The distance-based adaptive grouping protocol for heterogeneous wireless sensor networks

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Abstract

Wireless sensor networks (WSNs) are widely applied to many applications. Reducing energy consumption plays an important role in WSN. The concept of clustering is one of the popular energy-efficient protocols and it is applied to SEP, DEEC and SGCH technologies. Since the communication energy consumption depends on the communication distance, the communication distance and the residual energy of the sensor node should be considered for the clustering. In this paper, we propose a distance-based adaptive grouping protocol for the heterogeneous WSN. The energy and the distance of a group are used to generate the cluster head. This study compares the proposed method with LEACH, SEP, DEEC and SGCH with three-level heterogeneous WSN. The simulations also compare that the performances with the location of BS is outside and inside the WSN topology.

Key: energy-efficient, clustering, heterogeneous

1. Introduction

In recent years, the development of the micro-manufacture, communication and battery technologies has reduced the size of the communication equipment. It has also made the Wireless Sensor Network (WSN) come true [1]. We can compose the sensor, wireless communication, and data processing units into a sensor node which is the basis of WSN. A WSN contains a large number of sensor nodes. The sensor node not only senses, but also collects and transmits the sensed data to the base station (BS) by wireless communication. WSNs are widely used in many applications of smart living, environmental monitoring, industrial monitoring, agriculture, and traffic monitoring [1][20].
The SEP (Stable Election Protocol) is designed for two-level heterogeneous WSN that includes two type sensor nodes. The two type sensor nodes are the advance nodes and the normal nodes. The advance node carries more energy than the normal node at the beginning [16]. In the SEP, the choice of the cluster head does not only depends on the probability, but also considers the energy of the sensor node. This is why SEP extends the life time of the heterogeneous WSN. However, the SEP is only applied for two-level heterogeneous WSN.

The DEEC (Distributed Energy-Efficient Clustering) is proposed to improve the SEP scheme [14]. It can be used for multi-level heterogeneous WSN. The node expends energy uniformly by rotating the cluster head role among all nodes. The cluster heads are selected by the residual energy ratio of the sensor node and average network energy. If the node has more residual energy, it has the higher probability to be the cluster head. DEEC achieves longer lifetime than the SEP and it is also suitable for multi-level heterogeneous WSNs. However, to reduce energy consumption, we should not only consider the residual energy of sensor nodes (or the cluster heads), but also the distance of communication.

Considering the distance between the sensor node and the BS, the SGCH (Steady Group Clustering Hierarchy) is proposed [18]. At the beginning, the farthest node (whose distance is farthest from the BS) is chosen to be the first group head. The group head selects other sensor nodes close to the group head to be the group members with a fixed member number. When the group is filled, the other group head will be chosen from non-member nodes. The groups are generated until every sensor node belongs to a group. After the grouping stage, each group selects a sensor node with maximum residual energy from the group members to be a cluster head. The cluster heads also form their own cluster (this procedure is the same as LEACH). We can see that a fixed member number is used to form the group to make the cluster head distribution uniform. When SGCH is applied to the homogeneous WSN, the total energies of every group are the same. If we apply SGCH to the heterogeneous WSN, the total energies of every group may be different. However, since a greater distance requires more energy, the group farther from the BS should contain more energy.

In this paper, we modify the grouping scheme of SGCH, and propose a distance-based adaptive grouping protocol (DAGP) for the heterogeneous WSN. The total energy of a group is used in place of the fixed member number of a group. A simple distance ratio is also used to determine the total energy of a group. In the simulations, we compare the proposed method with LEACH, SEP, DEEC and SGCH with three-level heterogeneous WSN. Since the location of the BS influences the distance, the simulations also compare that the performances with the location of BS is outside and inside the WSN topology.

2. DAGP

The proposed method is based on SGCH. Like the SGCH, the method is divided into a grouping stage and a data transmission stage. The focus of this paper is to improve the grouping stage algorithm. The proposed scheme is called the distance-based adaptive grouping protocol (DAGP). The data transmission stage is the same in the SGCH.

At the beginning, we calculate the energy allocation of the groups. Since the farther group should contain more energy, the distance from the WSN topology to the BS is considered. In other words, we have to allocate more energy for the farther group.

We set \( k \) as the number of expected groups and it equals to the number of expected cluster heads. Firstly, we define the distance index (\( GD_i \)) and it can be obtained by

\[
GD_i = (D_n + D_f + (k - i + 1) \cdot \frac{D_n + D_f}{2k})^2,
\]

where \( GD_i \) is the distance index of the group \( i \), \( D_n \) is the nearest distance from BS to the sensing region, \( D_f \) is the farthest distance from BS to the sensing region are shown in Fig. 1. It should be noted that \( i \leq k \). The distance indices are used to compute the total energy of each group. The total energy of group \( i \) is denoted as \( GE_i \) which can be obtained by

\[
GE_i = E_i \cdot \frac{GD_i}{\sum_{j=1}^{k} GD_j},
\]

where \( E_i \) is the total energy of all nodes. According to Eq. (1) and Eq. (2), we can see that the farther group can be allocated more energy than nearer group. The process flow of the grouping stage is summarized as follows:

Step 1. BS broadcasts a group head request (GHR) message to all nodes. When
each sensor node received the GHR message, the node returns an acknowledgement (ACK) message to BS. The ACK message including the ID and the initial energy of the node.

