Residual energy level based clustering routing protocol for wireless sensor networks

Xu Yuan, Fangming Zhong, Zhikui Chen, Deli Yang
School of Software Technology, Dalian University of Technology, Dalian, P.R. China
Institute of Systems Engineering, Dalian University of Technology, Dalian, P.R. China

ABSTRACT

The wireless sensor networks, which nodes prone to premature death, with unbalanced energy consumption and a short life time, influenced the promotion and application of this technology in internet of things in agriculture. This paper proposes a clustering routing protocol based on the residual energy level (RELCP). RELCP includes three stages: the selection of cluster head, establishment of cluster and data transmission. RELCP considers the remaining energy level and distance to base station, while election of cluster head nodes and data transmitting. Simulation results demonstrate that the protocol can efficiently balance the energy dissipation of all nodes, and prolong the network lifetime.

Keywords: Wireless Sensor networks, Residual Energy Level, Clustering, Routing Protocol

1. INTRODUCTION

Wireless sensor network is an intelligent network, composed of a large number of cheap sensor nodes deployed in the monitoring region, through self-organizing wireless communication mode, achieving cooperative sensing, collecting and processing network information of objects in the coverage area, and sending it to users. Sensor nodes are usually powered by battery, and cannot be charged after its deployment, therefore the primary design goals of a sensor network is the efficient use of limited energy of sensor nodes, and maximizing the network lifetime.

As the first proposed hierarchical routing protocol for wireless sensor networks, LEACH, compared to the general plane multi-hop routing protocol and static clustering algorithm, to a certain extent, has solved fixed problems of occupying too much storage space, wide space for maintenance of the routing table, but it still has limitations in the following aspects. First of all, LEACH protocol does not take the residual energy of nodes into account while selecting the cluster head, which may make the node with little residual energy the cluster head node that resulted in the shortening of network’s lifetime. Secondly, because of the randomly selecting of cluster head node in LEACH, it may lead to a regional cluster of head nodes too concentrated in the certain domain of the network, in which case the distance between some member nodes and the cluster head node is too large and cause over consumption of energy for the communication within the clusters. Finally, the LEACH protocol uses direct hop in the inter-cluster communication, compared to the nodes near the base station, the farther ones are tend to run out of energy.

In view of the shortcomings of LEACH protocol, most studies of clustering routing protocol are focused on improving the cluster head selection algorithm, the inter-cluster multi-hop routing, uneven clustering strategies etc.. Jannu [1] proposed an algorithm for cluster head election that just considers the lower bond of node’s residual energy, neglect the balance of nodes’ residual energy. In MCEEC [2], average energy is taken into account for electing expected CHs, in addition the minimum distance to sink is considered. With randomly selecting head nodes from CHs, it couldn't balance the energy dissipation of cluster head nodes. Network area is divided into border area and inner area [3], to reduce the intra-cluster communication distance while increasing the lifetime, without balancing energy consumption of cluster headers; it may lead to hot spots problem.

Literature [4-7] in which the uneven clustering strategy is used to balance energy consumption between the cluster head nodes. [4]It proposes a clustering strategy of circular hierarchy. The closer to the base station, the smaller cluster structure size is, and the smaller covering region of the cluster head, thus energy that saves can be utilized for communication between clusters. But this algorithm just offers a clustering model, there is no clear point of the relationship of cluster structure size between each layer.[5] The sensor network is divided, the nearer the base station, the smaller area span is. Although this algorithm to a certain extent addressed the “hot spots”, the introduction of middle layer increased complexity of the algorithm and additional message expenditure. For inter-cluster communication, DEBUC [7] adopts an energy-aware multi-hop routing system and the unequal clustering to reduce and balance the

Sixth International Conference on Electronics and Information Engineering,
edited by Qiang Zhang, Proc. of SPIE Vol. 9794, 97940K · © 2015 SPIE
CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2205646

energy consumption of the cluster heads, and it can efficiently decrease the dead speed of the nodes, balance the energy dissipation of all nodes, and prolong the network lifetime.

