ZigBee Dynamic Routing Algorithm Based on Load Balance

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Abstract
Paths of data transmission in ZigBee network are often not optimal in which node death even segmentation death may prematurely appear thus causing certain limitation. This paper proposes to utilize directional RREQ packet to reduce network storm in which equilibrium cost is set according to energy of node and its neighbor nodes, average energy of network and routing path energy consumption. It also uses multi-objective optimization to choose optimal path thus constructing network dynamic routing and realizing its load balance. Simulation experiment results show that in comparison with classical ZigBee Routing Algorithm, algorithm in this paper could reduce the number of dead node, decrease energy consumption and lengthen network survival time.

Key words: ZigBee protocol, load balance, balance cost

1. INTRODUCTION
ZigBee is an emerging short-range wireless networking communication technology which is based on IEEE 802.15.4 Standard. It keeps features of low cost, low power consumption and high self-organization (Wang, 2013). ZigBee Wireless Sensor Network has advantages of low cost, low power consumption, ad hoc network and high security, because of which ZigBee Network is widely utilized in the field of Internet of Things (Tian, 2012). Sensor of ZigBee Network is battery-powered whose electric quantity is limited (Wang ,2012). Therefore the key of ZigBee routing protocol optimization is fully and reasonably utilizing energy in network to play its biggest role.

Literature (Cao, 2014) proposes to determine nodes with minimum communication cost according to node residual energy and energy consumption of transmission. These nodes would be utilized to transmit data to balance energy consumption of nodes. However, it just involves in single node, which could not balance network energy consumption and lengthen network survival time on the whole. Literature reduces Routing Request namely RREQ through setting reasonable clustering mechanism, in which standby node is arranged to protect father node. Literature (Song, 2015) comes up with the method of constructing weight based on energy consumption rate, link quality and hop count of nodes during a period of time to choose routing. While frequent energy interception consumes much energy. Meanwhile both of them do not take residual energy of nodes into consideration. Network partition would happen if there are nodes with low residual energy and low energy consumption rate which would prematurely die.

Literature (Mu, 2014) introduces neighbor table and node residual energy to protect nodes with low residual energy. Literature (Liu, 2012) proposes to set energy threshold to elect agent father node. Literature (Hu, 2008) divides conditions of node residual energy into three kinds including being sufficient, being insufficient and being about to run out. Then it determines RREQ message transmission direction which may reduce network storm. However, partition of these three kinds on node energy is so absolute that threshold should not be set according to the fixed initial energy of node, in which level of node energy in the whole network could not be determined and paths with low energy consumption may not be elected because energy in network dynamically and constantly decreases. Aiming at the problems above, this paper proposes dynamic routing optimization algorithm based on load balance.

2. PROPOSITION OF IMPROVED ALGORITHM
After network construction and operation, task difference of sending and receiving data may result in non-uniform energy of nodes thus leading part of nodes to die and network to be partitioned. When network efficiency is low, there still exist some nodes keeping sufficient energy which may protect other nodes with low energy and lengthen network lifetime. Energy consumption pressure of single routing path is reasonably shared to the whole network thus making nodes participating in the work be those with sufficient ones and protecting nodes with lower energy so as to make full use of overall energy of network. Meanwhile, the level of node residual energy dynamically changes with overall level of residual energy in the network. This guarantees the real-time and reliability of routing path election. Coordinator is supported by room electricity, which keeps sufficient energy. It may have functions of perceiving energy, evaluating energy of the whole network and...
determining level of node residual energy thus better managing the whole network. In ZigBee Routing Algorithm, AODVjr Algorithm utilizes multipath optimization algorithm improvement.

