(network size)</td>
<td>360×360 m</td>
</tr>
<tr>
<td>Cluster size</td>
<td>90×90 m</td>
</tr>
<tr>
<td>Virtual grid size</td>
<td>30×30 m</td>
</tr>
<tr>
<td>Number of sink</td>
<td>1</td>
</tr>
<tr>
<td>Eelec</td>
<td>50nJ/bit</td>
</tr>
<tr>
<td>E amp</td>
<td>0.0013pJ/bit/m²</td>
</tr>
<tr>
<td>Data packet size</td>
<td>64 bytes</td>
</tr>
<tr>
<td>Other packet size</td>
<td>32 bytes</td>
</tr>
<tr>
<td>Simulation times</td>
<td>150 seconds</td>
</tr>
<tr>
<td>Threshold energy</td>
<td>0.2w</td>
</tr>
</tbody>
</table>

Figure 6. The voting relation and the times of sending and receiving for each active node.

Figure 7. The weight of each active node using EEDCP

Figure 8. The weight of each active node using EEDCP

Figure 9. The average energy consumption of LEACH, UVDC and EEDCP
In this second series of experiments, we compare the three energy efficient clustering algorithm LEACH, UVDC and EEDCP with regard to the network lifetime, when the number of nodes in a cluster from 15 to 40. The LEACH algorithm that does never take energy into account and always randomly rotating the role of a cluster head among all the nodes. Simulation results are illustrated in Figure 10, assuming that the initial energy of the nodes is uniformly as 3J.

As expected, LEACH provides the smallest network lifetime. This shows that the random selection of the cluster head is not sufficient to save energy. UVDC provides better results than LEACH, but in the voting cluster head process, UVDC consumed large energy in voting and sending information. The main conclusion of these experiments is that EEDCP significantly outperforms LEACH and UVDC whatever the number of nodes in a cluster. Moreover, EEDCP prolongs the network lifetime of 21% compared with LEACH for a different number of nodes in a cluster. Notice that in the same conditions, UVDC prolongs the network lifetime of only 6%.

VI. CONCLUSIONS

In WSNs, it is significant to prolong network lifetime so that more data can be collected by the sensor(s) to transmit to sink node. It is well known that, efficiently use of energy is critical for network lifetime. Although some routing algorithms like voting dynamic cluster routing algorithm based on residual-energy (UVDC) can dynamic clustering, they usually place too heavy burden of voting information in cluster which consumed large valuable energy.

In this paper, an energy efficient dynamic clustering protocol (EEDCP) based on weight for wireless sensor networks is proposed, which is bale to dramatically prolong network lifetime and save energy. In the EEDCP, we introduce the typical energy model to compute energy consume, virtual grid technology to construct the cluster and a long sleeping state to reduce energy consumption. In addition, we use the value of weight to measure the size of residual energy instead of voting ,which can significant reduce the voting times and the number of transmitting information. Further, simulation experiments are conducted to compare the EEDCP with some well-known clustering algorithms and simulation results show that the proposed methods overcomes the existing methods in the aspects of energy consumption and network lifetime in wireless sensor networks.

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REFERENCES

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