To address the hot spots problem, in the stage of establishing a cluster, literature [8] considers distance between member nodes and cluster head nodes and the distance from cluster head nodes to base station. Member nodes join the cluster heads which are closer to themselves and far away from base station, thus to a certain extent reduces the burdens of cluster head nodes that are closer to base station. But in the stage of selecting cluster heads, with random, this algorithm generates candidate cluster head nodes with lower residual energy unavoidably. It is not obvious that the effect of balancing energy consumption between nodes. [9]It proposed a load-balanced residual energy level based routing protocol, using unequal clustering and multi-hop transmitting to alleviate the hot spots problem.

In view of the above problems, this paper proposes a clustering routing protocol based on the residual energy level, RELCRP, this strategy is similar to LEACH, including three stages: the selection of cluster head, establishment of cluster and data transmission. It focuses on three aspects of the problems, low residual energy nodes becoming cluster head nodes, uneven distribution of cluster heads and "hot spots", designing to balance the network node energy and prolong the network life time.

2. THE CLUSTERING ROUTING PROTOCOL BASED ON RESIDUAL ENERGY LEVEL

2.1 Network model

Suppose N sensor nodes randomly distributed in a square area M×M m2. Base station is located outside the sensor area. For the proposed protocol following assumptions are considered: (1) The location of the sensor node and base station (BS) are no longer altered after deployment. (2) The initial energy of all sensor nodes equals and cannot be added. The energy of the base station is sufficient. (3) Sensor nodes can calculate its distance to the base station by testing signal strength transmitted from base station. (4) Node can adjust its wireless transmitting power according to receiver's distance.

2.2 The remaining energy level

In order to measure the difference of residual energy between the nodes, this paper introduces the remaining energy level. Setting the initial energy of nodes as E0, if the initial energy of the nodes are divided into m levels (initial energy level is m), then the energy for each level is Eplevel=E0/m. When initializing network, each node’s remaining energy level is m. But with the consumption of node energy, its remaining energy level drops, and as for node i in the network its residual energy level at a certain time is:

$$REL_{i\_cur} = \left\lceil \frac{E_{i\_cur}}{E_{plevel}} \right\rceil \tag{1}$$

where, Ei_cur is the node’s current energy; RELi_cur is the top integral of Ei_cur /Eplevel. By formula (1), the node's remaining energy level is a positive integer from 1 to m.

2.3 Selection strategy of the cluster head based on priority

In the cluster head selection stage, cluster head nodes are generated randomly in the LEACH, and may be concentrated in an area within the network, which leads to individual nodes far away from cluster head nodes’ excessive consumption of energy. In addition, the cluster head selection method of LEACH may make low residual energy nodes cluster head nodes inevitably. In order to solve these two problems, this paper puts forward a cluster heads selection mechanism, which gives full consideration to the node's remaining energy level, making nodes with higher remaining energy level in the local area become cluster head nodes, and lets the cluster heads more evenly distributed in the sensing area through standardized cluster head broadcast radius r election. Hence, prolong the lifetime cycle of the whole internet.

Each node maintains two timers: Timer_election and Timer_termination. Timer_election is used to control time delaying of the cluster head nodes election which needs to wait. Timer_election value changes with the residual energy level fluctuation. While Timer_termination is used to control the time of cluster head selection phase for the entire network. Then the cluster head selection phase ends when the time controlled is up.

At the start of the cluster head selection, node has to initialize the value of Timer_termination, and then determines the priority of cluster head according to its residual energy levels:

$$P = \frac{REL_{i\_cur}}{\alpha} \tag{2}$$

where, RELi_cur is the residual energy level of node i, α is an adjustable parameter of system.
Then, according to the node's priority to determine the cluster head competition time delay telec=1/p, and then sets the timer of node Timer_election to t. There are two reasons for determining the cluster head election time delay by the residual energy level of node, instead of the residual energy of node. Firstly, not only the node with largest residual energy but also the closest node to the one with largest residual energy can campaign for nodes. Secondly, the way of determining election time delay by residual energy level reduces the cost frequent calculation and update, meanwhile, a positive integer is easier for the monitoring of Timer_election.

