A Limited IST and Random Uniform Clustering Algorithm

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Abstract. In order to solve the problems of unbalanced energy consumption and shortened network lifetime caused by the uneven distribution of cluster heads (CHs) in wireless sensor networks, a Limited IST and Random Uniform Clustering Algorithm (LIRUCA) is proposed. The algorithm comprehensively considers the energy of nodes, the distance to the sink, and the correlation between nodes when selecting CHs, and limits the intra-cluster communication distance, thus improving the uniformity of CH distribution. Compared with LEACH, EBCRP, and LEACH-improved protocols, results of simulation experiments show that the LIRUCA algorithm can effectively improve the uniformity of clustering, reduce the energy consumption, and prolong the network lifetime.

Keywords: Wireless sensor network, Energy consumption, Lifetime.

1. Introduction

A wireless sensor network (WSN) is constituted by spatially distributed autonomous devices communicating wirelessly[1]. Usually, sensor nodes are deployed in harsh environments, and it is not realistic to refresh or restore the batteries[2]. Therefore, how to reduce energy loss and balance energy is the key issue to improve the performance of a wireless sensor network.

In order to prolong the lifetime of the wireless sensor network, Heinzelman et al. proposed a low energy adaptive clustering hierarchy routing LEACH protocol [3], which collects data in rounds. In each round, the nodes not selected as CHs generate a random number and compare it with the threshold \( T(n) \). If the random number is less than \( T(n) \), the node will become a CH; otherwise, the node is an ordinary node. In the LEACH protocol, nodes take turns to CHs, which can effectively balance the network energy consumption. However, due to the randomness of CHs, it is easy to lead to uneven distribution of CHs, resulting in unnecessary energy waste. In[4] an Energy Balanced Clustering Routing Protocol (EBCRP) for WSN was proposed, in which a distance empirical factor was introduced to improve \( T(n) \), the probability of a node as a CH is inversely proportional to the distance to the sink. An improved energy-saving algorithm for the energy efficient and balanced protocol (LEACH-improved) was proposed by Huang Li-xiao et al., which comprehensively considered the factors such as distance, node density, and residual energy when selected the CHs, and set weighting factors for each factor according to different application scenarios, so the CHs were distributed relatively evenly[5]. Alsnousi et al. proposed a Reliable and Energy-Efficient Two Levels Unequal Clustering Mechanism for wireless sensor networks (REUCS)[6], which divided nodes into
two levels by setting a threshold. Nodes in each level select CHs according to relevant rules and the nodes at the same level are clustered.

The election of CHs in [7][8] has strong randomness, which ignores the problem of energy consumption caused by the uneven distribution of CHs. Therefore, a Limited IST and Random Uniform Clustering Algorithm (LIRUCA) is proposed, taking into account factors such as residual energy, distance, and the correlation between nodes. By limiting the intra-cluster communication distance, the algorithm avoids the CHs in a certain area being too dense or sparse due to the probability election of CHs and the unreasonable cluster scale, effectively balances the energy consumption of the network and prolongs the lifetime of wireless sensor networks.

2. Energy consumption model

Using the energy consumption model in [9]:

\[
E_t(d) = \begin{cases} 
  e_{elec} + \omega_{f_s} d^2, & d < d_0 \\
  e_{elec} + \omega_{amp} d^4, & d \geq d_0 
\end{cases}
\]

(1)

\[
E_r = e_{elec}
\]

(2)

Usually, the modules that consume energy in sensor nodes include a sensor module, a processor module, and a wireless communication module, among which wireless communication consumes most of the energy[10], which is mainly in the transmitting and power amplifying circuits[11]. When transmitting 1bit data, the transmitting circuit consumes \(e_{elec}\) energy and the energy consumption of the power amplifying circuit need to be determined according to the transmitting distance. If the transmission distance \(d\) is less than the distance threshold \(d_0\), the energy consumption of the power amplifier circuit is \(\omega_{f_s} d^2\), otherwise, it is \(\omega_{amp} d^4\). The calculation method of \(d_0\) is shown in (3), and (2) represents the energy required by a node to receive 1bit data. Since the energy consumption of data processing is far less than that of data transmission, the energy consumption of data compression is ignored[12].

\[
d_0 = \sqrt{\frac{\omega_{f_s}}{\omega_{amp}}}
\]

(3)

3. Design of LIRUCA algorithm

3.1. Network initialization

Nodes are randomly and uniformly deployed in the monitoring area, and the initial energy is \(E_0\). Sink is located in the center of the network and has unlimited energy. Neither node nor sink can be moved. Nodes perceive nearby nodes in \(R\) radius and put the sensed nodes into the set \(S_{near}\).

3.2. Node association

LIRUCA judges whether there is a correlation between nodes by a correlation factor \(r_{node}\) which can be represented as:

\[
r_{node} = \frac{N_{same}}{N_{total}}
\]

(4)

Where \(N_{same}\) is the number of the same sensors in the \(S_{near}\), \(N_{total}\) is the size of \(S_{near}\) which is dynamically changing. If \(r_{node}\) is greater than the threshold \(T_{rele}\) (0-1), node \(N_i\) is associated with the nearby node \(S_o\) and vice versa. If the size of nearby nodes is 1, that is, only one node is stored, it is judged that there is a correlation between nodes.

