A Power Efficient Routing Protocol for Wireless Sensor Network *

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Abstract—In recent years, the wireless sensor network (WSN), which has a good application prospect in both civil and military fields, has received increasing attention. But due to the particularity of the WSN, the traditional network routing protocol is not suitable to it. There is a great need for new routing protocols for the WSN. For WSN, the network node energy is usually limited, so how to save and even the consumption of the overall energy is an important problem. To deal with this problem, several algorithms have been proposed, such as LEACH which is a cluster-based routing protocol. In this paper, an improved protocol based on LEACH is proposed. In this protocol, the position and energy information are used and K - means clustering algorithm is adopted to determine the cluster heads and the traditional minimum-energy protocol like scheme is adopted to send data from the cluster heads to the base station. Inside the cluster the geography information is used to determine if some nodes are close enough to keep only one of them awake to monitor the environment and communicate with the cluster head while other nodes sleep to save energy without losing any monitoring information. The simulation results show the protocol proposed in this paper has better performance than LEACH.

I. INTRODUCTION

Recent advances in MEMS and wireless communication technique have enabled the combination of the low power, micro processor, micro sensor to be a small node, hundreds or thousands of which form a wireless sensor network (WSN). The nodes have the ability to communicate either with each other or directly with an external base station (BS). A greater number of nodes allow for sensing a larger geographical field with larger accuracy. Networking unattended nodes have profound effect on the efficiency of many military and civil applications such as target field imaging, intrusion detection, weather monitoring, inventory control and disaster management. Deployment of a sensor network in these applications can be in random fashion or can be planted manually. But the way in which the nodes send data to base station (that is the routing protocol) is a problem which is not that easy, and it determines the life time of the network and the liability of the data.

Routing in sensor WSNs can be very challenging due to the inherent characteristics that distinguish these networks from other wireless networks like mobile ad hoc networks or cellular networks. The main difference can be found in [1], where Jamal proposed seven points about the differences. According to differences and the objective of the network, several kinds of routing protocol have been proposed, such as the power-efficient routing protocols which aim at finding energy-efficient paths to prolong the life time of the network, the data centric routing protocol which is to monitor the environment or evaluate the field to get the data quickly where the main problem is to minimize the communication load, and the geography based routing protocols where the position information is used to track the objective. Because the node energy in WSNs is usually very limited while people want to prolong the life time of it we must save energy and make the energy consumption evenly among nodes. In this paper, we propose a power-efficient protocol that can realize this objective. The protocol is a hierarchical protocol that uses K - means clustering algorithm to divide the sensor network nodes into clusters and the position and energy information to select the cluster head. The traditional minimum-energy protocol is adopted to send the data from cluster head to base station. Inside the cluster, the geography information of the node is used to determine whether there exist some nodes that are close enough to keep only one of them awake to monitoring the environment and communicate with the cluster head while other nodes sleep without losing any monitoring information.

The rest of the paper is organized as follows: section II lists several other famous power-efficient routing protocols proposed before; the third section describes the network model and the radio model adopted in this paper. In the IV section we discussed the routing process and protocol details of the proposed protocol. Simulation and comparison with other energy-efficient protocol are implemented in section V. In the end, we give the conclusion.

II. RELATED WORK

The most famous and the base of other more energy efficient routing protocol is LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol [2]. It is a clustering-based protocol that uses randomized rotation of the cluster-heads to evenly distribute the energy load among the sensor nodes in a network. Once the clusters are constructed, the cluster heads broadcast TDMA (Time Division Multi Address) schedules providing the order of transmission for members in the cluster. Each node has its own time slot. It transmits data to the cluster head within its exclusive time slot. When the last node in the schedule has transmitted its data, the cluster head will be randomly elected in the next round. It employs localized coordination to improve the scalability and balance the energy usage of the network among all the nodes.

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Improvements on LEACH were proposed in [3], [4], both of which are hierarchical routing protocols. In TEEN (Threshold-sensitive Energy Efficient Sensor Network Protocol), a hard threshold and soft threshold are put on the transmission of the data. The data is only sent when the sensed attribute is bigger than the hard threshold and the sensed attribute change is bigger than the soft threshold. The hard threshold and the soft threshold can reduce the number of the data transmitted. A smaller value of the soft threshold gives a more accurate picture of the network at the expense of the more energy consumption. So the user can control the trade-off between the energy efficiency and the data accuracy. The main drawback of the scheme is that, if the thresholds are not received, the nodes will never communicate, and the user will not get any data from the network at all. APTEEN (Adaptive Periodicq Threshold-sensitive Energy Efficient Sensor Network Protocol) is proposed to make up the drawback. In APTEEN, two attributes: Schedule and the Count time (CT) are added. The TDMA schedule assigns a transmission slot for every node, and if one node does not send data for a time period equal to the count time, it is forced to sense and retransmit the data. The APTEEN avoids the drawback of the TEEN but add the overhead and the complexity.