If the cluster head election timer Timer_election of node is matured, and this node doesn't receive the cluster election notice from surrounded nodes, then the node changes its statement into cluster_head and broadcasts cluster head election notice by radius r. The cluster head notice includes the identity of cluster head node, the residual energy of cluster head node and the distance from cluster head to base station. To generate the reasonable amount of cluster head, the radius r of broadcasting cluster head election uses the value in literature [9]:

$$r = \lambda * \sqrt{\frac{A}{K * \pi}} \tag{3}$$

where, A is the area of the whole sensor region, K is the amount of cluster head nodes and λ is a distance correction coefficient that greater than one.

If the cluster head election timer Timer_election of node is not matured, and this node receives the cluster election notice from surrounded nodes, then it changes its statement into cluster_member. Before Timer_election timer gets matured, node has to record the corresponding cluster head related information into candidate cluster head nodes set Candidate_cluster_head.

When timer Timer_termination is matured, the period of cluster head election is over. To ensure the Timer_termination time, all the nodes are cluster head node or member node. The value of timer Timer_termination is tter=α/minREL, and minREL is 1.

2.4 The establishment of cluster

After the period of cluster head election, the node in network is either cluster head node or member node. If member node only receives one cluster head election notice, then it sends the message of join to corresponding cluster head. If the member node receives more than one cluster head election notices, then it calculates the corresponding weighted value w(Nk,Ci) of each cluster head according to the information from candidate cluster head node set, choosing the nearest cluster head with largest residual energy (weighted value w(Nk,Ci) is minimum) as the best one and sending message of join to it. The definition of the weighting function is:

$$w(N_k, C_i) = \frac{d(C_i, N_k)}{d_{\max}(C, N_k)} + 1 - \frac{E_{res}(C_i)}{E_{\max\_res}(C)} \tag{4}$$

where, Nk is member node. C is the cluster head set which is corresponding to the cluster head notice received by Nk; d(Ci, Nk)is the distance from the cluster head Ci of cluster head set C to member node Nk; dmax(C, Nk)is the maximum distance from the cluster head of cluster head set to Nk; Eres(Ci)is the residual energy of cluster head Ci, Emax_res(C)is the maximum residual energy of cluster head node in cluster head set C. Adding the residual energy as the indicator of choosing the best cluster head is benefit to reduce the burden of cluster heads with little residual energy. Cluster head sends confirmation message to the member node after receiving each join message from them. The confirmation message includes the corresponding slot information of member node. After all the member nodes join in their corresponding clusters, cluster head node starts to broadcast. Each cluster head node will maintain a cluster node set to record the other cluster head nodes' information of identity, residual energy, and distance to the base station etc..

2.5 Data transmission

In order to alleviate hot issues, this article puts forward the communication mechanism between cluster by adopting the combination of single hop and multi-hops. Cluster head nodes judges remaining energy level of itself and the candidates for the next hop cluster head nodes. If the residual energy level of cluster head nodes is lower than that of the candidate of cluster nodes. The cluster head sends the data to the base station using the method of multiple hops. Otherwise, the node sends the data to the base station directly by means of single hop.

The basic process of the data transfer phase of RELCRP algorithm is as follows:
[1] Cluster members send collected data to the cluster head nodes in the allocated time slot respectively by single hop way. Cluster nodes fuse the received data to eliminate redundancy.

[2] Cluster head node Ci, selects cluster head nodes whose distance to base station are shorter and residual energy level are higher than others by the formula (5), as a routing candidate set Ci_CH.

$$C_{i\_CH} = \left\{ \begin{array}{l} C_j \mid d(C_j, BS) < d(C_i, BS) \\ \wedge d(C_i, C_j) < d(C_i, BS) \\ \wedge REL_{C_j\_cur} >= REL_{C_i\_cur} \end{array} \right\} \tag{5}$$

where, d(Cj, BS) is the distance of cluster head Ci and the base station. d(Ci,Cj) is the distance of cluster head Ci and cluster head Cj, $REL_{C_i\_cur}$ is the remaining energy level of node, Ci_CH is the collection of cluster head nodes which meet the conditions.

