

## ZigBee Routing Algorithm Based on Energy Optimization

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**Abstract:** In wireless sensor networks which are mainly ZigBee Routing Protocol based, energy consumption of node keeps high randomness in which energy consumption condition of each node could not be predicted in advance. This leads node's energy to consume too much, makes routing efficiency be low and results in long time delay of network. Aiming at these problems, this paper introduces ZigBee Routing Algorithm based on energy optimization. During the process of network operation, one energy threshold is set. If minimum residual energy of node is higher than energy threshold, AODVjr Algorithm is utilized to fully give play to its routing function. While if it is lower than energy threshold, Cluster-Tree Algorithm would be applied to reduce energy consumption. Experiment simulation indicates that the improved algorithm effectively saves total energy consumption of network, realizes load balancing and maximizes its survival time. *Copyright © 2013 IFSA.*

**Keywords:** ZigBee, Cluster-tree, AODVjr, Energy optimization, Routing algorithm.

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### 1. Introduction

In Wireless Personal Area Network Technology, ZigBee Technology is more and more widely used in Wireless Sensor Network (WSN) relying on its features of low cost, low rate and low power consumption. As each node's energy in ZigBee Network is limited, time delay happens in data transmission and then performance of the whole network is influenced. Therefore under the existing technology condition, reducing node's energy consumption becomes the key research content in terms of ZigBee Network [1]. Network layer is the core layer of ZigBee Protocol. A large number of scholars studies the improvement and energy optimization of ZigBee Routing Algorithm which lays a good theoretical foundation for the application and development of Internet of things. Literature [2-4] partly improves Tree-based Routing Protocol of ZigBee Network utilizing neighbor table to decrease

routing hop and cost thus reducing energy consumption. Literature [5] proposes ZigBee Network Routing Algorithm based on routing node property. Literature [6, 7] reduces the group flooding of redundant RREQ (Route Request) in network through restricting broadcasting scope so that energy consumption is decreased. Literature [8] puts forward one kind of routing algorithm aiming at routing choice which combines AODVjr (Ad hoc On-Demand Distance Vector Routing Junior) Routing Algorithm with residual energy of network node so that balance point between the shortest path routing and energy aware routing would be found. Literature [9, 10] proposes that ZigBee Network may be divided into several logical clusters to realize reasonable sharing of network resource. However, the number of node in each logical cluster is limited. A majority of nodes in the network is  $RN+$  which never solves problem of group flooding of RREQ thus leading energy to excessively consume.

## 2. Design Philosophy of the Improved Algorithm

In consideration of the above-mentioned problems, ZigBee Routing Algorithm combining the advantages of AODVjr Routing Algorithm and Cluster-Tree Routing Algorithm and which is based on energy optimization is put forward in order to better promote the performance of ZigBee Network. AODVjr Routing Algorithm keeps function of querying routing in which data may be transmitted through neighbor nodes. Also this could do routing according to the destination address. Cluster-Tree Routing Algorithm directly transmits data to father node or child node without considering about routing. This decides its low energy consumption. During network operating process, an energy threshold is set up to distinguish both kinds of algorithms. If minimum residual energy of node is higher than energy threshold, it is to say that energy of this node is adequate. At this moment AODVjr Algorithm may be applied to fully express routing function. While if minimum residual energy of node is lower than energy threshold, it is to say that energy of this node is insufficient. Then Cluster-Tree Algorithm is used to reduce energy consumption. Finally energy load of the whole network is balanced so that its operation time is lengthened.

### 2.1. Minimum Residual Energy and Energy Threshold Definition

In terms of elements of energy and hop count and through combining it with minimum hop count and link quality to be a measure, minimum hop count and maximum energy of link are comprehensively taken into account in which minimum residual energy of the chosen node should be high to the greatest extent and route with low hop count may be the routing. This helps lead ZigBee Network to evenly consume energy in order to realize the purpose of lengthening network lifetime.

Suppose that initial energy of node is  $E_0$ , calculation of the minimum residual energy  $E_{Min}$  of a random node  $i$  is shown in Formula 1:

$$E_{Min} = \frac{1}{t} * \sqrt{E_0} * \frac{1}{d_i + 1} * \beta \quad (1)$$

Here  $t$  stands for network operating time,  $d_i$  is the depth of Node  $i$ , main function of  $\beta$  is to relieve the decreasing speed of  $E_{Min}$ .