The PEGASIS (Power-Efficient Gathering in Sensor Information Systems) proposed in [5] is also an enhancement on LEACH. In PEGASIS the node only communicates with a close node and takes turns transmitting to the base station. Unlike LEACH there is only one node to communicate directly with the base station. Greedy algorithm is adopted to select to node who sends data to base station.

In [6] Ruay proposed MECH (Maximum Energy Cluster Head) routing protocol. He pointed out that LEACH has a drawback that the cluster is not evenly distributed due to its randomized rotation of local cluster head. MECH uses the number of cluster members and radio range to construct a cluster in a certain area and improve the distance of cluster head communications with base station via a hierarchical tree. The drawbacks of MECH are that the control messages are more complex than LEACH and the synchronization mechanism is expensive in hardware equipments for sensor nodes.

III. NETWORK MODEL AND RADIO MODEL

A. Network Model

The network model we adopted in this paper has the following features:

- The nodes are distributed randomly in a square field as depicted in Fig. 1, where 100 nodes are distributed uniformly in a $100 \times 100$ square;
- All the nodes are immobile but some nodes may die when the power is depleted;
- All the nodes have the same transmitting range and the same power level, and the range guarantees the transmitting of data from any nodes to the station;
- All the nodes know its own position and power level left and can know this two attributes of their neighbors through "Hello" message.

B. Radio Model

We use the same radio model as discussed in [2] which is a first order radio model. In this model, a radio dissipates $E_{elec} = 50nJ/bit$ to run the transmitter or the receiver circuitry and $\varepsilon_{amp} = 100pJ/bit/m^2$ for the transmitter amplifier. The radios have power control and can expend the minimum required energy to reach the intended recipients. The radios can be turned off to avoid receiving unintended transmissions. The equations used to calculate transmission costs and receiving costs for a $k$-bit message and a distance $d$ are shown following in equation (1) and (2) respectively:

$$E_{Tx}(k, d) = E_{Tx-elec}(k) + E_{Tx-amp}(k, d)$$
$$E_{Rx}(k) = E_{Rx-elec}(k)$$

In the above two equations, $E_{Tx}(k, d)$ is the energy consumed to send $k$-bit data with a distance $d$. And $E_{Rx}(k)$ is the energy consumed to receive $k$ bit data from other nodes or base station. In this paper, the receiving energy is not thought to be negligible, and it is added to the total energy when the energy consumed by the network is computed.

IV. ROUTING PROCESS

As proposed in [6] by Ruay that the main drawback of LEACH is that the select of cluster head is random which may lead to the uneven distribution of the clusters. In this paper, we use the traditional clustering algorithm to divide the nodes into several clusters at the beginning of the first round; in the later rounds, the partition of nodes is never changed, and the node with the highest energy level in the cluster is selected as the cluster head. Inside the clusters, the geography information of the nodes are used to determine whether there exit some nodes that are close enough that only one of them keep awake without impact the performance. Routing process can be divided into the following steps: set-up phase, steady phase and the forwarding phase. As in LEACH, we construct clusters before each round.

Fig. 1. Nodes Distribution.
A. Initialization of Clusters

The first round and the later rounds should be considered respectively for the initialization of cluster. At the beginning of the first round, all the nodes send a message including its position information to the base station. Then the base station classifies the nodes into clusters and broadcasts the cluster head to the members of the cluster. The number of the clusters is determined by the network topology and the relative costs of computation versus communication. And the clustering algorithm adopted in this paper is K-means clustering algorithm where the clustering criterion function is showed in the following equation (3) which is to minimize the sum of the distance from the cluster members to the cluster head and the letter K means the predefined number of cluster heads.

\[ J_j = \sum_{x \leq S_j(k)} \| x - z_j(k + 1) \|^2 \]  

(3)

