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# A Balancing Algorithm in Wireless Sensor Network Based on the Assistance of Approaching Nodes

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**Abstract:** Sensor node in wireless sensor network is a micro-embedded system with limited memory, energy and communication capabilities. Some nodes will run out of energy and exit the network earlier than other nodes because of the uneven energy consumption. This will lead to partial or complete paralysis of the whole wireless sensor network. A balancing algorithm based on the assistance of approaching nodes is proposed. Via the set theory, notes are divided into neighbor nodes set and approaching nodes set. Approaching nodes will help weaker nodes forward part of massages to balance energy consumption. Simulation result has verified the rationality and feasibility of the balancing algorithm. *Copyright © 2013 IFSA.*

**Keywords:** Wireless sensor network, Approaching nodes, Balancing algorithm, Set theory.

## 1. Introduction

Wireless sensor network (WSN) is a kind of distributed and self-organization network and it is composed of sensor nodes with limited memory, energy and communication capabilities [1]. A sensor node is a micro-embedded system whose role is to detect process and transmit information [2]. Sensor nodes are supplied by energy-limited batteries. The energy restriction is one of the most key constraints in the design of the whole wireless sensor network [3]. It determines the whole lifetime of the network directly [4]. Since the uneven energy consumption of senor nodes, some nodes will run out of energy and exit the network earlier than other nodes. In order to avoid this situation, a serious of energy balancing algorithms is proposed.

Literature [5] puts forward an energy-balanced short routing algorithm (EB-SPR) in WSN. This algorithm extends the network lifetime further and produces smaller network latency [4]. Literature [6] constructs a bi-level programming model to maximize the network lifetime [5]. Literature [7] researches the issue of load balancing in WSN on the microscopic scale. Literature [8] proposes a reduced identical composite event transmission (RICET) algorithm to eliminate redundant transmission and save power consumption. Literature [9] proposes a fuzzy-based filtering nodes assigning method for WSN to cope with energy inefficiency. An energy-efficient online reprogramming protocol called EEORP is proposed in Literature [10]. EEORP improves the dynamic adjustment algorithm of transmit rate of advertisement to reserve energy. The existing algorithm relies on the residual energy which can only exist in the physical layer, while the energy balance algorithm is in the network layer, so they are cross-layer algorithm. In addition, huge computation and complex algorithm are the limitations of these methods.

A balancing algorithm based on the assistance of approaching nodes is proposed in the mesh network. To makes the algorithm easy to understand and operate, the term of set theory is introduced to



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describe this algorithm creatively. Via the set theory, notes are divided into neighbor nodes set and approaching nodes set. Approaching nodes will help weaker nodes forward part of massages to reduce the amount of data forwarded by the weaker nodes and consequently to realize energy balancing and lifetime extension for the whole network.

## 2. Balancing Algorithm Based on the Assistance of Approaching Nodes

### 2.1. Description of the Algorithm

Nodes bare heavier forwarding task consume more energy in a WSN. In the same initialization condition, these nodes are more likely to enter the state of energy scarcity. Necessary measures should be taken to ease their burden. Some nodes are called neighbor nodes as they can reach one node in one jump. In other words, they are in a circle centered at one node whose radius is the radiofrequency radius. In the mesh network, one node has more than one neighbor nodes, and some neighbor nodes are near while others are far. With energy reducing, the radiofrequency radius decreases. The farthest neighbor node will lose contact first, then it informs its own neighbor nodes that the energy of the node is insufficient and stops asking it to forward data. In order to express the logic more clearly, the following concepts about set are defined.

The $A_k$ ={node $j \mid j$ is the neighbor node of node $k$ }, $j$ , $k \in N$ , $N$ is set of natural numbers. Namely, $A_k$ is the collection of all neighbor nodes of node $k$ .

The $A_k'$ represents the new collection of all neighbor nodes of node $k$ . Then there is formula (1):

$$A_k' = \begin{cases} A_k & k \text{ lost none} \\ A_k - \{j\} - A_j \cap A_k & k \text{ lost neighbor node } j \end{cases} \quad (1)$$

The theoretical foundation is given in equation (1). Namely once node $k$ lost its neighbor node $j$ because of energy scarcity, $k$ will remove not only $j$ out of its neighbor table, but also the common neighbor nodes of $j$ and $k$ . The $k$ changes its neighbor table by cutting the link between $j$ and also the link between the common neighbor nodes of $j$ and $k$ . So those disconnected nodes cannot let the node $k$ forwards their data any longer and node $k$ will switch to a low power state. To a mesh network, cutting link partially will not affect the connectivity of the whole network, but the network topology will be changed.

