Applied Mathematics & Information Sciences
An International Journal

Research on the algorithm of Load-balanced Hierarchical Topology Control for WSN

Yongxin Feng, Wenbo Zhang, Xiaobo Tan and Lidong Fu*

School of Information Science and Engineering, Shenyang Ligong University, Shenyang 110159, P. R. China

Received: 9 Oct. 2012, Revised: 5 Nov. 2012, Accepted: 17 Nov. 2012
Published online: 1 Feb. 2013

Abstract: In terms of the characteristics of itself node number, density and topology dynamic change in wireless sensor network, according to the wireless transmission energy consumption model REDM, Load-balanced Hierarchical Topology Control Algorithm based on LEACH algorithm is designed. The algorithm still uses the concept of ”round”. Substitute cluster head and load evaluation method are introduced in view of frequent election of cluster head after cluster head failure. It can reduce cluster formation frequency, balance network energy consumption, extend the network lifetime and improve network management efficiency. Finally, the simulation results have verified this conclusion.

Keywords: Wireless sensor network, Load-balanced, RED, LHTCA

1. Introduction

Wireless sensor network (WSN) is a kind of wireless network composed of a set of sensors in an Ad-hoc manner, which is collaboration perception; collection and processing perception object information within the network coverage, then release the management node [1][2].

WSN-Hierarchical topology control selects some nodes in the network as cluster head through clustering algorithm, a data processing and transmission backbone network is formed by the cluster head, other non-backbone nodes can temporarily turn off the communication module into hibernation to save energy; This will not only ensure data communication within the network coverage, but also significantly reduce the overall network data traffic, saving the node energy, thereby prolong the network lifetime[3]. Thus, the hierarchical topology control technique is of great significance for rational and efficient use of energy in WSN and improving network management efficiency[4].

However, due to the characteristics of WSN itself node number, density and topology dynamic change, Hierarchical topology control algorithm in the WSN network management is facing new challenges: First, in all aspects the cluster head has a heavier burden and faster energy consumption than the normal nodes, algorithm elected cluster-head should have a higher residual energy; Second, the elected cluster head should be evenly distributed as far as possible in order to reduce the energy consumption of the intermediate nodes for forwarding packets; Finally, since the frequent cluster after the cluster failure will add to the nodes energy consumption, the algorithm need to consider to extend the lifetime of the original cluster[5].

Considering factors in WSN node residual energy, the distance from the cluster center and communication radius, load-balanced Hierarchical Topology Control Algorithm (LHTCA) based on LEACH is designed in this paper.

2. LEACH algorithm introductions

Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm is a cyclical low-power adaptive clustering topology algorithm designed by MITs Chandrakasan etc for WSN; it is a representative of the hierarchical topology control algorithm [6][7]. LEACH defines round” concept, including clusters formation phase and stable data communication phase.

In cluster formation phase, the adjacent nodes randomly generate cluster head and dynamically cluster. The cluster head selection process is described as: Nodes generate a $[0-1]$ random number; if this number is less

* Corresponding author e-mail: zhangwenbo@yeah.net

than the threshold , broadcast themselves as ADV message of cluster head. is calculated as follow:

$$T_{(n)} = \frac{p}{1 - p * [r \mod (1/p)]}, n \in G \quad (1)$$

Where p is the percentage of cluster head in all nodes, r is the election rounds, $r \mod (1/p)$ is the number of nodes which is elected as cluster head in this round, G is never elected as cluster head node set this round . Along with $r \mod (1/p)$ increasing, $T_{(n)}$ will also increase, then that the node is less than the probability $T_{(n)}$ increases, that is, the probability of node elected cluster head increases. When only one node is not elected, $T_{(n)} = 1$ means that this node must be elected. After the node is elected a cluster head, it posts a message through wireless channel to inform other nodes itself is a new cluster head.

After non-cluster nodes receive the broadcast information from the cluster head, according to the distance between themselves and the cluster head then it joins the strongest signal cluster and informs the cluster head; When the cluster head receives all the join information, it creates a TDMA timing message, and notifies all the nodes in the cluster; In order to avoid signal interference from nearby clusters, cluster head can decide the CDMA coding of all nodes in this cluster, the CDMA code used for the current phase together with TDMA are timing sent; When nodes in the cluster receive the news, it begins to enter the data communication phase [8].

