Journal of Computers Vol. 28, No. 6, 2017, pp. 52-63
doi:10.3966/199115992017122806005

A Topology Maintenance Algorithm Based on Power Control for Mobile Wireless Sensor Network

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Received 30 July 2016; Revised 7 February 2017; Accepted 7 March 2017

Abstract. According to the current topology maintenance algorithm is based on the topology reconstruction when the nodes movement, some nodes joining and exiting the network, node failure may cause the topology changes. This paper proposes a power control based on the topology maintenance algorithm PCTMA. PCTMA algorithm contains three mechanisms: Relay Node Selection Mechanism Based on Node Energy Consumption Model; Power Adjustment Prejudging Mechanism and Maintenance Mechanism Based on Event Triggering. Exploits the node energy consumption model to select the relay nodes and achieve the purpose of reduce the overall network energy consumption. Power Adjustment Prejudging Mechanism according to the relationships between the nodes transmit power and communication radius, the nodes maintain connectivity with each other based on the power control.The mechanism can prejudge how to adjuste the transmission power when the network topology changed.To deal with the different situation that causes the topology changes, the maintenance mechanism based on event triggering was proposed in the paper. The simulation results show that the PCTMA algorithm is superior to the XTC algorithm and NAPC algorithm in terms of average transmits power, network connectivity, and the number of live nodes in the network.

Keywords: energy consumption of nodes, power control, topology maintenance, topology reconstruction

1 Introduction

In the mobile wireless sensor networks, because the moving speed or direction of nodes may change at any time, new nodes join the network, some nodes exit the network due to the movement or because of energy depletion, all of these cases can lead to large and frequent topology changes, seriously affecting network connectivity and network life cycle [1-2]. Therefore, when the topology changes through the topology maintenance algorithm to maintain it, which is very important to improvement the communication reliability and extend the network life cycle [3-4].

Topology maintenance refers to monitor the state of the network topology real-time, is a process to repair the network topology when it has changed and this change is about to affect or has affected the network performances [5-6]. The main purposes are repair the topology of the network and extend the network life cycle [7-8]. Due to topology maintenance techniques not yet been widespread concern by academia, resulting in a special topology maintenance algorithm also rare. There have been many topology maintenance schemes proposed. But most of them perform the topology construct algorithm again. However, the maintenance strategy based on topology reconstruction can not be quickly and effectively for topology maintenance. Firstly, topology construction and topology maintenance has different emphases. The topology construction it is more important to define the network topology based on the topology construction algorithm, and this algorithm and topology structure can help to improve the performances of the network [9]. In contrast, the topology maintenance is more important to repair the network when the topology changed or network failure. Secondly, if topology reconstruction scheme adopted that need to get the nodes information again and then reconstruct the topology, which increases the communication overhead and network convergence time. In addition, in the high node density networks when one node failure results in network topology changes, it will involve a lot of "unnecessary" nodes if the topology reconstruction scheme was adopted. This will undoubtedly increase the communication overhead, node energy consumption, network convergence time. While some topology maintenance scheme based on topology control are proposed, but their essence is topology reconstruction.

2 Related Work

Shen, Chang and Zhang proposed STMP algorithm is to maintain the connectivity and topology performance of the network, and reduce the overhead as much as possible during topology maintenance [10]. It's mainly aimed at the situation of node failure in wireless Ad hoc networks. STMP algorithm was based on the SPTTC algorithm [11]. SPTTC algorithm is a kind of topology control algorithm based on power control. The main idea of the algorithm is that each node based on the local topological structure run shortest path tree algorithm to determine the transmission power of nodes. Liu and Liproposed to control the network topology by SPTTC algorithm, then the topology changes, the neighbors of faulty node are first triggered to respond through the STMP algorithm, each responding node judges whether the network is connected by the "*Hello*" messages from its neighbors [11]. If the network is not connected, then the other reachable nodes of the failure node can be triggered. However, SPTTC algorithm was run again when the neighbors of faulty node are first triggered to respond. So the essence of algorithm of STMP algorithm is topology reconstruction. An energy efficient topology maintenance scheme (EETMS) was proposed to maintain the network connectivity and performance while reducing the maintenance overhead when nodes fail [12]. The EETMS introduced the judgment criterion of graph connectivity. When the faulty node in the network, the transmission power of the neighbors of faulty node was adjusted firstly. Then the local adjacency matrix of neighbor node set of faulty node is calculated. And finally construct an energy efficient local topology. But the algorithm does not give the detection mechanism of the fault nodes, and the maintenance strategy of the algorithm is also the reconstruction of the local topology. Song proposed NAPC algorithm [13], which is also a kind of topology control algorithm based on power control and is an improvement of the XTC algorithm [14]. NAPC algorithm controls the node transmit power and optimizes the topology structure by exploiting the relationship between the nodes transmit power and the nodes communication radius. When a node detects lost contact with its adjacent node, the node maintains connectivity with adjacent nodes through adjusts its transmission power. However, the NAPC algorithm is only for nodes caused by movement is no longer become the other neighbor nodes and the algorithm has problems that a large overhead and network convergence time when the node updates it's transmit power. This paper mainly aims at the defects and shortcomings of the above maintenance algorithm based on the topology reconstruction. We proposes Topology Maintenance Algorithm Based on Power Control (PCTMA)