Since the topology has changed, the corresponding routing has to be re-found. NS2 is used to simulate the balancing algorithm and to obtain the information of routing table. Viewing from theoretical point, the packets routed by node $k$ will reduced significantly, and those packets will be forwarded by the approaching nodes of $k$ . That is called the assistance of approaching nodes. Pay attention to the difference between neighbor nodes and approaching nodes. The former has a strict definition which has already been mentioned, while the latter is a relative term which refers to those nodes close to the energy scarcity node.

### 2.2. Processes of the Algorithm

The flow chart of this algorithm is shown in Fig. 1 to make the algorithm more intuitive.

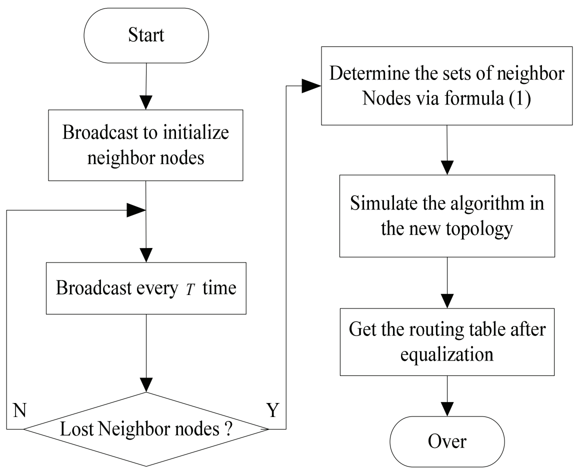


**Fig. 1.** Basic algorithm flow chart.

At the beginning of establishing a network, the energy of every node is sufficient. Broadcasting at this time can get the most comprehensive neighbor nodes. In order to confirm whether each node has got into the state of energy scarcity, all nodes broadcast a test packet every $T$ time and confirm their approaching nodes at the same time. The value of $T$ should be appropriate. If $T$ is too short, it will broadcast frequently and increase the load of the network. If $T$ is too long, those energy scarcity nodes cannot be found timely. The reference value of $T$ is ten hours or one day.

### 2.3. Extension of the Algorithm

It is easy to see that formula (1) has discussed the situation of one node losing one neighbor. If two nodes lose one neighbor node respectively, the formula (1) can be applied respectively. But what should be done if one node lost more than one neighbor node in $T$ time? The equation (1) must be modified as follows.

$$A_k' = A_k - \sum_{j \in L} (\{j\} + A_j \cap A_k), \quad (2)$$

where $L$ is the set of all the neighbor nodes that $k$ has lost. If $k$ lost none, $L=\varnothing$, $A_k'=A_k$. Therefore formula (2) is simplified from formula (1) and contains more situations. In addition, it is obvious that the formula (1) removes the lost node and the common neighbor nodes between the lost node and the energy scarcity node as well as formula (2). But, shall the common neighbor nodes between the common neighbor nodes and the energy scarcity nodes be removed? Obviously, it is a matter of degree. The balancing algorithm described in formula (1) and (2) is called single-balancing. If the common neighbor nodes between the common neighbor nodes and the energy scarcity node are removed out of the neighbor table, this balancing algorithm will be called dual-balancing. Dual-balancing can save the weak node more effectively than single-balancing, but it also makes weak node easier to be isolated from the network (when all neighbor nodes are removed out of the neighbor table). Therefore, the dual-balancing should be used with caution. And formula of dual-balancing is given as follows.

$$A_k'=A_k-(\{j\}+A_j\cap \mathrm{A}_k)-\sum_{n\in A_j\cap \mathrm{A}_k}(A_n\cap \mathrm{A}_k) \quad (3)$$

Here $n$ is the common neighbor node of $j$ and $k$, $j$ is the lost node and $k$ is the energy scarcity node.

### 2.4. Processes of Extension Algorithm

Those three formulas given above correspond to different scenarios. They can be integrated into one flow chart as shown in Fig. 2.

