Research on Balanced Energy Consumption of Wireless Sensor Network Nodes Based on Clustering Algorithm

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***Abstract*—A multi-cluster-head based clustering routing algorithm is researched and realized in order to achieve better balance the energy consumption of wireless sensor network nodes as well as promote the stability and extend the service life of the network. By taking cluster as the basic unit, it divides the wireless sensor network into multiple clusters, each of which includes a main cluster head node, an assistant cluster head node, a cluster management node and several ordinary nodes. The article elaborates the energy consumption model of the wireless sensor network, the network topological structure of the multi-cluster-head based clustering routing algorithm and the method for realization. In addition, it conducts simulation and analysis on the multi-cluster-head based clustering routing algorithm. According to the results, the algorithm can achieve preferable balance on energy consumption of various nodes in the wireless sensor network, which effectively extends the service life and improves the stability of the wireless sensor network. It has good application prospects.**

Keywords---Wireless sensor network; Balanced energy consumption; Clustering algorithm; Multi-cluster-head; Data fusion

I. INTRODUCTION

The wireless sensor network is composed by large quantities of sensor nodes deployed within the supervision region, which forms a multi-hop self-organizing network system with wireless communication, in order to coordinate perception as well as collect and manage the information of the perceived objects within the coverage of the network [1, 2]. Operating in unattended environment for a long term, the nodes of the wireless sensor network are generally powered with batteries. Due to the limited energy of batteries, nodes lose efficacy with the exhaustion of energy in batteries. There are unbalanced energy consumptions between cluster head nodes and ordinary nodes in a cluster, in which the former ones need to receive and integrate the data of other nodes in the cluster, and then send the data to the base station in a way of single-hop or multi-hop. Cluster head nodes generally consume more energy considering that they need to receive and transmit data frequently. Ordinary nodes in the cluster generally have less energy consumption considering that they need only to perceive information and send it to cluster head nodes. Cluster head nodes in different clusters have unbalanced energy consumptions [3]. Due to unbalanced energy consumptions among various nodes in the wireless sensor network, the ones with more energy consumption will die soon, which gives rise to influence on the stability and the topological structure of the wireless sensor network and shortens the service life of the network [4]. The preferable balance on energy consumptions among various nodes in the wireless sensor network plays an important role in extending the service life and improving the stability of the wireless sensor network.

II. THE MODEL FOR ENERGY CONSUMPTION OF WIRELESS SENSOR NETWORK NODES

The energy consumption of wireless sensor network nodes includes the calculation energy consumption and the communication energy consumption, in which the latter one occupies larger proportion in node energy consumption [5]. TABLE I shows the energy consumption of a communication module.

TABLE I. ENERGY CONSUMPTION OF A WIRELESS COMMUNICATION MODULE

State of the wireless communication module	Energy consumption[mW]
Sending	14.73
Receiving	12.29
Idle	12.10
Dormant	0.015

The energy consumed for sending the data of m bit by the node in the wireless sensor network is as shown in (1) and (2).

$$E_{fs}(m,d) = mE_{elec} + m\varepsilon_f d^2 (d \le d_0) \quad (1)$$

$$E_{fs}(m,d) = mE_{elec} + m\varepsilon_n d^4 (d > d_0) \quad (2)$$

The E_{elec} in (1) and (2) is the energy consumed for sending the data of 1 bit by the node; ε_f is the energy consumption magnification times within unit distance in condition of free space model as the transmission channel; ε_n is the energy consumption magnification times within unit distance in condition of multi-route attenuation model as

the transmission channel; d is the distance between the sending node and the receiving node. The energy consumed for receiving the data of m bit by the node is as shown in (3). The energy consumed for integrating the data of m bit by the node is as shown in (4).

$$E_{js}(m) = mE_{elec} \tag{3}$$

$$E_{rh}(m) = mE_r \tag{4}$$

The E_r in (4) is the energy consumed for integrating the data of 1 bit by the node. The energy consumption of the cluster head node in the wireless sensor network usually includes the energy consumed for data transmission with ordinary nodes in the cluster, the energy consumed for data integration to the data in the cluster as well as the energy consumed for data transmission between the cluster head node and another cluster head node or the base station. The energy consumption of the cluster head node is as shown in (5) and (6).