3 NAPC Algorithm Principle and Problem Analysis

The basic idea of the NAPC algorithm is to ensure network connectivity while allowing each node to control their transmission power. When the mobile node sends data to neighbor nodes farther away from itself, select distance it close neighbors as a relay node forwards. So the node can reduce its own transmission power. At the same time, it can also guarantee the connectivity of the network, and it will not lead to the conflict of the link because of too much power.

3.1 NAPC Algorithm Principle

The NAPC algorithm is mainly based on the nodes adopt different transmission power with a different transmission range. By dynamically adjusting the transmission power of nodes in the network, while maintaining the network connectivity, as far as possible to allow the network node to send data with the minimum power. The relationships between the nodes transmit power and the nodes communication radius such as formula (1) [13]. NAPC algorithm is mainly divided into three parts: to find qualified nodes, determine and modify the node transmit power, and update the node's transmission power.

$$P_i = C * r_i^a \quad \textbf{(1)}$$

Where, P_i is the transmission power of node V_i.r_i is communication radius of node V_i. C is a constant. a is an integer in the [2, 4] range, it indicates the energy attenuation factor. C and a has different value in different environments.

The first part, to find qualified node refers to the node finds out the closer nodes from the neighbor nodes set, and the nodes can become the relay node for the distant nodes. Then delete the nodes from the node's neighbor nodes set which one is far from it. As shown in Fig. 1, V_i, V_j, V_k respectively represent nodes. d is the distance between the nodes. When the distance between the nodes V_i, V_j, V_k are simultaneously satisfied the conditions: $d_1 <d$, $d_2 <d$, V_j is the qualified node. The node V_i removes the V_k from it's neighbor nodes set. The direct communication between the node V_i and V_k is adjusted to through the relay node V_j forwarded. Node V_i can adjust its transmission power according to the distance of the node V_j, so as to achieve both to maintain link connectivity and save the energy consumption of the node. r_i is communication radius of node V_i after adjusted the transmission power. r_{max} is the maximum communication radius of node V_i.

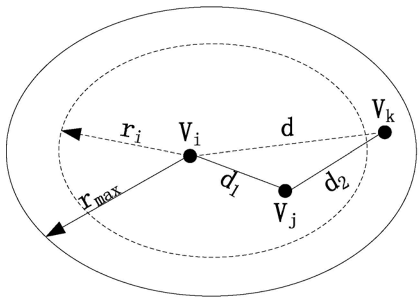

Fig. 1. Schematic diagram of NAPC algorithm

The second part, after found out the qualified nodes, nodes according to the formula (1) to determine and modify their transmit power. As shown in Fig. 1, after the node V_i finds out the qualified node V_j, the node V_i finds its own neighbor nodes set who is the most distant from itself. Then put this distance value into the formula (1) and calculated the transmission power P_i, replace the maximum transmit power P_{max} with P_i.

The third part, update the node's transmission power refers to maintain the network topology. In order to maintain the connectivity of the network, the NAPC algorithm detects the state of the network nodes. For example in Fig. 1, each node V_i sends the "*Live*" message every time t_m. And each node only receives one-hop neighbors' message. If the node V_i dose not receive the feedback message from one of it's neighbors V_j after the time t_0, the node V_i will record the transmission power value P_i at this time. Then the node V_i increases its transmission power 1.5 times and send a message to the node V_j. If the node V_j feedback the message, the node V_i will according to the current distance with the node V_j and calculate a new transmission power instead of P_i. If the node V_i does not receive the feedback message from the node V_j, the node V_i will continue to increase its transmission power 1.5 times, then detect, until it's transmission power is increased to the maximum or receives the feedback message from the node V_j that is no longer increased. If the node V_i increases it's transmission power to the maximum and can not be connected with the node V_j, the node V_i will be tell it's parent node that can not reach the node V_j.