[3] If Ci_CH is empty, it means that either all the distances of other cluster head nodes to base station are longer than that of Ci, or the residual energy level of cluster head nodes with shorter distance to base station is lower than that of Ci. Then, Ci sends the data to the base station directly, and go to (6).

[4] If there is the only one cluster Head in Ci_CH, then Ci will choose Cj as the next hop routing node and transmit the data to cluster head Cj , Cluster head Cj become cluster head Ci and then jump to (2).
[5] If more than one cluster head nodes are in Ci_CH, then Ci will choose the node Cj with minimal transmitting cost as the next hop routing node and Ci forward the data it. The forwarding data communication overhead function is:

$$\cos t = d^2(C_i, C_j) + d^2(C_j, BS) \tag{6}$$

where, d(Ci,Cj) is the distance of cluster head Ci and Cj, d(Cj, BS) is the distance of cluster head Ci to base station. Then cluster head Cj become cluster head Ci and jump to (2).

[6] The base station receives the data sent by cluster head Ci.
Compared to LEACH and PEGASIS,RELCRP's energy consumption will be more evenly distributed in the cluster head nodes, it can avoid the premature death of nodes that distant or too closer to base station, so as to prolong the network lifetime.

3. SIMULATION EXPERIMENT

[1] The simulation platform and experimental parameters
We perform the simulations in MATLAB in order to compare the RELCRP's performance with LEACH. 100 nodes

are deployed in a 100m×100m network area. The parameters used in the simulation are shown in table 1, which are set from the literature [10].

Table 1: experimental parameter list

Parameter Name	value	Parameter Name	value
The base station location	(50m,175m)	Data fusion energy cost	5n J/bit/signal
number of nodes	100	ε_{fs}	10p J/bit/m^2
Initial energy of nodes E_o	0.5 J	ε_{amp}	0.0013 pJ/bit/m^4
Node failure energy E_{in}	0.0001 J	Packet size	4000 bit
Circuit energy cost Eelec	50 nJ/bit	Burst control packet size	100 bit

[2] The simulation result and analysis.

This paper mainly compares LEACH and RELCRP according to two evaluation standards of the network survival time and the energy equilibrium factor of these. Survival time is defined as the failure time of the first node in network (when the node residual energy is less than the Ein, the node is considered as failure), with a round number. Energy equilibrium factor refers to the ratio of the maximum residual energy and the minimum residual energy of each node. First of all, test the initial energy level of m's influence on the network survival time and assign m a certain value.

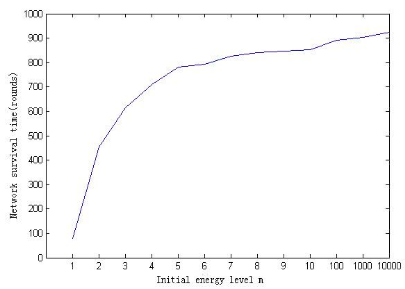

Fig. 1. Relationship between initial energy level and network survival time

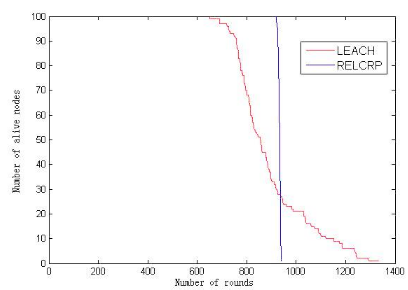

Fig. 2. Network lifetime of LEACH and RELCRP

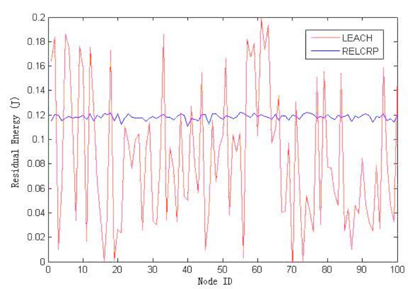

Fig. 3. Energy balance of LEACH and RELCRP

The fig. 1 shows that, when the value of m is 1, the network life time is minimal, because of all the nodes energy level is 1, cluster head selection strategy based on priority is equivalent to random strategy, which cannot avoid low residual energy of nodes selected as the cluster head nodes. There is a large number of experiments show that when m is greater than or equal to 10000, the network holds its survival time about 900 to 930 rounds.