In data communication phase, cluster nodes send data to the cluster head in the respective time slot, after a period of data transmission, cluster head nodes collect the data from all nodes in the cluster, run data fusion algorithm to process the data and send the results directly to the sink node.

LEACH algorithm can guarantee that each node has the same probability as the cluster head, nodes in the network are relatively balanced energy consumption. Compared with other hierarchical topology control algorithm, the network can extend the life cycle of 15%. But frequently election cluster head in the algorithm causes traffic consuming energy; In addition, cluster head election mechanism proposed by LEACH does not take into account the specific location of the node, cluster-head selected is not even [9].

3. HTCA algorithm analysis

3.1. Description of problem

The primary concern in WSN network management is how to reduce nodes energy consumption and extend network life cycle. Load-balanced hierarchical topology control algorithm LHTCA focuses on how to balance and reduce nodes energy consumption.In the analysis of the WSN energy consumption, current research usually adopts Radio energy dissipation model REDM as shown in figure 1

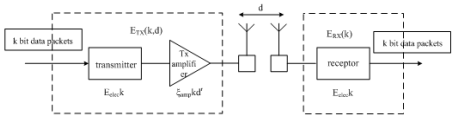


Figure 1 Radio energy dissipation model REDM

It is assumed that the distance between the transmitting node and the receiving node is d , preseted a threshold d_0 , the node energy consumption to send bit data packet is:

$$E_{TX}(k,d) = E_{elec} \times k + \xi_{amp} \times k \times d^r \quad (2)$$

The energy consumption to receive bit data packets is:

$$E_{RX}(k) = E_{elec} \times k \quad (3)$$

Among them, E_{elec}=50nJ/bit is nodes energy consumption of each transmitting or receiving 1bit data; ξ_{amp}= 100 pJ/bit/m^2 is the power consumption of signal amplifier launching 1 bit data per unit area. The signal transmission energy consumption is proportional to d^r in the wireless channel. In the short-range transmission $d < d_0$, $r = 2$, otherwise, $r = 4$; E_{DA} is the energy consumption when the integration of packet number is n and the number of bits within the package is k [10].

According to Radio energy dissipation model (REDM), in the nodes operations of data transmission, reception and integration, the energy consumption of transmission is the most, while the distance be guaranteed with minimum average distance to the cluster nodes, which requires the cluster head in the cluster center position as much as possible, and be evenly distributed in the network. It not only can ensure network coverage, but also can reduce the energy consumption of the intermediate nodes in forwarding packets and the communication costs.

In addition, Compared to the normal nodes, cluster-head burden is heavier, and energy consumption is faster. Therefore, the low-power, adaptability and long-life WSN topology control algorithm based on REDM should also achieve: cluster-head selected should have higher residual energy; can reduce the data transfer amount and communication frequency between nodes, and solve the cluster-head failure problems [11].

Based on the above analysis, this paper proposes Load-balanced Hierarchical Topology Control Algorithm (LHTCA) based on LEACH. LHTCA is also cyclical, still uses “round” concept of LEACH, a round includes clusters formation phase, data communication phase, and load evaluation phase.

3.2. clusters formation phase

In the selection cluster heads phase, the algorithm took residual energy, distance between the node and cluster

center, and current communication radius as consideration, and introduced the node capability comparison function:

$$F_{\text{capability}} = E_{resident} * r_1 + (1/d) * r_2 + R * r_3 \quad (4)$$
$$(r_1 + r_2 + r_3 = 1 \text{ and } r_1 > r_2 > r_3)$$

In which, $E_{resident}$ is residual energy, d represents the distance between the node and cluster center. It is assumed that the nodes in the network have got its position through positioning algorithm. R denotes the node communication radius, which is the information transmission distance under the current launch power. r_1, r_2 and r_3 is the proportion of each part, the sum is 1, the value of r_1, r_2, r_3 is preset according to the requirement.

The cluster head node needs more energy, so the residual energy occupies a large proportion in the entire function; according to radio energy dissipation model REDM, in order to ensure that the cluster head is in the cluster center position, the distance between nodes with cluster center is as the second parameter of the node capacity, usually $r_2 < r_1$;In addition, the node communication radius is larger, it can cover a greater range, so the current communication radius is as the third parameter of the node capacity, and assign weights r_3 , $r_3 < r_2 < r_1$. Accordingly, the cluster formation process in the LHTCA algorithm is as follows:

Step1: Nodes in the network randomly generates a [1,9] positive integers, and decrements the number every certain time until 0.