**Step 2.** BS creates an order list (OL) according to the received order to the ACKs. The BS calculates energy allocation of each group by Eq. (1) and Eq. (2) when all ACKs are received.

**Step 3.** BS selects a node whose OL number is the maximum to be the first group head. The first group is denoted as $G_1$ and the first group head is denoted as $GH_1$. Then BS sends a group head (GH) message to $GH_1$. The GH message includes the group ID and the total energy of $G_1$.

**Step 4.** A node is $GH_i$ (the group head of $i$th group) when it received the GH message. $GH_i$ has to find the members of the group. The group head broadcasts a group request (GR) message to all nodes. The GR message includes the group ID and the group head ID.

**Step 5.** When the node receives the GR message from $GH_i$, it will respond with an ACK message to $GH_i$ unless it belongs to a group. On receiving the ACK messages, $GH_i$ accumulates the initial energy of nodes in the sequence according to the receiving order. When the sum of the accumulated energy is equal to, or bigger than, the allocated group’s total energy, the nodes whose energies are accumulated are set to be the members of the group. The node of the next ACK reception is set to be the head of the next group. $GH_i$ sends the GH message with adding 1 into the group ID.

Steps 3-5 are repeated until each sensor node belongs to a group. When the grouping stage is finished, the BS will broadcast a message to all sensor nodes for starting the data transmission stage. The data transmission stage is the same in the SGCH.

### 3. Model

We have created a simple radio model to simulate the WSN performance [6]. The transmitter dissipates energy to run the radio electronics and the power amplifier. The receiver dissipates energy to run the radio electronics. When a node transmits a message with $l$ bits through a distance $d$, it expends $E_{Tx}(l,d)$ energy and

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\epsilon_{fs} d^2, & d < d_0 \\ lE_{elec} + l\epsilon_{mp} d^4, & d \geq d_0 \end{cases}$$

(3)

When the node receives the message, it expends $E_{Rx}(l)$ energy and

$$E_{Rx}(l) = l\epsilon_{elec}$$

(4)

where $\epsilon_{elec}$ and $\epsilon_{fs}d^2$ (or $\epsilon_{mp}d^4$) are the electronics energy and the amplifier energy, respectively. The parameters of energy in this paper are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\overline{E}_{elec}$</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>$\epsilon_{fs}$</td>
<td>10 pJ/bit/m$^2$</td>
</tr>
<tr>
<td>$\epsilon_{mp}$</td>
<td>0.0013 pJ/bit/m$^4$</td>
</tr>
<tr>
<td>Data size</td>
<td>4000 bits</td>
</tr>
<tr>
<td>Message size</td>
<td>100 bits</td>
</tr>
</tbody>
</table>

We also assume a wireless sensor network model with the following properties:

1. The nodes are uniformly deployed in a 100m $\times$ 100m square region at random.
2. This study compares that the performances with the location of BS is outside and inside the WSN topology. If the BS is located outside, its coordinates are (50, 175). Otherwise, its coordinates are (50, 50).
3. There are 100 sensor nodes which are immobile.
4. The number of clusters and groups is 5.
5. There are three types of sensor nodes: the high advanced node, middle advanced node and normal node with initial energy of 2J, 1J and 0.5J, respectively.
6. The nodes have the power control ability to vary their transmitted power.
7. The node senses at a fixed rate and always has data to transmit to the BS.
8. The cluster head transmit the aggregated data to the BS directly.
9. We ignore collision and interference in the wireless communications.

### 4. Simulation results

MATLAB is used to evaluate the per-
formance of LEACH, SEP, DEEC, SGCH and the proposed method. Each method is simulated with three-level heterogeneous WSN. If all nodes are alive while WSN runs, it means that the network is complete. When the first node dies, the network becomes incomplete, and the network performance will decrease. In this study, the time of the first node’s death is used to evaluate the lifetime of the WSN.

In the first simulation, we generate 20 WSN topologies. In each topology, we deploy 30 high advance nodes, 30 middle advance nodes and 40 normal nodes at random. The BS is located outside the topology. The results of the average number of nodes alive over rounds and the average number of messages received in BS at first node dead are shown in Fig. 2(a) and (b), respectively. We can see that lifetime of the proposed method is longer than that of other methods. When using the proposed method, the BS also receives the most data. The performance of the proposed method is the best in this case.

In the second simulation, the setup of the WSN topologies is the same in the first simulation, but the BS is located inside the topology. We also generate 20 WSN topologies at random. The results of the average number of nodes alive over rounds and the average number of message received in BS at first node dead are shown in Fig. 3(a) and (b), respectively. We can see that the performance of the proposed method is slightly lower than that of SGCH.

5. Conclusion
Since reduction of the energy consumption plays an important role in WSN. In this paper, a distance-based adaptive grouping protocol is proposed for the heterogeneous WSN. The energy and the distance of a group are used to generate the cluster head. This study compares the proposed method with LEACH, SEP, DEEC and SGCH with three-level heterogeneous WSN. According to the simulation results, we can see that the performance of the proposed method is the best when the BS is located outside the WSN topology. When the BS is located inside the WSN topology, SGCH achieves the better performance than other methods.

Reference


Figure 1. The nearest and farthest distance from BS to the sensing region.

Figure 2. The results of the first simulation. (a) number of nodes alive and (b) number of BS receive.

Figure 3. The results of the second simulation. (a) number of nodes alive and (b) number of BS receive.