If the parent node of the node V_i receives the message from the node V_i that can not reach to the node V_j, the node will look for a suitable relay node based on the above strategy or tell it's parent node that can not reach the to node V_i.

3.2 Problem Analysis

Through in-depth research we found that there are 3 problems in NAPC algorithm:

(1) The purpose of NAPC algorithm to find a qualified relay node is that to effectively save the node energy. But the algorithm is based on the the size of the distance between the nodes, rather than the energy consumption between nodes, which is obviously unreasonable and can not reduce the overall network energy consumption. For example, as shown in Fig. 1, When the distance between the nodes V_i, V_j, V_k are simultaneously satisfy the conditions: $d_1 <d, d_2 <d,$ but this does not mean that the total energy consumption for the node V_i sends the message to the node V_k through the node V_j forwarded is less than the energy consumption for the node V_i sends the same message to the node V_k directly. If we want to achieve the purpose of reduce the overall network energy consumption, the strategy that to find qualified relay nodes based on the the size of the distance between the nodes was undesirable.

(2) NAPC algorithm maintains the connectivity of the network topology by updating the node's transmission power. As shown in Fig. 1, when the node V_j moved out of communication range of node V_i, the node V_i continue find the node V_j acts as the relay node for the node V_i and the node V_k. There are two defects that the node increases its transmission power 1.5 times every time. First, there may be other qualified nodes except for the node V_j when find qualified relay nodes. So when the node V_j moved out of communication range of node V_i, the node V_i increases its transmission power 1.5 times to find the node V_j, it is blind and increases the communication overhead. Second, if the node V_j moved out of the maximum communication range of node V_i at first, or the node V_j moved out of 1.5 times transmission power corresponding to the communication range every time. The node V_j can not be found even though the node V_i increased its transmission power 1.5 times every time t_m. So this strategy increases the communication overhead and the convergence time of the network.

(3) NAPC algorithm is only given the maintenance measures the arbitrary node V_j moved out of communication range of node V_i, but the not considers the state of the node V_j. This may become the other nodes' neighbor, leaving the network, or become failure node due to energy depletion.

In order to solve the above problems, this paper improves the NAPC algorithm, and proposes Topology Maintenance Algorithm Based on Power Control (PCTMA).

4 PCTMA Algorithm Principles

PCTMA algorithm is mainly to improve the shortcomings of the NAPC algorithm. In order to reduce the overall energy consumption of the network, the relay nodes find more reasonable. The PCTMA algorithm exploits node energy consumption model to calculate the energy consumption of the node transmission unit bit data packet and select relay nodes with the condition of energy consumption size. When selecting relay node, preference to the minimum energy consumption node that transmit the unit bit packets. So that the energy consumption is minimum for nodes transfer data in each hop. The node first to finds the forwarding set and checks whether there are other nodes to replace the failure node. Then prejudge increase its transmission power 1.5 times or directly increase the power to the maximum can repair the link. Defining different events for the network topology change which caused by the different status of the network of nodes (joining network, leaving the network, node failure). The node detects the events and according to different events to make different maintenance strategies. In this paper the PCTMA algorithm is mainly divided into three mechanisms: relay node selection mechanism based on node energy consumption model, power adjustment prejudging mechanism and maintenance mechanism based on event triggering.