Step2: Counting over nodes send ability request to all neighbor nodes within the communication range, nodes which receive the request default to count over, nodes within the requested node communication range start to capability comparison, after comparison the best node is selected as cluster head node.

Step3: For the still counting nodes, to execute the Step2 after the implementation of counting, until all cluster heads are elected.

Step4: Cluster head sends broadcast message that contains the residual energy, position, communication radius to the node within its communication range. For non-cluster node that receives the broadcast message, if there is only one cluster head within its communication range, it is directly to join in the cluster. Otherwise, the non-cluster nodes select the optimal cluster head from the multiple cluster heads and join in the cluster.

For the possible new join nodes choose a more excellent cluster head in its communication range and join. After the clustering algorithm is completed, all nodes are added to a cluster, thus, the cluster construction is completed.

3.3. data communication phase

The execution process of LHTCA algorithm is the same with LEACH algorithm in this phase: the nodes in the cluster begin sending data to the cluster head, after a period of data transmission, the cluster-head nodes finish processing and forwarding the received data, then send the results to remote task management node through sink node.

3.4. load evaluation phase

LHTCA algorithm follows the idea of periodic clusters of LEACH algorithm; the nodes in the network in turn serve as the cluster nodes, which balances the energy consumption to a certain degree.

However, in a cycle after a period of time data transmission, Cluster head is once spent, the original cluster will be automatically dissolved, and the node is ready to enter the next round of cluster formation phase, which affects the WSN network management efficiency. At the same time, the frequent election of cluster head will increase the network node energy consumption.

In clusters formation phase, LHTCA algorithm elects the cluster head with the capability comparison; residual energy information of the mediator nodes is saved in the cluster-head node information list. In order to better achieve the node load balancing and extend network lifetime, when cluster head load capacity is too low, LHTCA algorithm through cluster head selects the best node as substitute cluster head from the remaining nodes in the original cluster, this way avoids the original cluster premature dissolution, prolong the lifetime of clusters thus extends the network time.

In order to determine whether the cluster head load capacity is too low, load evaluation function is introduced:

$$F_{load} = E_{resident} * t_1 + (1/d) * t_2 \quad (5)$$
$$(t_1 + t_2 = 1 \text{ and } t_1 > t_2)$$

Among them, $E_{resident}$ and the definition D are the same with the formula (5), F_{load} has a load threshold value F_{load0} , and the value of $F_{load}0$, t_1 and t_2 is preset according to need. After calculating cluster head load value F_{load} according to the formula (3), if $F_{load} < F_{load0}$, then go into the load evaluation. Node load evaluation algorithm is described as follows:

if (load capacity of original cluster-head is normal)
original cluster-head continues to work;
else
{
do fault-tolerant judge limited times;
if(load capacity of original cluster-head is normal)
original cluster-head continues to work;
else
{
original cluster-head appoints a substitution cluster-head;
if(load capacity of substitution cluster-head is normal)

replace original cluster-head with substitution cluster-head;
else
dissolve the original cluster, and construct the new cluster;
end
}
end
}
end

WSN has certain instability because of its feature vulnerable to interfere. The node may appear short-term low load capacity. In order to avoid misjudgment, when $F_{load} < F_{load0}$ happens, fault-tolerant judge limited times is given. If the results always are low load capacity, the cluster head is ready to be given up.

After cluster-head is determined low load capacity, cluster-head selects an optimal node as substitute cluster head according to the node information list.

In order to avoid new cluster-head appearing low load capacity, the substitute cluster head also needs to go through the load evaluation before becoming new cluster-head. If the load capacity is up to standard, then make it a new cluster-head. At the same time the original cluster head needs to send node information list to new cluster head, and this cluster is in the stable data communication phase again; otherwise, it is necessary to dissolve the original cluster to restructure. All nodes in the original cluster regenerate [1,9] random integer then ready to enter the next round of clusters formation phase.

From the process above we can see that the cluster head elected by the LHTCA algorithm has advantages on residual energy, distance between the node and cluster center and current communication radius. The situation that the lower capacity node presents as a cluster head is avoided, thus greatly reduce excessive retransmission message; In addition, substitute cluster-head and load evaluation function are also introduced which further realize the node energy balance.

4. LHTCA Algorithm Simulations

OMNET++ 4.1 is used as a simulation tools, simulation platform is built in the Windows.