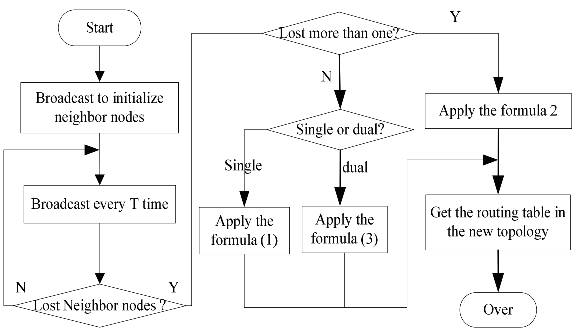


**Fig. 2.** Algorithm flow chart after extension.

A final note is that balancing algorithm which is deeper or more powerful than the dual-balancing will not be used.

## 3. Simulation and Analysis

In order to verify the correctness and validity of this algorithm, NS2 is chose to simulate it. NS2 is one of the most popular software committed to network simulation. It has been widely used for network analysis, research and teaching [11]. While NS2 simulates the algorithm, it shows the topology, the neighbor nodes table and the routing table after energy balance.

To make a comparison, two cases are simulated. First, the node has sufficient energy. Second, the energy is insufficient. In order to meet different application needs, the latter is divided into four cases to do the simulation.

### 3.1. When the Energy is Sufficient

Firstly, the network should be initialized, and each node broadcasts a test packet to determine its own neighbor nodes. The following Fig. 3 is the schematic diagram when broadcasting.

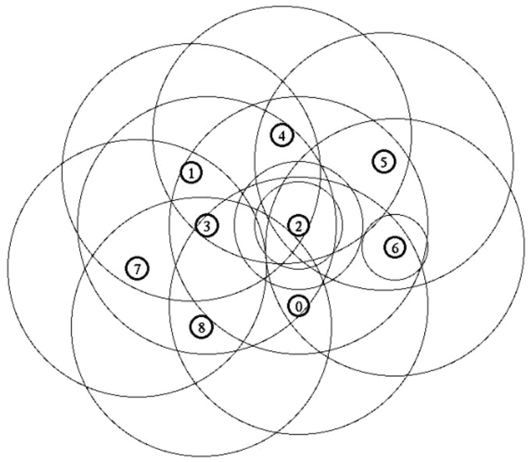


**Fig. 3.** Schematic of broadcasting when the energy is sufficient.

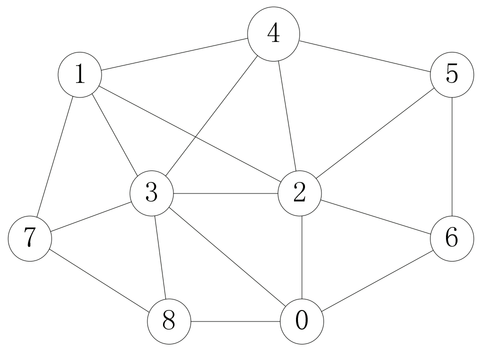


**Fig. 4.** Topology of WSN when the energy is sufficient.

The largest circle centered on one node is the radiation area of this node, and nodes in the circle are its neighbor nodes. The topology is obtained just as Fig. 4 shows and the neighbor table is displayed as Table 1 shows via NS2 simulation.

**Table 1.** The neighbor table when the energy is sufficient.

| Node number | Neighbor nodes number |
|---|---|
| 0 | 2, 3, 6, 8 |
| 1 | 2, 3, 4, 7 |
| 2 | 0, 1, 3, 4, 5, 6 |
| 3 | 0, 1, 2, 4, 7, 8 |
| 4 | 1, 2, 3, 5 |
| 5 | 2, 4, 6 |
| 6 | 0, 2, 5 |
| 7 | 1, 3, 8 |
| 8 | 0, 3, 7 |

On the principle of minimum hops, the routing table can be acquired just as Table 2 shows. N suggests that they are neighbors (the same below).

**Table 2.** The routing table when the energy is sufficient.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | - | 2 | N | N | 2 | 2 | N | 8 | N |
| 1 | 3 | - | N | N | N | 2 | 2 | N | 7 |
| 2 | N | N | - | N | N | N | N | 3 | 0 |
| 3 | N | N | N | - | N | 2 | 2 | N | N |
| 4 | 3 | N | N | N | - | N | 2 | 1 | 3 |
| 5 | 2 | 2 | N | 2 | N | - | N | 2<-3 | 2<-0 |
| 6 | N | 2 | N | 2 | 2 | N | - | 2<-3 | 0 |
| 7 | 3 | N | 1 | N | 1 | 1<-2 | 1<-2 | - | N |
| 8 | N | 7 | 3 | N | 3 | 3<-2 | 0 | N | - |

The “2” underlined means that node 2 forwards the data from node 3 to node 5. The “1<-2” underlined means the link from node 7 to node 6 is 7-1-2-6.