Set an energy threshold  $E_{warning}$  and compare node residual battery power with energy threshold. Divide node energy into two areas as follows:

**Standard Area:** If residual energy  $E_{Min}$  of the current node is higher than  $E_{warning}$ , it is in standard area. Nodes in standard area utilize AODVjr Routing Algorithm through which dynamic routing and data transmission are done.

**Warning Area:** If residual energy  $E_{Min}$  of the current node is lower than  $E_{warning}$ , it is in warning area. Nodes in warning area adopt Cluster-Tree Routing Algorithm through which data is transmitted.

Suppose that initial energy of node is  $E_0$ , set of  $E_{warning}$  is expressed in Formula 2:

$$E_{warning} = \frac{\beta}{f(x)} \sqrt{E_0} \quad (2)$$

Here  $\beta$  is a specific coefficient whose main function is relieving the reducing speed of  $E_{warning}$ .  $f(x)$  is a function changing with  $x$ . Its setting is seen in Formula 3:

$$f(x) = \begin{cases} 1 & x=0 \\ \frac{N^2}{N-x} & 1 \leq x < N \end{cases} \quad (3)$$

Here  $N$  stands for the number of node in the network which is a constant.

### 2.2. Data Package Processing Flow of Each Node

FFD (Full Function Device) Node with routing effect could do routing discovery using AODVjr Routing Algorithm in which one node can directly send information to other nodes within the communication scope without following set membership. At the same time nodes without routing effect continue to send and receive data and control the grouping according to Cluster-Tree Routing Algorithm. RN+ keeps enough memory space and energy to perform AODVjr Algorithm. While RN- can just utilize Cluster-Tree Algorithm to deal with data package because its energy is limited.

**Data Package Processing Flow of Each RN+ Node:**

After RN+ Node receives data package, it firstly judges whether minimum residual energy of the node is lower than energy threshold or not. If it is higher than energy threshold, then AODVjr Algorithm is used to do routing.

RN+ Node checks whether one data package is sent to itself. If not, it would check whether it is sent to its neighbor node. If it is sent to itself, it is directly handed to the upper layer to handle and ACK is replied to confirm information.

If the destination node of data package is not its neighbor node, then its routing table would be checked to find out whether there exists routing reaching the destination node. On the contrary, it would be directly sent to the neighbor node.

If there is not any routing reaching the destination node, AODVjr Algorithm would be started to check out the routing which can reach the destination node. If this type of routing exists, data package would be sent to the next hop of this very destination node.

If routing is found according to AODVjr Algorithm, data package would be sent to the next hop and routing of this time is recorded by routing table at the same time. If the routing is not found, source node would be noticed that transmission is of failure.

Data Package Processing Flow of RN- Node:

After RN- Node receives one data package, it checks whether it is sent to itself. If it is sent to itself, it would be handed to the upper layer to handle and ACK is replied to confirm.

If data package is not sent to it, it would check whether it is sent to its neighbor node. If it is sent to its neighbor node, data package would be directly sent to the neighbor node.

If data package is not sent to the neighbor node, it would be sent to relevant father node or child node according to Cluster-Tree Algorithm.

Data Package Processing Flow of RFD (Reduced-Function Device) Node:

First, RFD Node judges whether this data package is sent to itself or not after it is received. If it is sent to itself, data package would be directly handed to the upper layer to handle.

If RFD Node finds that it is not sent to itself, data package would be transmitted to the father node to handle.

### 3. Energy Efficient Routing Algorithm

During communication process, energy consumption has to be taken into account. Meanwhile, it also has to be seen that routing choice of nodes includes two aspects: One is that a route from source node to destination node must be found which has to keep the lowest total energy consumption. The detailed action is that sending power of nodes is controlled to guarantee the lowest power consumption of data grouping in transmission process. It is to say that the reducing of total transmission power of the route mainly helps save energy for the network so that energy consumption of the whole network could be the lowest. The other is that choosing nodes with high residual energy to join in data transmission so that the whole network evenly consumes energy. At the same time nodes without enough energy fail to join in routing transmission which avoids death when energy is used up and network segmentation phenomenon comes into being.

Detailed Routing Algorithm:

If the next hop node is not the destination node, then minimum residual energy is used to decide which routing algorithm will be applied by nodes. S stands for the address of nodes transmitting data. Specific routing algorithm is below:

Initialize each node's routing table and initialize nodes' residual energy.

if (Destination node lies in the neighbor table of S.)

The next hop node is the destination node.