2.1 AODVjr Multipath Optimization Routing Algorithm

Among clusters of AODVjr Algorithm, ratio between node residual energy and overall residual energy of network could reflect energy level of the whole network in real time. At the same time, the node’s neighbors are the objects of data transmission. Their energy levels should also become consideration of energy balance. Therefore energy entry of neighbor nodes should be added into its neighbor table. Suppose that En is node residual energy and Enb stands for average energy of neighbor nodes. Average residual energy Eave of all nodes in the network reflects its overall energy level. In terms of single node in routing path, its energy balance function is shown in the following formula.

\[ f = \alpha \frac{E_n}{E_{ave}} + \beta \frac{E_{nb}}{E_{ave}} \]

(1)

Here \( \alpha \) and \( \beta \) are impact factors. As level of node residual energy should be given priority consideration, there exists \( 0 < \beta < \alpha \), in which \( \alpha \) is set to be 10 and \( \beta \) be 5. Their reciprocal is selected to act as equilibrium cost. Equilibrium energy cost of one path is shown as follows.

\[ \sum_{i=1}^{n} \frac{1}{f_i} \]

(2)

Here \( f_1, f_2, ..., f_n \) are energy equilibrium function values of nodes 1, 2.. n in the path. \( \frac{1}{f_i} \) is its energy equilibrium cost. The lower \( f_i \), the bigger equilibrium cost. At the same time, \( E_1, E_2, ..., E_n \) are residual energy of nodes 1, 2, ..., n. The reciprocal \( \frac{1}{E_i} \) acts as path energy consumption cost. The lower is energy, the higher is cost. Energy consumption cost in the path is shown in the following formula.

\[ \sum_{i=1}^{n} \frac{1}{E_i} \]

(3)

Meanwhile, set energy equilibrium ratio of nodes.

\[ V = \frac{E_n}{E_{ave}} \]

(4)

Energy security equilibrium ratio of nodes caters for \( V_{safe} = \epsilon \). \( \epsilon \) is security value of node energy relative to the whole network. When \( V \) is lower than \( V_{safe} \), node energy is at a low level in the whole network which should be protected. Here value of \( \epsilon \) is set to be low when node initial energy is high and energy consumption of data transmission is low. On the contrary, it is set to be high value. In the experiment of this paper, \( \epsilon \) is set to be 0.2. The elected routing path caters for \( V \) being lower than \( V_{safe} \) and the number of node being minimum, which is shown as follows.

\[ \min \left( \mu \sum_{i=1}^{n} \frac{1}{f_i} + \lambda \sum_{i=1}^{n} \frac{1}{E_i} \right), \mu > \lambda > 0 \]

(5)

When initial energy of node is low and the number of network node is small, difference value between \( \mu \) and \( \lambda \) is chosen to be high. Otherwise, it is set to be low. In the experiment of this paper, \( \mu \) is 2 and \( \lambda \) is 1. As \( E_n, E_{nb} \) and \( E_{ave} \) dynamically change with network operating, Formula 1-Formula 5 also present dynamic changes according to real-time situations of network.

Other researchers utilizes AODV Algorithm which abandon hop count and target sequence to directly set energy region according to depth in order to calculate average residual energy, in which concern is depth. Being different from these researchers, this paper pays attention to node residual energy. It could reflect energy consumption cost of path and energy equilibrium of node in real time. Do weighting optimization on energy equilibrium cost and energy consumption cost of nodes in routing path so as to dynamically acquire routing path with minimum cost. Utilize routing path keeping the highest network energy to protect node with lower energy, in which nodes with higher energy are fully utilized.

2.2 Limitation of Broadcast Storm

When coordinator does broadcast networking, do layering on nodes in sequence in accordance with networking orders in which layer number is set to be \( L \). Nodes joining in the network at the same time are in the same layer. Nodes joining in the network later are in the sub-layer in which \( L \) progressively increases. Those joining in the network ahead are in the parent layer in which \( L \) progressively decreases. Add \( L \) value of neighbor into neighbor table. RREQ message searched by routing signs the \( L \) value of node which sends RREQ packet. Do directional selection transmission according to \( L \). Specific flow of algorithm is shown below.

When source node initiates routing requests, directly broadcast RREQ packet and enter step 2.
When other nodes receive RREQ packet, the node which is destination node replies with RREP packet, abandons the received RREQ and establishes routing. Otherwise, they would turn to step 3.

If L in RREQ packet is equal to that of node, it means that these nodes are from the same layer. Then it would broadcast and transmit RREQ packet. On the contrary, it enters step 4.