$$E_{ct}(d) = nE_{elec} + pE_r + mE_{elec} + m\varepsilon_f d^2 \quad (d \le d_0) \tag{5}$$

$$E_{ct}(d) = nE_{elec} + pE_r + mE_{elec} + m\varepsilon_n d^4 \quad (d > d_0) \tag{6}$$

The d in (5) and (6) is the distance between the cluster head node and the base station or between different cluster head nodes. The energy consumption of the cluster head node is related to the quantity of ordinary nodes in the cluster and the distance between the cluster head node and the base station. Large quantity of nodes in the cluster leads to large energy consumption for data integration between the cluster head and the data in the cluster. In condition that the single-hop method is adopted for the direct data transmission between the cluster head and the base station, the cluster heads far away from the base station consume more energy during data transmission with the base station. In condition that the multi-hop method is adopted for data transmission between the cluster head and the base station, the cluster heads closer to the base station consume more energy. Due to unbalanced energy consumptions of different cluster heads, the ones with large energy consumption will become failure nodes or death nodes very soon, giving rise to influence on the stability and the service life of the wireless sensor network.

The energy consumption for ordinary nodes in the cluster mainly involve in the energy consumption for data transmission with cluster heads, with the energy consumption expression as shown in (7) and (8).

$$E_{ct}(d) = aE_{elec} + bE_{elec} + b\varepsilon_f d^2 \quad (d \le d_0) \tag{7}$$

$$E_{ct}(d) = aE_{elec} + bE_{elec} + b\varepsilon_n d^4 \quad (d > d_0) \tag{8}$$

The d in (7) and (8) is the distance between ordinary nodes and cluster head nodes in the cluster. Considering that there are different distances between various ordinary nodes and cluster head nodes in the cluster, the ordinary nodes closer to cluster head nodes consume less energy, and the ones far away consume more energy. Due to the unbalanced energy consumptions for ordinary nodes, the ordinary nodes with larger energy consumption will become failure nodes or death nodes very soon, giving rise to the stability and the service life of the wireless sensor network. The effective balance on the energy consumption of various nodes in the wireless sensor network plays a very important role in improving the stability and extending the service life of the wireless sensor network.

III. CLUSTERING ALGORITHM BASED ON MULTI-CLUSTER-HEAD

A. Clustering Algorithm for Single-cluster-head

Clustering algorithm refers to the division and management on the wireless sensor network with unit of cluster. A cluster includes cluster head nodes and ordinary nodes. In which cluster head nodes conduct management on ordinary nodes in the cluster and receive the data from the ordinary nodes in the cluster; in addition, cluster head nodes integrate and transmit data, in order to effectively reduce network energy consumption and extend the service life of the network [6,7]. LEACH algorithm is a typical clustering routing algorithm; the nodes in the cluster collect data and send the data to cluster head nodes, which integrate the data and directly send the integrated data to the base station [8]. Each node in the wireless sensor network selects a value from 0-1 randomly; in condition that the randomly selected value by the node is less than the threshold value $T(n)$, the node is selected as the cluster head node [9]. The expression for calculation of the threshold value $T(n)$ is as shown in (9) .

$$T(n) = \begin{cases} \frac{p}{1 - p \times \mathrm{mod}(r, 1/p)} & n \in G \\ 0 & \end{cases} \tag{9}$$

The p In (9) is the proportion of cluster head nodes in all the nodes of the wireless sensor network; $\mathrm{mod}(r, 1/p)$ is the number of the selected cluster head nodes in current round of circulation; G is the set of the unselected cluster head nodes in recent $1/p$ round; r is the round of the

network. The design of $T(n)$ can effectively balance the energy consumptions of various nodes in the cluster [10].