In nodes' routing table else checks whether there exists routing reaching S Node.

if(Nodes' minimum residual energy in the routing >  $E_{\text{warning}}$  )

Start the AODVjr Routing Algorithm.

else (minimum residual energy of node <  $E_{\text{warning}}$  )

Start the Cluster-Tree Routing Algorithm.

Add the address of the next hop node into data package and then transmit data. Meanwhile modify its own residual energy value. Send information to neighbor nodes and modify relevant information of neighbor nodes such as neighbor table.

## 4. Simulation Experiment

Compare property of the improved ZigBee Routing Algorithm with those of AODVjr and Cluster-Tree Algorithm utilizing NSZ (Network Simulator, Version 2).

### 4.1. Simulation of Packet Delivery Ratio and End to End Delay

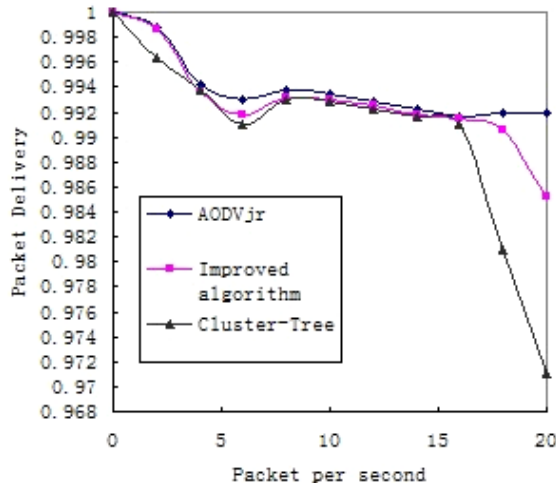
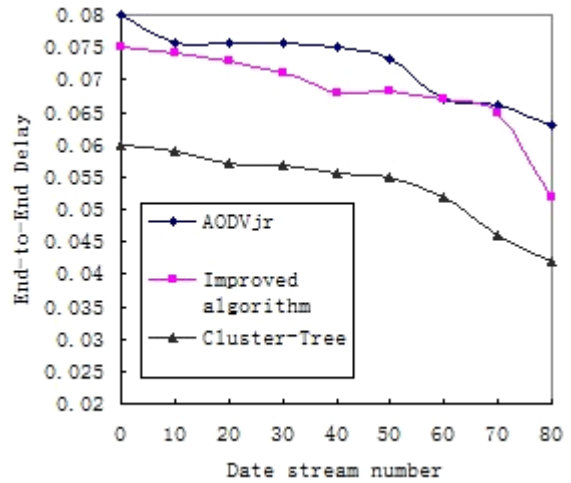
Simulation Parameters of Packet Delivery Ratio and End to End Delay Shown in Table 1. Within the scope of 500×500, 40 nodes are randomly distributed in which 10 CBR (Constant BitRate) data sources are used to test packet delivery ratios of the improved ZigBee Routing Algorithm, AODVjr Algorithm and Cluste-Tree Algorithm under different rates of sending packet. Simulation results are seen in Fig. 1.

It is seen from simulation results that packet delivery ratio of the improved ZigBee Algorithm is almost the same with those of AODVjr and Cluste-Tree Algorithm when rate of sending packet is low. However, with the increasing of packet sending rate, collision probability owing to grouping becomes higher leading packet delivery ratio to fall. Among these algorithms, down trend of AODVjr Routing Algorithm is the lowest. On the contrary, the one of Cluster-Tree is the highest. The improved ZigBee Algorithm is between them. As the improved algorithm generally considers energy balance and combines with AODVjr Algorithm and Cluste-Tree Algorithm, its performance index of packet delivery ratio is slightly lower than that of AODVjr. However, it still covers more than 98 %. Therefore it would not produce great influence on data packages of the whole network.

When rate of sending packet is kept at 1 packet/s, average end-to-end delays of the improved ZigBee, AODVjr and Cluster-Tree Routing Algorithm are measured with the increasing of data flow. Simulation results are in Fig. 2.