If L in RREQ packet is lower than that of node, RREQ packet would be directly sent to nodes with equal or higher L. On the contrary, it enters step 5.

If L in RREQ packet is higher than that of node, RREQ packet would be directly sent to nodes with equal or lower L. On the contrary, it enters step 2.

This algorithm would reduce quite a number of useless RREQ packets.

When routing requests are initiated, source node would broadcast and send RREQ packet to all surrounding neighbor nodes. Neighbor nodes continue to broadcast it after receiving RREQ packet. If nodes which receive RREQ packet resend the requests to those which have already received the packet, it means waste of much energy. Therefore sending direction of RREQ packet from sub-layer or parent layer should be determined to reduce the number of the sent RREQ packet.

Fig.1 shows the flow of AODVjr dynamic multipath optimal routing algorithm.

3. SIMULATION ANALYSES

For the purpose of effectively evaluating performance of routing algorithm in this paper, it utilizes NS2.33 to do network simulation comparison on classical ZigBee routing algorithm, representative improved algorithm in Literature (Hwang, 2013) and algorithm in this paper. In the simulation scene whose coverage area is 200m multiplying by 200m, in which 100 fixed nodes with random positions are set, 50 CBR data information sources are arranged, packet length is 80 Byte, cluster tree parameter Lm is 3, Cm equals to Rm which is 4, initial energy of all nodes is 5J, data sending power is 0.6W, data receiving power of node is 0.3W and simulation time is 1200s. Parameters of algorithm in this paper are set to be ε =0.2, α = 10, β = 5, μ =2, λ = 1.

Fig.2 shows that with data being transmitted in network, the conditions of nodes exhausting energy and being dead in the improved algorithm and algorithm of this paper are better than that in classical one. The improved algorithm reduces RREQ which protects nodes with lower energy. However, singularity of optimal routing path election results in death of some nodes. Under the premise of reducing RREQ, algorithm in this paper dynamically choose nodes with higher energy in order to share burden of nodes with lower energy. Load balance postpones dead time of nodes and lengthens network survival time.

It is seen from Fig.3 that network energy consumption of classical algorithm rapidly increases during the beginning 400s, which tends to be stable with network going to death. The improved algorithm reduces flooding of RREQ and does election on routing path thus leading energy consumption to be gentle. From Fig.6 we see that the number of death node in this algorithm is the minimum in which more nodes keep working. Its network efficiency is higher and overall energy consumption lies in ideal condition.

Fig.4 expresses that network in classical algorithm does not set optimization mechanism. During the beginning 400s, its end-to-end delay is low. With network operating, the number of death node increases and delay lengths.
Source node broadcasts and sends RREQ

Receive RREQ, whether it is destination node

Whether L of RREQ is equal to L of this node

Yes
Transmit RREQ

No

Whether L of RREQ is higher than L of this node

No
Transmit RREQ to nodes whose L is higher than or equal to L of this node, update L of RREQ

Yes
Transmit RREQ to nodes whose L is lower than or equal to L of this node, update L of RREQ

Abandon RREQ; send RREP to determine this routing path

Judge V of nodes in each path according to step 4

There exists one path catering for $V > V_{safe}$

No
Judge V of nodes in each path according to step 4

Yes
Select this path

Yes
Whether there exists path with nodes catering for $V > V_{safe}$

Yes
Continue to send data in this path

No
Choose eligible path based on step 5

No

Acquire relevant cost in accordance with step 1 to step 3

Yes

Figure 1 Flow of AODVjr Dynamic Multipath Optimal Algorithm
Figure 2 Number of Death Node Changing with Simulation Time

Figure 3 Network Energy Consumption Changing with Simulation Time

Figure 4 Network Delay Changing with Simulation Time
5. CONCLUSIONS

Nowadays ZigBee Technology has been widely utilized in the Internet of things. On the basis of ZigBee routing and current research achievements, this paper proposes dynamic routing algorithm based on load balance, which establishes cluster tree protection mechanism, reduces equilibrium energy consumption and lengthens network lifetime through determining RREQ sending direction and setting equilibrium cost. Although some extra control and management cost comes into being, it improves network efficiency on the whole and reduces energy consumption.

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