There may be single or multiple cluster head nodes in each cluster in the clustering algorithm. In condition of cluster division and management in a way of single cluster head, compared with other ordinary nodes in the cluster, cluster head nodes need to consume more energy due to frequent receiving of the data of other nodes in the cluster as well as integrating and transmitting of data. The energy consumed by cluster head nodes is different from that of ordinary nodes in any cluster. Due to different numbers of ordinary nodes in different clusters as well as different distances between cluster head nodes and the base station, different cluster head nodes consume different energies in the wireless sensor network. In order to effectively balance the energy consumption among nodes in the wireless sensor network and avoid premature failure or death of cluster head nodes due to too much consumption, the wireless sensor network needs to select cluster head nodes at set interval of t. In condition of too large t value, cluster head nodes may lose efficacy or die due to too much consumption, leading to influence on the topological structure and the service life of the wireless sensor network. In condition of too small t value, the wireless sensor network consumes large quantities of energies due to frequent selection of cluster head nodes, shortening the service life of the wireless sensor network. It is critical to select a suitable t value for the balancing of the energy consumption among various nodes in the wireless sensor network. However, it is difficult to accurately select and set a suitable t value. The re-selection of cluster head nodes in the whole wireless sensor network needs to consume a lot of energy consumption of nodes, which gives rise to the service life of the network. The reduction on the energy consumed for re-selection of cluster head nodes plays a critical role in extending the service life of the wireless sensor network. The energy consumption of cluster head nodes in the clustering algorithm of single cluster head includes data receiving related energy consumption, data integrating related energy consumption and data transmission related energy consumption [11]. Data receiving related energy consumption mainly includes the energy consumed for receiving the data of other nodes by cluster head nodes; data integration related energy consumption mainly involves in the energy consumed for integrating the data in the cluster by cluster head nodes; data transmission energy consumption mainly refers to the energy consumed for the transmitting of the data in the cluster to the base station or other cluster head nodes by cluster head nodes. The energy consumption of ordinary nodes in the cluster mainly involves in data transmitting related energy consumption. Effective reduction of energy consumption of cluster head nodes plays a critical role in balancing the energy consumption among various nodes in the wireless sensor network.

B. Clustering Algorithm for Multi-cluster-heads

A multi-cluster heads based clustering algorithm is designed aiming at the characteristics of single-cluster-head based clustering algorithm, with the topologic structure of the wireless sensor network as shown in Fig. 1. Each cluster includes a main cluster head node, an assistant cluster head node, a cluster management node and several ordinary nodes.

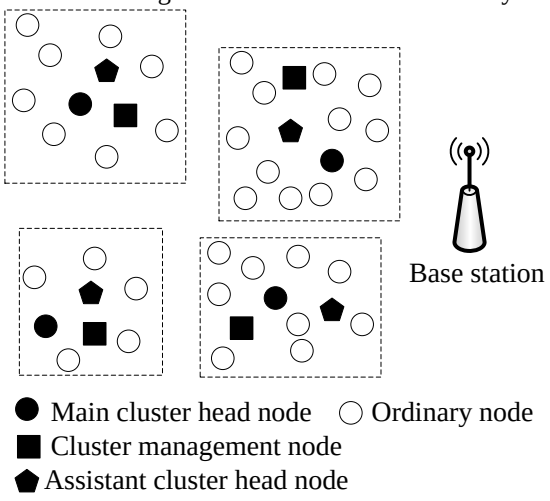

Figure 1. Topologic structure of the wireless sensor network

The basic process of the clustering algorithm is listed as follows.

Step 1: Select main cluster head nodes. Select several main cluster head nodes from the wireless sensor network by adopting the cluster head selection algorithm, and assumes that each node can perceive its own residual energy.

Step 2: Add the nodes into corresponding main cluster head node network by taking cluster as the unit, and send related information such as the residual energy of the nodes to main cluster head nodes for saving.

Step 3: According to the residual energy of various member nodes, the main cluster head node selects two nodes with the highest residual energy as the assistant cluster head node and the cluster management node.