**Table 1.** Simulation Parameters of Packet Delivery Ratio and End to End Delay.

Type	Number	Packet size	Rate of sending packet	Node sending power	Node receiving power	Region size	Simulation time
CBR	40	70 byte	1 packet/s	0.6 W	0.3 W	500×500	800 s

**Fig. 1.** Simulation of Packet Delivery Ratio.**Fig. 2.** Simulation of Average End-to-end Delay.

It is seen from simulation results that with the increasing of the number of data flow, average end-to-end delay of the improved ZigBee is in the middle. All nodes in AODVjr Algorithm can discover routing and establish optimal path of destination node which is to say its delay should be the lowest. Nodes in Cluste-Tree Algorithm directly send data packages to father node or child node after they receive them in which the routing may not be the optimal path. Therefore its delay may be a little higher. The improved ZigBee Algorithm makes use of RN+ and RN- Nodes in which RN+ uses AODVjr to look for routing and produce optimal path. While RN- Node applies Cluste-Tree to produce route leading its average end-to-end delay to be higher than that of AODVjr and lower than that of Cluste-Tree.

Synthesizing these above-mentioned analyses on the improved ZigBee Algorithm, both indexes of its packet delivery ratio and average end-to-end delay are in the middle of AODVjr and Cluster-Tree

Algorithm because the improved algorithm utilizes both of them in it to finish routing.

#### 4.2. Simulation of Network Nodes' Survival Number and Total Network Energy

Simulation Parameters of Network Nodes' Survival Number and Total Network Energy Shown in Table 2.

Within the scope of 1000×1000, 100 nodes are randomly distributed in which coordinator position is (50, 175). Through extracting relevant information of nodes to document, different awk programs are written to handle trace document and get relevant data. According to the data, performances of three algorithms are compared to do drawing and to observe packet delivery ratio and control expense and average end-to-end delay in order to analyze these algorithms.

**Table 2.** Simulation Parameters of Network Nodes' Survival Number and Total Network Energy.

Type	Number	Packet size	Rate of sending packet	Node sending power	Node receiving power	Region size	Coordinator position	Initial energy of node	Simulation time
CBR	80	70 byte	1 packet/s	0.6 W	0.3 W	1000×1000	(50, 175)	10 J	800 s

With operating time of the whole network lengthening and each node's energy consumption increasing, some certain nodes would die because of excessive energy consumption when reaching a

certain period of time. This would influence performance of the whole network and lead to network partitioning. Its simulation results are seen in Fig. 3.

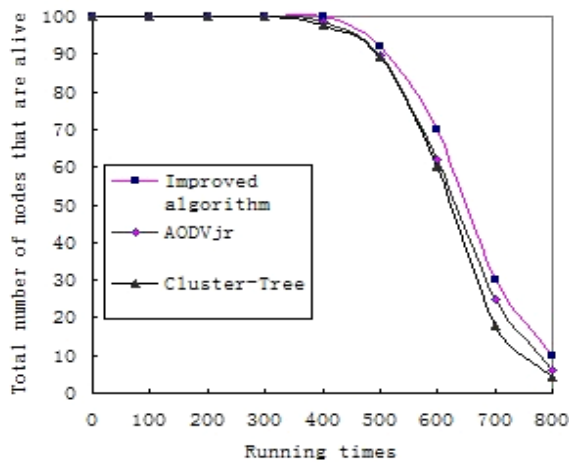


Fig. 3. Simulation of Node Survival Number.

It is seen from simulation results that with network operating time increasing, survival number of node in all the algorithms reduces. When it reaches about 400 s, excessively active nodes in network would die because of too much energy consumption. Aiming at the whole curve, survival number of node in the improved ZigBee Algorithm is the highest at the same moment. This explains that the improved algorithm could afford network operation longer.

#### Total Energy Consumption of Current Nodes:

During network operating process, each node needs to consume energy to look for routing, send or receive data packages. Seen from the whole network, total energy of nodes must be an important index for measuring energy performance of the whole network. Simulation results aiming at three algorithms are in Fig. 4.

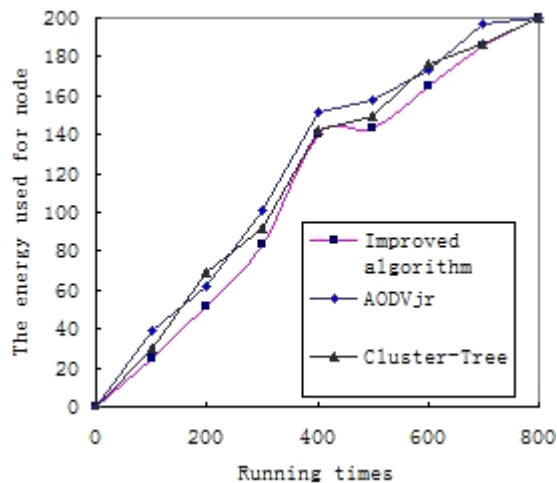


Fig. 4. Simulation of Total Energy Consumption of Nodes.