3.3. Cluster mechanism of LIRUCA algorithm

At the initial stage of the network, the nodes with empty \(S_{near}\) directly become CHs until the energy is exhausted or the network dies. The remaining candidate nodes elect CHs iteratively according to the remaining energy and the distance to the sink in each round. In each iteration, the node with the largest \(F(E, D)\) is the CH.

\[
F(E, D) = \frac{E_r}{E_0} + \frac{D_{max} - D_{cur}}{D_{max} - D_{min}}
\]

(5)
Where $E_r$ represents the residual energy of the current node, $D_{\text{max}}$ and $D_{\text{min}}$ are the maximum distance and the shortest distance between the node and the sink respectively, $D_{\text{cur}}$ is the distance between the current node and the sink. When a node becomes a CH, in order to avoid the CH being too dense, the nearby nodes should not participate in the CH competition in this round, but considering that the nearby nodes may be the CHs needed by other nodes in the communicable range, it is more suitable to compete for CHs. Therefore, nodes that are not related to the CH continue to participate in the CH election. The LIRUCA process is shown in Fig.1.

![Flow chart of CH election](image)

**Fig. 1** Flow chart of CH election
In the first round of CH election, the nodes whose $S_{\text{near}}$ is empty are clustered separately until their energy is exhausted or the network dies. Then, the node with the largest value of $F(E, D)$ becomes the CH when the CH is elected iteratively. In order to avoid too dense CHs, the following two judgments should be made: (1) If the $N_{\text{total}}$ value of the node selected as the CH is 0 and other CHs already exist in the communicable range, it is regarded as an ordinary node. (2) If a nearby node is related to the CH, it will withdraw from this round of CH election. Update $S_{\text{near}}$ before the next CH election, and delete nodes (CHs and related nodes) that no longer participate in CH competition from $S_{\text{near}}$. When no node participates in the CH election again, the sink broadcasts the CH ID to the whole network.

The CH broadcasts its own information with itself as the center and $R$ as the radius, and the ordinary node chooses to send the cluster request to the cluster with a strong signal. The CH election mechanism of the proposed algorithm ensures that all ordinary nodes in the network can be clustered in the $R$ range, which limits the communication distance within the cluster.

Fig.2 shows the average variance of the number of nodes in the cluster of four protocols in the network lifetime. Variance indicates the deviation degree between the number of nodes in each cluster and the average number of nodes in the cluster. The smaller the variance is, the more uniform the clustering is. It can be seen from Fig. 2 that the variance of the proposed algorithm is much smaller than other algorithms, which proves that the CH distribution of LIRUCA algorithm is more uniform and the clustering is more reasonable.

![Fig. 2 Comparison chart of the average variance of node number in cluster](image)

### 4. Simulation analysis

#### 4.1. Simulation parameter setting

Set the size of the wireless sensor network is $400 \times 400$ m. Other parameters required for the experiment are shown in Tab.1.

| Parameter         | Value                        |
|-------------------|------------------------------|
| Number of nodes   | 200                          |
| $E_0$             | 0.5J                         |
| Data packet size  | 4000bit                      |
| Control packet size | 200bit                      |
| $w_{fs}$          | $10 \text{ pJ} / (\text{bit m}^2)$ |
\[
\begin{array}{ll}
\text{\textit{w}}_{\text{amp}} & 0.0013 \text{ pJ/(bit\cdot m^4)} \\
\text{\textit{e}}_{\text{elec}} & 50 \text{ nJ/bit} \\
R & 50 \\
T_{\text{rel}} & 0.6
\end{array}
\]

\textbf{Tab.1 Simulation Parameters}

4.2. \textit{Experimental results and analysis}

Compare LIRUCA algorithm with LEACH, EBCRP, and LEACH-improved protocol. The number of surviving nodes of each protocol changes as shown in Fig.3.

\textbf{Fig.3} Changes in the number of surviving nodes

It is defined that when the number of surviving nodes in the network is less than 21\% of the original total number, the network is regarded as invalid. As can be seen from Fig.3, in the proposed LIRUCA algorithm, 79\% of the nodes dead occur in 380 rounds, that of LEACH, EBCRP, and LEACH-improved protocol occurs in 232 rounds, 244 rounds, and 265 rounds respectively. In the 1~52 rounds of the proposed algorithm, the number of surviving nodes is basically consistent with LEACH protocol. However, in the 53rd round, there is a turning point, the death rate of nodes begin to slow down, and the number of surviving nodes is significantly higher than that of LEACH protocol. Compared with the EBCRP protocol, the proposed algorithm always has the node number curve above the EBCRP protocol from the 14th round to the network death. In 1~125 rounds, the curve decline trend of the proposed algorithm is similar to that of LEACH-improved protocol, and there is a little difference in the number of surviving nodes. At the beginning of the 126th round, the curves show significant differences, which become larger and larger with the increase of network running rounds. In short, compared with LEACH, EBCRP, and LEACH-improved protocol, the proposed LIRUCA algorithm balances the global energy consumption more effectively, slows down the decline of nodes, and effectively prolongs the network lifetime.

The comparative diagram of the residual energy of four protocol networks is shown in Fig.4, from which we can see that the proposed algorithm curve is always above the three other protocol curves under the same initial energy. Obviously, the proposed protocol has a lower energy consumption and higher energy utilization rate, which strongly proves the conclusion drawn from Fig.3.
Fig. 4 Change of residual energy

5. Conclusion
Aiming at the problem of energy consumption in wireless sensor networks, a limited IST and random uniform clustering algorithm (LIRUCA) is proposed. Simulation results show that the algorithm is better than LEACH, EBCRP, and LEACH-improved protocol in CH distribution, cluster size, and network energy balance, which balances node energy consumption more effectively, improves energy utilization, and prolongs the lifetime of wireless sensor networks.

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