In equation (3), \( j \) means the \( j \)th cluster, and \( J_j \) is the criterion function for cluster \( j \). \( x \) is a member of cluster \( j \). \( S_j(k) \) is the list of the cluster members of cluster \( j \) and \( z_j \) is the cluster head. According to equations (1) and (2), when the distance \( d \) is large enough, the energy consumed by the transmitter and receiver can be omitted compared with that of the transmitter amplifier. Because the energy consumed to send a message is mainly determined by the distance between the source and the destination, minimizing the sum of the distance from cluster members to the cluster head is beneficial to save the total energy and the K - means clustering algorithm is suitable to the WSN clustering. At the beginning of later rounds, instead of the position information, the energy level of each node is sent to the base station. In this situation, we don’t change the cluster structure of the nodes, but the cluster head of every cluster is displaced by the node with the highest energy level. As stated in the previous situation, the cluster head is rebroadcast to the nodes of every cluster by the base station. To avoid that the number of nodes in some cluster is extremely high, which may put a high load on the cluster head to drain the power of it quickly, we set a high threshold \( N_t \) to the maximized number of nodes one cluster can have. If the number of nodes in one cluster is large than \( N_t \), the number of the clusters is added by one and the huge cluster is divided into two to lessen the load of the cluster head.

B. Geography based routing In The Cluster

At the beginning of the new round another important process is to find whether there exist some nodes who are positioned so close that only one of them must keep awake to monitor the environment and communicate with the cluster head, while others can sleep to save energy. As in the previous subsection, in the first round, the base station has computed the distance between any two nodes, and the station has the information of which nodes are in the same cluster. Then if there is a zone with a diameter less than a threshold value \( d_T \) and with more than two nodes in it, the information gathered by the nodes in this zone is exactly the same so that only one node should keep awake to monitor the environment, and others can go to sleep. At the start of the first round, the base station will also tell the nodes whether they are in the typical zone described above and whether the current node should be awake. In the later round, the awaken node is selected randomly among the nodes who has not be awake before. If all the nodes have been tried, then the node with the highest energy level will be awake for the new round. The awake node will send a message to other nodes in the zone to let them sleep.

C. Set-up Phase

Because the maximum number of the cluster members is determined, the TDMA scheme can be used to schedule the cluster member at every round. At the beginning of every round, all the nodes turn on the receiver. Then the cluster head will broadcast a message that contains the TDMA time slot information. Each cluster member will know the time slot that belongs to it. Thus the cluster member will keep the transceiver off until its time slot. It transmits the sensing data to the cluster head during its time slot. Once the clusters are created and the TDMA schedule is fixed, data transmission can begin, when the nodes transmit data during its own TDMA schedule and only turn on its radio. Only the cluster head turns on the radio all the time.

D. Forwarding Phase

In this phase, the cluster heads transmit data to the base station. Unlike LEACH, not all the cluster heads communicate with the base station directly. We take the measure similar to the traditional minimum energy routing protocol (the TME in [2]). After the clusters have been constructed, the cluster head broadcasts its position and current energy level to the whole network. All the current cluster head nodes store a routing table. Assumed that A and B are two cluster heads, node A who wants to send data to base station will first consider node B as its next hop node, if node B satisfies the following inequality (4) and the energy level of node B is higher than node A. Node A will save node B in the routing table and will

\[ E_{Tx - AB} + E_{Rx} + E_{Tx - BS} < E_{Tx - AS} \]

\[ E_{elec} + \varepsilon_{amp} \cdot d_{AB}^2 + E_{elec} + E_{elec} + \varepsilon_{amp} \cdot d_{BS}^2 < E_{elec} + \varepsilon_{amp} \cdot d_{AS}^2 \]

\[ 2 \cdot E_{elec} + \varepsilon_{amp} \cdot d_{AB}^2 + \varepsilon_{amp} \cdot d_{BS}^2 < \varepsilon_{amp} \cdot d_{AS}^2 \]

(4)

selected the node B as the next hop if \( d_{AB} \) is the minimum among the distance from node A to other cluster heads and satisfies the above condition. Then the data will be sent in the style of multi-hop from the cluster heads to the base station.

V. SIMULATION AND COMPARISON

In this paper, simulations are given for the protocol proposed with MATLAB, and the results compared with that of LEACH and MTE. The following experiments are implemented: the partition of nodes to clusters; the energy consumption when \( E_{elec} \) is changed from 10nJ/bit to 100nJ/bit and the diameter \( D \) of the nodes field is changed from 100m × 100m to 1000m × 1000m; the life time of the sensor network in which the nodes have three different energy level and are distributed in a 100m × 100m and 1000m × 1000m respectively.
A. The Clustering

The nodes of the sensor network are randomly with uniform distribution placed in a $100 \times 100$ field depicted in Fig. 1 and the results of the clustering of LEACH and our protocol are shown in Figs. 2 and 3 respectively. In the figure, the points with hollow center are the cluster members and the points with solid center are the cluster heads. We can see from Fig. 2 that most of the cluster heads of the first round of LEACH are in the right bottom of the field, because the base station in this paper is placed at (0,-100), then the energy consumed for the nodes in the left to send data to their cluster head is not much less than that to the base station directly. And the clustering dose not achieve the objective of saving energy. But in Fig. 3, the cluster heads are selected near uniformly according to the distribution of the nodes which will get a near optimal result which will be shown in the next experiment.