It is seen from simulation results that with network operating time increasing, energy consumption of all nodes in network is constantly

increasing. During the whole network operating process, energy consumption of the improved ZigBee Routing Algorithm is the lowest because it fully takes nodes' energy balanced load into account so that some nodes would not die because of excessive load.

## 5. Conclusions

Synthesizing the above-mentioned analyses on the improved ZigBee Routing Algorithm, it is the best in the aspects of energy balance and energy consumption. Therefore its network operating time is also the longest. As AODVjr Algorithm could start neighbor nodes to do routing, its packet delivery ratio is the highest. However, its average end-to-end delay is lower than that of Cluster-Tree Algorithm because searching for routing greatly consumes energy whose process is also complicated. Although packet delivery ratio of Cluster-Tree Algorithm is not as good as AODVjr, it is the best in the aspect of controlling expense and average end-to-end delay. Through combining their advantages and disadvantages, both indexes of packet delivery ratio and average end-to-end delay in the improved algorithm are kept in the middle. While it is the best at keeping energy balancing in the whole network which realizes the prospective goal.

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## References

- [1]. Li Wenjiang, Wei Juan, Design of Low-Power Consumption ZigBee Wireless Sensor Networks Nodes, *Journal of Chengdu University (Natural Science)*, 9, 27, 2008, pp. 239–241.
- [2]. T. Kim, D. Kim, *et al.*, Shortcut Tree Routing in ZigBee Networks, in *Proceedings of the 2<sup>nd</sup> IEEE International Symposium on Wireless Pervasive Computing (ISWPC' 2007)*, United States, 2007, pp. 42-47.
- [3]. W. Qiu, Q. Cheng and E. Skafidas, A Hybrid Routing Protocol for Wireless Sensor Networks, in *Proceedings of the IEEE International Symposium on Communications and Information Technologies 2007(ISCIT' 2007)*, United States, 2007, pp. 1388.
- [4]. Youn-Soo Kim, Eun Ju Lee, Bong Soo Kim, Hyung Seok Kim, Quasi-Hierarchical Routing Algorithm for ZigBee/IEEE 802.15.4 Networks, *IEICE Trans.*, E91-A, 8, 2008, pp. 2269-2271.
- [5]. Liu Dan, Qian Zhi-Hong, Liu Ying, Study on ZigBee network energy optimization routing based on node

- characteristics, *Journal of Northeast Normal University (Natural Science Edition)*, 41, 4, 2009, pp. 58-63.
- [6]. Zijing Lin, Max Q.-H. Meng, Huawei Liang, A Route Discovery Method based on Limited Flooding in ZigBee Networks, in *Proceedings of the IEEE International Conference on Automation and Logistics (ICAL' 2008)*, United States, 2008, pp. 3039-3044.
- [7]. Kwang Koog Lee, Seong Hoon Kim, Hong Seong Park, An Effective Broadcast Strategy for Route Discovery in the ZigBee Network, in *Proceedings of the 10<sup>th</sup> IEEE International Conference on Advanced Communication Technology*, United States, 2008, 2, pp. 1187-1191.
- [8]. Fenghui Zhang, Huiling Zhou, Xiaoguang Zhou, A Routing Algorithm for ZigBee Network Based on Dynamic Energy Consumption Decisive Path, in *Proceedings of the International Conference on Computational Intelligence and Natural Computing*, 2009, pp. 429-432.
- [9]. Lee K. K., Kim S. H., Park H. S., Cluster Label-based ZigBee Routing Protocol with High Scalability, in *Proceedings of the 2<sup>nd</sup> International Conference on Systems and Networks Communications (ICSNC' 2007)*, Cap Esterel, France, 2007, p. 12.
- [10]. Bhatia A., Kaushik P., A Cluster Based Minimum Battery Cost AODV Routing Using Multipath Route for ZigBee, in *Proceedings of the 16<sup>th</sup> International Conference on Networks (ICON' 2008)*, New Delhi, India, 2008, pp. 1-7.

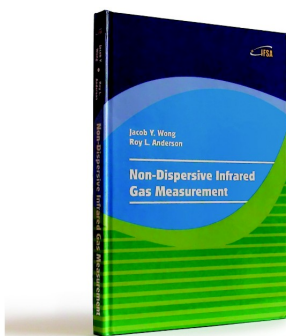
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