Simulation environment settings: There are the same sensor nodes which is randomly distributed in the 300m $\times$ 300m square network area; there is one sink node location in the network regional center(150,150); Nodes communicate through the wireless channel, all nodes have the same maximum transmission radius, which is set to 30m in the simulation.

We make the following assumptions: Each node has known their location and sink node location, sink node knows the location of all nodes; the initial energy of nodes is set to 10000 units; sending a packet consumes one unit of energy, receiving a packet consumes 0.3 unit of energy, other operations (such as data processing) consumes 0.1unit of energy; the current communication radius is proportional to the current transmission power. The sink node need not consider the energy problem. Channel error rate is 0 without communication collision.

Table 1 Node information table

No.	location	residual energy	communication radius
1	(213,174)	9897	22
2	(50,196)	8547	19
3	(126,240)	7998	17
4	(200,232)	7142	17
5	(190,270)	7253	14
6	(150,100)	7550	17
7	(44,80)	7756	18
8	(37,239)	7736	18
9	(255,208)	8037	15
10	(162,82)	9870	21
11	(213,67)	9854	21
12	(78,135)	7218	15
13	(219,28)	7659	18
14	(80,195)	9863	22
15	(163,75)	8791	16
16	(119,88)	7549	15
17	(181,37)	7910	16
18	(78,79)	8520	15
19	(38,164)	7659	19
20	(79,158)	8073	18
21	(263,80)	8175	19
22	(163,262)	8624	15
23	(112,210)	8416	20
24	(181,75)	9810	22
25	(125,277)	7592	15
26	(94,98)	9831	22
27	(100,46)	7938	18
28	(263,164)	7715	15
29	(225,155)	8506	15
30	(190,208)	7868	15
31	(83,240)	7815	18
32	(194,208)	7849	16
33	(231,57)	8390	15
34	(38,121)	7559	18
35	(199,136)	7691	15
36	(150,59)	7816	17

After a period of time the simulation, the current position, residual energy and the current communication radius are shown in Table 1.

In a cycle, six network management clusters are elected based on load-balanced topology control algorithm, namely 1(9,28,29,30,35), 10(3,4,5,22,25), 11(13,20,21,33), 14 (2,8,19,20,23,31), 24(6,15,17,32,36), 26(7,12,16,18,27,34). Network topology generated by OMNeT++ is shown in Figure 2.

In order to distinguish cluster head and non-cluster head, cluster head nodes 1, 10,11,14,24 and 26 are marked in blue. We can see from Fig.2 that the cluster head nodes elected by LHTCA algorithm are more evenly distributed in the place with many nodes. Combination of

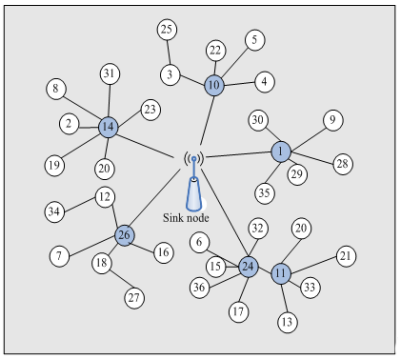


Figure 2 Network topology diagrams

Table 1, these cluster heads have an advantage on residual energy, distance between the node and cluster center and the current communication radius.

It can be seen from Figure 3 that compared with the LEACH algorithm the LHTCA algorithm can make network nodes with higher residual energy, this is because cluster head elected by LHTCA is evenly distributed in the place with more nodes, which reduce energy consumption of the intermediate node forwarding message. In addition, cluster-head is selected through the capacity comparison function, the situation that the lower capacity node presents as a cluster head is avoided, which greatly reduce the message transmission and save node energy consumption.

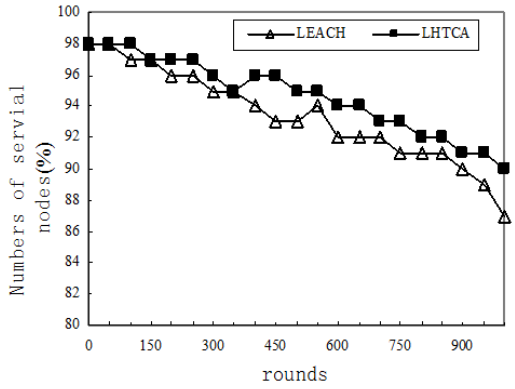


Figure 3 Network node residual energy percentage comparison

As can be seen from Figure4, compared with the LEACH algorithm, the algorithm LHTCA can make the network node with a longer survival time, it is because LHTCA introduces substitute cluster head and load evaluation function, which better realize load balance, avoid frequent clustering after the failure of the cluster header, save the node energy, extend the survival time of cluster, thereby prolong the network life cycle and improve the network management efficiency.