### 3.2. The Energy is Insufficient

#### 3.2.1. One Node Lost One Neighbor Node (Single-balancing)

Assuming that node 2 lost its neighbor node 1 and Fig. 5 is the schematic of radiation area at that time. It is screenshot when using the Nam tool to demonstrate. Nam is the abbreviation of Network Animator and it is often used in conjunction with the NS simulator. It demonstrates the network operation through animation.

It can be seen from Fig. 6 that node 1 has been out of the radiation area of node 2. Table 1 shows that $A_1=\{2,3,4,7\}$, $A_2=\{0,1,3,4,5,6\}$. Through formula (1), get $A_2'=A_2-\{1\}-A_1\cap A_2$ = {0, 1, 3, 4, 5, 6} - {1} - {3,4}= {0,5,6}.

Topology after balancing is showed in Fig.6, and the corresponding neighbor table is Table 3. When node 2 lost node 1, node 2 cut the link between it and node 3, as well as node 4, according to the balancing algorithm.

The routing table can be acquired just as Table 4 shows below.

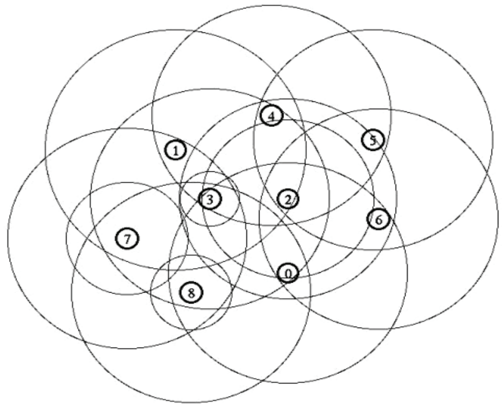

**Fig. 5.** Schematic of broadcasting indicates node 2 lost node 1.

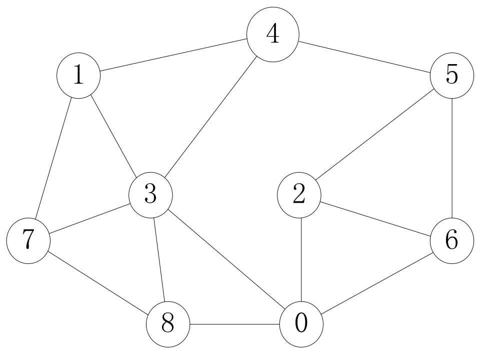


**Fig. 6.** Topology of WSN after node 2 lost node 1 (single-balancing).

**Table 3.** The neighbor table after node 2 lost node 1 (single-balancing).

| Node number | Neighbor nodes number |
|---|---|
| 0 | 2, 3, 6, 8 |
| 1 | 3, 4, 7 |
| 2 | 0, 5, 6 |
| 3 | 0, 1, 4, 7, 8 |
| 4 | 1, 3, 5 |
| 5 | 2, 4, 6 |
| 6 | 0, 2, 5 |
| 7 | 1, 3, 8 |
| 8 | 0, 3, 7 |

**Table 4.** The routing table after node 2 lost node 1 (single-balancing).

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | - | 3 | N | N | 3 | 6 | N | 3 | N |
| 1 | 3 | - | 3<-0 | N | N | 4 | 3<-0 | N | 3 |
| 2 | N | 0<-3 | - | 0 | 5 | N | N | 0<-3 | 0 |
| 3 | N | N | 0 | - | N | 4 | 0 | N | N |
| 4 | 3 | N | 5 | N | - | N | 5 | 1 | 3 |
| 5 | 6 | 4 | N | 4 | N | - | N | 4<-1 | 4<-3 |
| 6 | N | 0<-3 | N | 0 | 5 | N | - | 0<-3 | 0 |
| 7 | 8 | N | 3<-0 | N | 3 | 1<-4 | 8<-0 | - | N |
| 8 | N | 7 | 0 | N | 3 | 0<-6 | 0 | N | - |

Comparing Table 2 and Table 4, it can be easily concluded that the wireless sensor network reduces the load of node 2 after balancing. For example, in Table 4, the “3” underlined forwards the packets from node 1 to node 0. However in Table 2, it is node 2 that forwards this kind of packets. In short, node 3 assists node 2 to forward packets. Then the purpose of energy balance is achieved.