In Fig. 4, the mesh on the top describes the energy consumed by the network with LEACH and the bottom one is that of the proposed protocol. The picture describes that the energy consumed by the network with the proposed protocol is less than that with LEACH protocol though there exists some vibration because of the random distribution of the network nodes. And as the extent of the field becomes larger, the energy difference is larger which is show in Fig. 5 where $E_{elec}$ is 50nJ/bit, and $D$ is changed from $1000m \times 1000m$ to $10450m \times 10450m$. We can see from figure that, the energy consumed is much less by the network with the proposed protocol than that with LEACH, where the biggest improvement is bigger than 25% except for some limited points which evince the uneven distribution of cluster head with LEACH.

B. The Situation when $E_{elec}$ and $D$ change

The following Fig. 4 shows the energy consumed by the nodes with the LEACH and the proposed routing protocol when $E_{elec}$ is changed from 10nJ/bit to 100nJ/bit and the extent of the field is changed from $100m \times 100m$ to $1000m \times 1000m$.

C. The life time of the network

At last, we compare the network life time of the network using our routing protocol with that of LEACH and Direct. The life time of the network means the life time of most of the nodes in it, not that of the last node. The simulation results are shown in Fig. 6 and Fig. 7, and the nodes life are shown in
Table 1 and Table 2. In Fig. 6, the $E_{elec}$ is $10nJ/bit$ and $D$ is $100m$, the $x$ axis of the figure is the index of the nodes in our nodes array. The figure shows that most of the nodes have life time more than 1200 rounds except for several nodes with the life time of 500 plus rounds. And Table 1 records the first round and the last round the node dies, which are 585 and 1596 respectively when the node has the initial energy level 0.5J. But in the network with the routing protocol LEACH, the first node dies at the 346 round and the last node dies at the 3753 round, which can also be seen from Fig. 6 where the life time of the nodes is very different from each other and there are not less than 80 nodes when there are only 1000 rounds. It is known all that if number of the dead nodes accounts for some proportion to the total number the network will lose its function. So though the node in the network with LEACH die last at the 3753 round which is much larger than that of network using our protocol, the nodes die gradually in the former where the network will be malfunction quickly and the later shows a much even situation than the former. And the performance is even better when the extent of the network is larger which is shown in Fig. 7 and Table 2.

Fig. 7 and Table 2 show the life time when the extent of the field is $1000m \times 1000m$ and the initial energy of the nodes is $1J$. Under this condition, the three protocol show the similar performance as the previous experiment. But the curve for the proposed protocol is more smoothly than the previous one, but the performance difference among the three protocol is more obvious such as there are about 85 nodes left and 65 nodes left respectively for the protocol proposed in this paper and LEACH at the 20 plus round. This experiment shows the protocol proposed in this paper has a better environment flexibility than LEACH.

VI. CONCLUSION

In this paper, a power-efficient routing protocol for wireless sensor network which is also a cluster based and is an improvement on LEACH is proposed. The traditional clustering algorithm is adopted to divide the nodes into clusters and the cluster heads are selected according to the left energy level of the nodes which guarantees the even consumption of the energy among the nodes. The MTE like method is used for the cluster head to send data to the base station and geographical routing scheme is used for the cluster members to send data to cluster head. The simulation results show that the network life time using the proposed protocol is much longer than that with LEACH, and there is also an improvement of the energy saving on LEACH. Overall the protocol proposed in this paper overtakes the two main drawbacks of LEACH.

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TABLE II
THE LIFE TIME OF NODE OF THE FOLLOWING PROTOCOLS WHEN THE ZONE IS IN A SIZE OF 1000m × 1000m

<table>
<thead>
<tr>
<th>Energy (J/node)</th>
<th>Protocol</th>
<th>Round First Node dies</th>
<th>Round Last Node dies</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>Direct</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>LEACH</td>
<td>1</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Proposed</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>1</td>
<td>Direct</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>LEACH</td>
<td>3</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td>Proposed</td>
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<td>42</td>
</tr>
<tr>
<td>2</td>
<td>Direct</td>
<td>3</td>
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<td>LEACH</td>
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REFERENCES