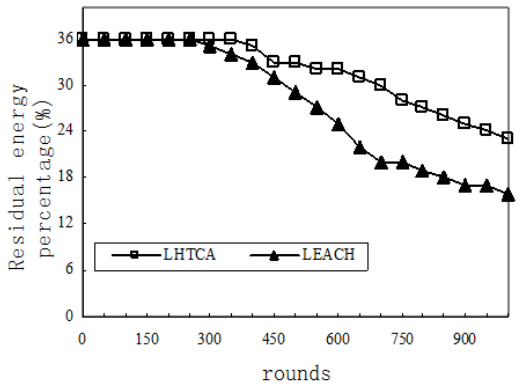


Figure 4 The network life cycle comparison

Acknowledgement

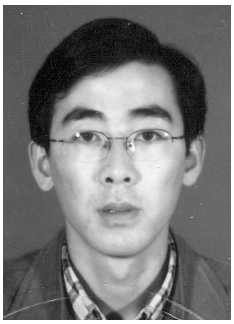
This work is partially supported by The National Natural Science Foundation of China(# 60802031), Funding Project for Liaoning province innovation group (#LT2010091, #LR201034)

References

[1] Peng Bao, Localization Algorithm Based on Sector Scan for Mobile Wireless Sensor Networks[J], Appl. Math. Inf. Sci. Vol. **6** No. 1S (2012) pp. 99-103.
[2] Ning Zhang, Research on Control Routing Technology in Communication Network[J], Appl. Math. Inf. Sci. Vol. **6** No. 1S (2012) pp. 129S-133S.
[3] Limin Sun, Jianzhong Li, Yu Chen, Hongsong Zhu. Wireless sensor network [M]. The first-edition. Beijing: tsinghua university press, 2005: 89-106.
[4] Min Xiang, Wei-ren Shi, Chang-jiang Jiang, Ying Zhang, Energy efficient clustering algorithm for maximizing lifetime of wireless sensor networks[J], AEU-International Journal of Electronics and Communications, vol. **64**, issue 4, pp. 289-298, April 2010.
[5] Handy M, Haase M, Timmermann D, Low Energy Adaptive Clustering Hierarchy with Deterministic Cluster-Head Selection[C], In:Proc.of the 4th IEEE Conf.on Mobile and Wireless Communications Networks, 2002, pp. 368-372.
[6] Heinzelman W, Chandrakasan A, Balakrishnan H. Energy efficient communication protocol for wireless microsensor networks[J]. In: Proceedings of the 33rd Hawaii International Conference on System Sciences. Maui: IEEE Computer Society, 2000, 3005-3014.
[7] Wei Wang, Yuan-jing Feng, Li Yu, Energy-Efficient Routing Protocol for Wireless Sensor Net works[J], Chinese Journal of Sensors and Actuators, Vol. **21**, No. 12, pp. 2061-2066, December 2008.
[8] Chen Shenglai etc. Improved routing protocol based on the LEACH and performance analysis [J]. Science and Technology Forum (second half), 2010, 6-20.
[9] Yu Jingtao etc. Wireless sensor network routing protocol LEACH Research and Improvement [J]. Computer system application, 2009, **12(3)**: 35-40.

[10] Zhang Weihua, Li Layuan, Zhang Liumin, Wang Xuanzheng. Wireless sensor network LEACH protocol energy balance improvement [J]. Journal of computer science and technology, 2008, **21(11)**: 1918-1922.
[11] Kang Yimei etc. A low-power hierarchical wireless sensor network topology control algorithm [J]. Automation Journal, 2010, **4(4)**: 543-549.

Yongxin Feng received the MS degree in Computer science from Northeastern University in 2000, and the PhD degree in Computer science from the school of Information and Engineering, Northeastern University 2003. She is currently a professor in Shenyang Ligong University. Her research interests are in the areas of network management, wireless sensor network, and information systems.



Wenbo Zhang received the PhD degree in Computer science from the school of Information and Engineering, Northeastern University 2006. He is currently a associate professor in Shenyang Ligong University. His research interests are in the areas of network management, wireless sensor network, and embedded systems.