### 3.2.2. One Node Lost one Neighbor Node (Dual-balancing)

Dual-balancing algorithm is more effective than single-balancing, it can be deduced from its definition. In order to prove it, there is an assumption that node 2 lost its neighbor node 1, and the radiation area of the node 2 was showed in Fig. 5.

Since $A_1 \cap A_2 = \{3,4\}$, $A_3 \cap A_4 = \{0,1,4\}$, $A_4 \cap A_2 = \{1,3,5\}$. According to formula 3, $A_2' = \{0,1,3,4,5,6\} - \{1\} - \{3,4\} - \{0,1,4\} - \{1,3,5\} = \{6\}$.

Topology after balancing is showed in Fig. 7, and the corresponding neighbor table is showed in Table 5.

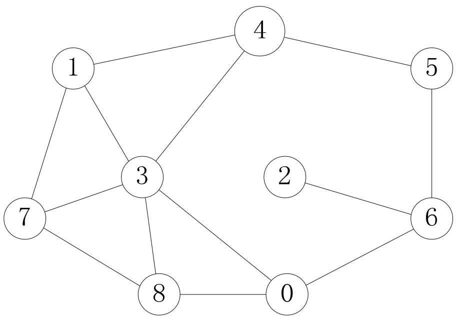


**Fig. 7.** Topology of WSN after node 2 lost node 1 (dual-balancing).

**Table 5.** The neighbor table after node 2 lost node 1 (dual-balancing).

| Node number | Neighbor nodes number |
|---|---|
| 0 | 3, 6, 8 |
| 1 | 3, 4, 7 |
| 2 | 6 |
| 3 | 0, 1, 4, 7, 8 |
| 4 | 1, 3, 5 |
| 5 | 4, 6 |
| 6 | 0, 2, 5 |
| 7 | 1, 3, 8 |
| 8 | 0, 3, 7 |

Similarly, the theoretical result is consistent with Fig. 7 and Table 5. Because there is only one neighbor node on node 2, that is node 6. No node needs node 2 to forward packets. Node 2 only needs to send its own data to node 6. The routing Table 6 is obtained via simulation, and there is no node 2 in this table because node 2 is no longer a router. Thus, dual-balancing has a greater degree of energy saving than single-balancing.

**Table 6.** The routing table after node 2 lost node 1 (dual-balancing).

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | - | 3 | 6 | N | 3 | 6 | N | 3 | N |
| 1 | 3 | - | 3<-0<-6 | N | N | 4 | 3<-0 | N | 3 |
| 2 | 6 | 6<-0<-3 | - | 6<-0 | 6<-5 | 6 | N | 6<-0< | 6<-0 |
| 3 | N | N | 0<-6 | - | N | 4 | 0 | N | N |
| 4 | 3 | N | 5<-6 | N | - | N | 5 | 3 | 3 |
| 5 | 6 | 4 | 6 | 4 | N | - | N | 4<-3 | 4<-3 |
| 6 | N | 0<-3 | N | 0 | 5 | N | - | 0 | 0 |
| 7 | 3 | N | 3<-0<-6 | N | 1 | 3<-4 | 3<-0 | - | N |
| 8 | N | 3 | 0<-6 | N | 3 | 0 | 0 | N | - |

Comparing Table 2 with Table 6, it can be found that even if only one node lost only one neighbor node, large changes will happen to the topology in dual-balancing algorithm. So dual-balancing algorithm is powerful but should be used with caution.

### 3.2.3. One Node Lost two Neighbor Nodes

When there are many neighbor nodes, a loss of two or more neighbor nodes is normal. Assuming that node 2 lost its neighbor node 1 and node 5. Fig. 8 is schematic of radiation area.