Under the same experimental parameters, run LEACH protocol 100 times independently, the mean network survival time is 667 rounds, therefore, compared with LEACH, RELCRP survival time increased about 35% to 39%.

Fig. 2 shows the number of alive nodes in certain number of rounds for the selected protocols at the initial energy level of m=10000.

It can be seen from fig. 2 in RELCRP, all nodes die very close in time, other the nodes in the internet die one after another after the first node’s death within a short time (about 30 rounds). However, in LEACH, there are about 700 rounds between the first node’s death and the last ones.

In order to measure effect of the two protocols on balancing energy consumption, this paper extracts residual energy of each node in two protocols at the 700th round, as shown in fig. 3.

Fig. 3 shows that when the LEACH protocol is used, the energy consumption of the nodes in the network very disequilibrium, maximum residual energy is 0.2J, the lowest is 0J. But when it comes to RELCRP, all node residual energy is about the same, with fluctuate around 0.12J, energy equilibrium factor is 1.086, the reason is that RELCRP considers the node remaining energy level, balances energy consumption within cluster nodes and the cluster head nodes, hence achieving the extension of the life cycle and the objective of balancing network load.

CONCLUSION

A load balancing clustering routing protocols based on the residual energy level is proposed in this paper, it determines the election of cluster head nodes delay according to the node's remaining energy level, which ensures the nodes of the higher remaining energy level in the area becoming cluster head nodes. Through constraint broadcasting radius of the cluster head election notices within the cluster spacing, and the cluster head nodes are evenly distributed throughout the network. During communication between cluster head nodes, they switch its single hop and multi-hop routing selection mechanism according to themselves’ and next candidate hop, cluster head nodes’ remaining energy level, alleviating the hot spot problems when multiple hops transfer mode is adopted. The simulation results show that, RELCRP effectively uses the node energy, balances the network load and prolongs the network lifetime.

REFERENCES

[1] Srikanth, J., “Energy Efficient Unequal Clustering and Routing Algorithms for Wireless Sensor Networks,” IEEE Press, 2091-2097 (2014)

[2] Javaid, N., “Multi-hop Centralized Energy Efficient Clustering Routing Protocl for WSNs,” IEEE Press, 1784-1789(2014)

[3] Vipin, P., “Cluster head Selection Scheme for Data CentricWireless Sensor Networks,” IEEE Press, 330-334(2013)

[4] Wan, R., “An Energy Efficient Unequal Clustering Algorithm Based on Wireless Sensor Networks,” Computer Engineering and Science 31(9), 31-35 (2009)

[5] Lv, L., “ Energy-balanced WSN Uneven Clustering Routing Algorithm .” Computer Engineering 35(21), 117-119 (2009)

[6] Li, C. and Chen, G., “An Uneven Cluster-Based Routing Protocol for Wireless Sensor Networks,” Chinese Journal of Computers 30(1), 27-36 (2007)

[7] Jiang, C., “Energy-Balanced Unequal Clustering Routing Protocol for Wireless Sensor Networks,” Journal of Software 23(5) , 1222-1232 (2012)

[8] Zhang, X., “ An improved WSNs clustering routing algorithm and its performance ,” Sciencepaper Online 2, 92-96 (2010）

[9] Chen,Z. and Ni, J., “A Load-Balanced Residual Energy Level Based Routing Protocol in Wireless Sensor Networks ,” Microelectronics and Computer 27(12), 82-86(2010)

[10] Xu, G. Hu, F., “ An Energy Efficient Clustering Routing Algorithm for Wireless Sensor Networks ,” Journal of Tianjin University of Science and Technology 25(5), 113-116 (2009)