Step 4: The main cluster head node sends the information of various member nodes and main cluster head nodes in the cluster to cluster management nodes for saving.

Step 5: The assistant cluster head node receives the data of various ordinary nodes in the cluster and integrates the data, and then transmits it to main cluster head nodes. The energy consumption of assistant cluster head nodes is as shown in (10).

$$E_{fct}(d) = aE_{elec} + bE_r + cE_{elec} + c\varepsilon_f d^2 \tag{10}$$

The d in (10) is the distance between the assistant cluster head node and the main cluster head node

Step 6: The main cluster head nodes receives the data of the assistant cluster head node, and sends the data to the base station or other cluster head nodes in a way of single-hop or multi-hop. The energy consumption of the main cluster head node is as shown in (11) and (12).

$$E_{zct}(d) = kE_{elec} + zE_{elec} + z\varepsilon_f d^2 \quad (d \le d_0) \tag{11}$$

$$E_{zct}(d) = kE_{elec} + zE_{elec} + z\varepsilon_n d^4 \quad (d > d_0) \quad (12)$$

In which the d in (11) and (12) is the distance between the main cluster head node and the base station or between different main cluster head nodes.

Step 7: In the wireless sensor network, it is necessary to reelect cluster head nodes in time in condition of too much energy consumption due to unbalanced energy consumption among cluster head nodes in the cluster, in order to avoid the influence on the stability and the service life of the wireless sensor network caused by failure or death of cluster head nodes. Considering that various cluster head nodes consume different energy consumptions, it is unnecessary to reelect cluster head nodes for the ones with sufficient residual energy, but it is needed to reelect cluster head nodes in time for the ones with insufficient residual energy. The reelection of cluster head nodes in the whole range of the wireless sensor network at regular intervals needs to consume a lot of energy of nodes. This algorithm conducts management and reelection to cluster head nodes in the cluster by taking cluster as the basic unit, in order to effectively reduce the energy consumed for reelection of cluster head nodes. Cluster management nodes in the cluster inquire the residual energy of the main cluster head node and the assistant cluster head node in the cluster at regular intervals. In condition that the residual energy of the main cluster head node or the assistant cluster head node is lower than the preset threshold value, cluster management nodes give a warning message to the main cluster head node, to reelect cluster head nodes in the cluster. In condition of accidental failure or death of the main cluster head node or the assistant cluster node, cluster management nodes take over the functions of the main cluster head node or the assistant cluster head node temporarily and reelect cluster head nodes. The energy consumption of cluster management nodes is as shown in (13).

$$E_{cgl}(d) = jE_{elec} + kE_{elec} + k\varepsilon_f d^2 \quad (13)$$

In which the d in (13) is the distance between cluster management nodes and the main cluster head nodes or between different assistant cluster head nodes.

Step 8: In order to better balance the energy consumption among various nodes in the cluster and reduce the energy consumption for data integration of the assistant cluster head node, ordinary nodes in the cluster conduct integration to collected data and then send the integrated data to the assistant cluster head node. The energy consumption of ordinary nodes in the cluster includes data transmission energy consumption and data integration consumption, with related expression as shown in (14).

$$E_{pt}(d) = mE_r + pE_{elec} + p\varepsilon_f d^2 \quad (14)$$

The d in (14) is the distance between ordinary nodes and the assistant cluster head node in the cluster.

IV. Experimental Analysis

The nodes in the wireless sensor network with too much energy consumption lead to premature failure or death, giving rise to influence on the topological structure and the service life of the network. Balanced energy consumption of nodes leads to large quantities of survival nodes in the wireless sensor network as well as stable topological structure and long service life of the network. Simulation is conducted through simulation software, obtaining the relationship between the number of the survival nodes and the time of the network as shown in TABLE II.