4.1 Relay Node Selection Mechanism Based on Node Energy Consumption Model

In order to save energy more effectively, according to size of the energy consumed act as the decision condition for selecting the relay nodes that the node to transmit and receive the unit bit packet. Energy consumption model of sensor nodes [15] as shown in Fig. 2

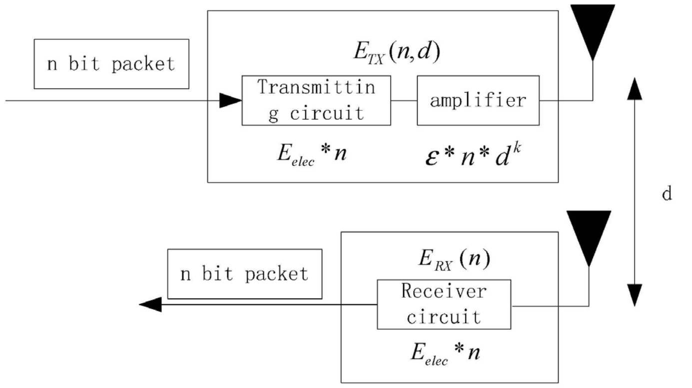

Fig. 2. Energy consumption model of sensor nodes

$$E_{TX}(n,d) = E_{TX\text{-}elec}(n) + E_{TX-amplify}(n,d) = E_{elec} * n + \varepsilon * n * d^k \quad \textbf{(2)}$$

$$E_{RX}(n) = E_{RX-elec}(n) = E_{elec} * n \quad \textbf{(3)}$$

$$E_{total} = E_{TX}(n,d) + E_{RX}(n) = 2 * E_{elec} * n + \varepsilon * n * d^k \quad \textbf{(4)}$$

Where, E_{elec} denotes the energy consumption of transmit or receive unit bit data. ε denotes the energy consumption of the transmit amplifier transmit unit bit data. *k* denotes propagation attenuation index, and $2 \leqslant k \leqslant 5$. $E_{TX}(n,d)$ denotes the energy consumption of transmit *n-bit* data and the distance is *d*. $E_{RX}(n)$ denotes the energy consumption of receive *n-bit* data. E_{total} denotes the total energy consumed that the node transmits *n-bit* data and the distance is *d*.

During the initialization of the network, each node calculates the energy consumed that transmits or receives unit bit data packets with the neighboring nodes based on the distance between each other. At the same time, set the threshold E_{th} for each node's residual energy. If the node's residual energy E_{res} Less than or equal to threshold $E_{res} \leqslant E_{th}$, this node will no longer serve as a relay node for any node. As shown in Fig. 1, *E(i,k)* denotes the energy consumption that the node V_i transmits unit bit data packets to the node V_k and the node V_k received it. *E(i,j)* denotes the energy consumption that the node V_i transmits unit bit data packets to the node V_j and the node V_j received it. *E(j,k)* denotes the energy consumption that the node V_j forward unit bit data packets to the node V_k and the node V_k received it. Compare the size of *E(i,k)* and *E(i,j)+ E(j,k)*. If the node V_j simultaneously meet the conditions:

$$E(i,j) + E(j,k) < E(i,k) \quad \textbf{(5)}$$

$$E_{res}(j) \geq E_{th} \quad \textbf{(6)}$$

Formula (5) and (6) shows that the node V_i transmits *n-bit* data packets to the node V_k through the node V_j forwarding save energy more than the node V_i directly transmits n-bit data packets to the node V_k. The node V_j can be used as relay node of the node V_i and the node V_k. So the node V_j is qualified relay node. The formula (5) can calculate, where formula (4) *k=2*, then

$$E(i,j) = 2E_{elec} * n + \varepsilon * n * d_1^2 \quad \textbf{(7)}$$

$$E(j,k) = 2E_{elec} * n + \varepsilon * n * d_2^2 \quad \textbf{(8)}$$

$$E(i,k) = 2E_{elec} * n + \varepsilon * n * d^2 \quad \textbf{(9)}$$

If we want the inequality (5) holds, so

$$2E_{elec} * n + \varepsilon * n * d_1^2 + 2E_{elec} * n + \varepsilon * n * d_2^2 < 2E_{elec} * n + \varepsilon * n * d^2 \quad \textbf{(10)}$$

$$2E_{elec} * n + \varepsilon * n * d_1^2 + 2E_{elec} * n + \varepsilon * n * d_2^2 - 2E_{elec} * n + \varepsilon * n * d^2 < 0 \quad \textbf{(11)}$$

$$\frac{2E_{elec}}{\varepsilon} + d_1^2 + d_2^2 - d^2 < 0 \quad \textbf{(12)}$$

$$\frac{2E_{elec}}{\varepsilon} + (d_1 + d_2)^2 - d^2 - 2d_1 d_2 < 0 \quad \textbf{(13)}$$