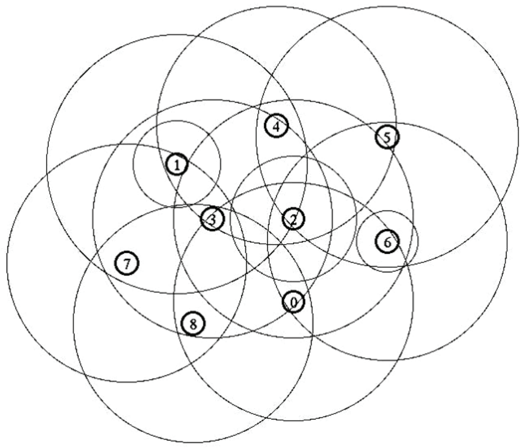


**Fig. 8.** Schematic of broadcasting when node 2 lost its neighbor node 1 and node 5.

It can be clearly seen from Fig. 8 that node 1 and node 5 has been out of the radiation area of node 2. According to the flowchart in Fig. 2, formula 2 should be substituted. The set of losing nodes $L = \{1,5\}$, and $A_1 \cap A_2 = \{3,4\}$, $A_5 \cap A_2 = \{4,6\}$.

So, $A_2' = \{0,1,3,4,5,6\} - \{1\} - \{3,4\} - \{5\} - \{4,6\} = \{0\}$.

Topology after balancing is Fig. 9, and the corresponding neighbor table is Table 7. They meet theoretical results above.

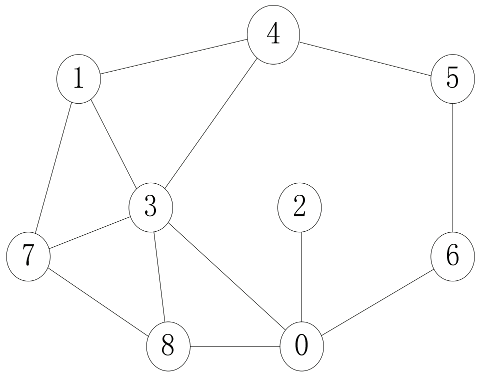


**Fig. 9.** Topology of WSN after node 2 lost its neighbor node 1 and node 5.

**Table 7.** The neighbor table after node 2 lost node 1 and node 5.

| Node number | Neighbor nodes number |
|---|---|
| 0 | 2, 3, 6, 8 |
| 1 | 3, 4, 7 |
| 2 | 0 |
| 3 | 0, 1, 4, 7, 8 |
| 4 | 1, 3, 5 |
| 5 | 4, 6 |
| 6 | 0, 5 |
| 7 | 1, 3, 8 |
| 8 | 0, 3, 7 |

The topology and the neighbor table indicate that when node 2 lost two neighbor nodes, single-balancing algorithm is able to balance the energy consumption of node 2. Thus, dual-balancing doesn't work. Table 8 is the routing table after node 2 lost node 1 and node 5. Node 2 doesn't have to forward packets, which can be confirmed by Table 8.

**Table 8.** The routing table after node 2 lost node 1 and node 5.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | - | 3 | N | N | 3 | 6 | N | 8 | N |
| 1 | 3 | - | 3<-0 | N | N | 4 | 3<-0 | N | 7 |
| 2 | N | 0<-3 | - | 0 | 0<-3 | 0<-6 | 0 | 0<-8 | 0 |
| 3 | N | N | 0 | - | N | 4 | 0 | N | N |
| 4 | 3 | N | 3<-0 | N | - | N | 5 | 3 | 3 |
| 5 | 6 | 4 | 6<-0 | 4 | N | - | N | 4<-3 | 6<-0 |
| 6 | N | 0<-3 | 0 | 0 | 5 | N | - | 0<-8 | 0 |
| 7 | 8 | N | 8<-0 | N | 3 | 3<-4 | 8<-0 | - | N |
| 8 | N | 7 | 0 | N | 3 | 0<-6 | 0 | N | - |

### 3.2.4. Two Nodes Lose one Neighbor Node Respectively

When the network scale unceasingly expands, it is prone to the lack of energy for two or more nodes in a broadcast period of T. As an example to explain the balancing algorithm when the energy of multiple nodes is insufficient, there is a hypothesis that node 2 and 3 lose node 1 and node 4 respectively. Schematic of broadcasting is showed in Fig. 10, where node 1 is out of the radiation area of node 2 while node 4 is out of the radiation area of node 3.