TABLE II. Changes of Number of Survival Nodes with Time

Time[s]	Number of survival nodes
0	200
2000	200
5026	199
10000	196
20000	189
30000	185
40000	173

According to TABLE II, no node died within the first 2000s during the operation of the network; the 1st node died at the 5026s during the operation of the wireless sensor network. The change on number of died nodes in the network is gentle during 10000s-40000s, without sudden death of large quantities of nodes, and there are sufficient surviving nodes in the network and balanced energy consumption among various nodes in the wireless sensor network.

V. Conclusions

In the wireless sensor network, the nodes with too much energy consumption will become premature failure nodes or death nodes due to unbalanced energy consumption among various nodes. Increased number of failure nodes and death nodes give rise to the topological structure of the wireless sensor network, shortening the service life of the wireless sensor network. This article researches and realizes a multi-cluster-head based clustering routing algorithm. By taking cluster as the basic unit, it divides the wireless sensor network into multiple clusters, each of which includes a main cluster head node, an assistant cluster head node, a cluster management node and several ordinary nodes. The assistant cluster head node is in charge of integrating the data in the cluster. The main cluster node is in charge of sends the data in the cluster to the base station or other cluster head nodes in single-hop or multi-hop. The cluster management node conducts management to the main cluster head node, the assistant cluster head node and ordinary nodes in the cluster; in addition, the cluster management nodes conducts supervision on the residual energy of the main cluster head node and the assistant cluster head node, and determines if it is necessary to reelect cluster head nodes in the cluster according to the residual energy of the main cluster head node and the assistant cluster head node. According to the results of simulation and test, the multi-cluster-head based

clustering routing algorithm proposed in this article can preferably balance the energy consumption among various nodes in the wireless sensor network, which effectively extends the service life of the wireless sensor network and improves the stability of the network.

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REFERENCES

[1] Y. Xu, L.J. Chen and L.X. Gan, "Principles and Applications of Wireless Sensor Network," Beijing, Tsinghua University Press, 2015, pp. 23-36.

[2] M.N. Yang, D. Yang and C. Huang, "An Improved HEED Clustering Algorithm for Wireless Sensor Network,"Journal of Chongqing University, vol. 35, Aug. 2012, pp. 101-106.

[3] X.L. Lu, Y.Y. Wang, H.B. Wang and B.G. Xu, "Energy-balanced Unequal Clustering Algorithm in Wireless Sensor Network, " Computer Science, vol. 40, May. 2013, pp. 78-81.

[4] C.X. Yang, L. Gao and C. Lu, "Research on the Clustering Algorithm of a Balanced Energy Consumption of Nodes for WSN," Journal of Jiamusi University(Nztural Science Edition), vol. 33, Nov. 2015, pp. 925-928.

[5] X.Q. Wang, Y.J. Ou and N.L. Huang, "Design and Implementation of ZigBee Wireless Sensor Network," Benjing, Chemical Industry Press, 2012, pp. 125-150.

[6] L. Kang and Z.S. Dong, "An Improved Unequal Clustering Algorithm Based on Cluster Head Classification," Chinese Journal of Sensors and Actuators, vol. 28, Dec. 2015, pp. 1841-1845.

[7] Z.Y. Tao and S.F. Jiang, "Clustering Algorithm for Wireless Sensor Networks with Mobile Clusterheads," Computer Engineering and Applications, vol. 52, Mar. 2016, pp. 75-78.

[8] H.B. Yu, W. Liang and P. Zeng, "Intelligent Wireless Sensor Network System," Beijing, Science Press, 2013, pp. 161-173.

[9] Z.Y. Sun and C. Zhou, "Adaptive Clustering Algorithm in WSN Based on Energy and Distance," Journal of Northeast Dianli University, vol. 36, Feb. 2016, pp. 82-86.

[10] C.S. Zhang, J. Xing and S.Q. Zhao, "Energy-efficeent Uneven Clustering Algorithm, " Computer Engineering and Applications, vol. 52, Apr. 2016, pp. 106-109.

[11] J.Z. Li, H.T. Wang and A. Tao, "An Energy Balanced Clustering Routing Protocol for WSN," Chinese Journal of Sensors and Actuators, vol. 26, Mar. 2013, pp. 396-401.