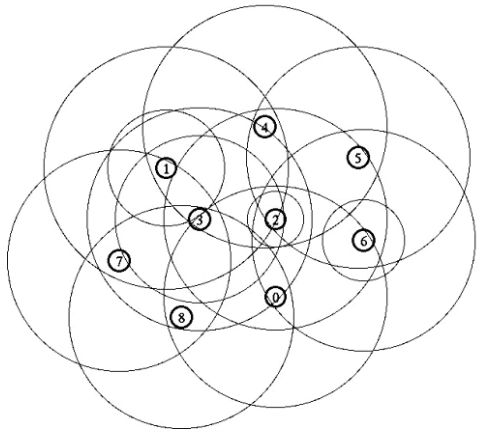


**Fig. 10.** Schematic of broadcasting when node 2 lost node 1 and node 3 lost node 4.

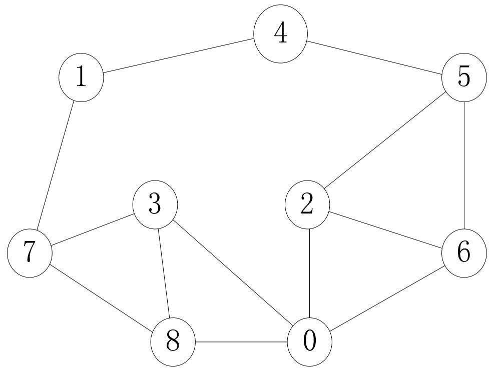


**Fig. 11.** Topology of WSN after node 2 lost node 1 and node 3 lost node 4.

Substituting the formula 1 on node 2 and 3 respectively, and then it can be got that

$$A_2{}' = A_2 - \{1\} - A_1 \cap A_2 = \{0,1,3,4,5,6\} - \{1\} - \{3,4\} = $$
$$= \{0,5,6\},$$
$$A_3{}' = A_3 - \{4\} - A_3 \cap A_4 = \{0,1,2,4,7,8\} - \{4\} - \{1,2\} = $$
$$= \{0,7,8\}.$$

Topology after balancing is showed in Fig.11, and the corresponding neighbor table is Table 9. The neighbor information conforms to theoretical derivation. The simulation routing table is showed in Table 10.

Comparing Table 2 with Table 10, it can be found that the number of packets which need node 2 and 3 to forward has been reduced from 20 to 4 and 10 to 4 respectively. The neighbor Table 9 and simulation topology comply with theoretical derivation, which shows that the balancing algorithm can handle multiple nodes in a large scale network.

**Table 9.** The neighbor table after node 2 lost node 1 and node 3 lost node 4.

| Node number | Neighbor nodes number |
|---|---|
| 0 | 2, 3, 6, 8 |
| 1 | 4, 7 |
| 2 | 0, 5, 6 |
| 3 | 0, 7, 8 |
| 4 | 1, 5 |
| 5 | 2, 4, 6 |
| 6 | 0, 2, 5 |
| 7 | 1, 3, 8 |
| 8 | 0, 3, 7 |

**Table 10.** The routing table after node 2 lost node 1 and node 3 lost node 4.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | - | 8<-7 | N | N | 6<-5 | 6 | N | 3 | N |
| 1 | 7<-8 | - | 4<-5 | 7 | N | 4 | 4<-5 | N | 7 |
| 2 | N | 5<-4 | - | 0 | 5 | N | N | 0<-3 | 0 |
| 3 | N | 7 | 0 | - | 7<-1 | 0<-6 | 0 | N | N |
| 4 | 5<-2 | N | 5 | 1<-7 | - | N | 5 | 1 | 1<-7 |
| 5 | 2 | 4 | N | 2<-0 | N | - | N | 4<-1 | 2<-0 |
| 6 | N | 5<-4 | N | 0 | 5 | N | - | 0<-3 | 0 |
| 7 | 8 | N | 8<-0 | N | 1 | 1<-4 | 3<-0 | - | N |
| 8 | N | 7 | 0 | N | 7<-1 | 0<-6 | 0 | N | - |

## 4. Conclusions

A new energy balancing algorithm is introduced based on the set theory. The core is to modify the nodes' neighbor table information to reduce the packets that need to be forwarded by the weak nodes, and then achieve the goal of energy balance. Four kinds of situations have been simulated and analyzed and the simulation results prove the correctness and validity of the balancing algorithm.

## Acknowledgments

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