Because $d_1 + d_2 > d$, so $(d_1 + d_2)^2 > d^2, (d_1 + d_2)^2 - d^2 > 0$.

$$\frac{2E_{elec}}{\varepsilon} - 2d_1 d_2 < 0 \quad \textbf{(14)}$$

$$\left| \frac{2E_{elec}}{\varepsilon} - 2d_1 d_2 \right| > \left| (d_1 + d_2)^2 - d^2 \right| \quad \textbf{(15)}$$

Therefore, when the value of $\frac{E_{elec}}{\varepsilon}$ is constant, the condition of inequality (14) can be satisfied. That is to say qualified relay nodes can be selected according to the formula (5) and (6). Specific steps are as follows:

Step 1. During the initialization of the network, all mobile nodes broadcast the "*hello*" message with the maximum transmission power P_{max}. The "*hello*" message included node's unique ID, position, and current moving speed.

Step 2. Each mobile node calculates the distance to the neighbors after receiving the "*hello*" message from its neighbors. And calculated the total energy consumed that transmitted unit bit data packets to the neighbors according to the formula (4). Then put the neighbors and the corresponding energy consumption values into the First Neighbor Set (FNS).The First Neighbor Set FNS(i) of the node V_i is shown in Table 1. The First Neighbor Set FNS (j) of the node V_j is shown in Table 2.

Table 1. The First Neighbor Set FNS (i) of the node V_i

FNS(i)	Energy consumption of transmission unit bit data packet
V_k	*E(i,k)*
V_j	*E(i,j)*

Table 2. The First Neighbor Set FNS (j) of the node V_j

FNS(j)	Energy consumption of transmission unit bit data packet
V_i	*E(j,i)*
V_k	*E(j,k)*

Step 3. Each mobile node broadcasts the FNS after they obtained their own FNS. So each node knows the FNS of all its one hop neighbors. For Fig. 1, the node V_i stores FNS(i), FNS(j), FNS(k).

Step 4. The node V_i arranged the energy consumption of transmission unit bit data packet of FNS (i) in descending order. The node V_i selects the node V_k from it's owe FNS (i) with the largest energy consumption of transmission unit bit data packet in turn. Then selects the other remaining neighbor V_j and check FNS (j). If there is no V_k in the FNS (j), continue to select other remaining neighbor nodes of node V_i. If the node V_k is also in the FNS (j), take out the corresponding energy consumption value *E(j, k)* and add the node V_i to the node V_j energy consumption value *E(i,j)*, *E(j,k)+E(i,j)*. Then compare with *E(i,k)*. If *E(j,k)+E(i,j)* and *E(i,k)* meet the conditions (5) and the node V_j meet (6), it shows that the node V_j can act as the relay node of node V_i and node V_k. The node V_i can remove the V_k from the FNS(i) and transfer the node V_j from the FNS (i) to the FS (Forward Set). According to the above method, the node V_i complete the search on the FNS (i) of all nodes.

Step 5. The neighbor nodes of any node in the network can be divided into FNS and FS after the node executed the the first part of the PCTMA algorithm. The node finds out the farthest distance node from itself in the FNS and FS, then according to the distance between the two nodes to calculate the transmission power based on the formula (1). Replace the the initial value of the maximum transmission power P_{max} with calculated result.

4.2 Power Adjustment Prejudging Mechanism

In order to maintain the connectivity of the topology in the running process of network, any node V_i in the network transmits the "*Live*" message every time t_m. And each node only receives one-hop neighbors' message. Specific steps are as follows:

Step 1. The node can update the FNS and FS according to the received "*Live*" messages. If the node V_i dose not received the one of it's neighbors message from the node V_j after the time t_0, the node V_i will record the transmission power value P_i at this time.

Step 2. Tthe node V_i will first to find it's FS(i) and check whether there are other nodes satisfy the condition(5) (6) can replace the the node V_j. If there is, the node V_i does not adjust its transmission power, using the qualified node in the FS(i) replace the node V_j. And remove the node V_j from the FS(i).

Step 3. If there is not, the node V_i will prejudge whether adjusted its transmission power to the maximum or should be adjusted its transmission power to the current 1.5 times.

Step 4. If the node V_i adjusted its transmission power to the current 1.5 times can not repair the link, the node V_i will adjuste its transmission power to the P_{max} directly. Then find out qualified nodes.

Step 5. If the node V_i can not find out qualified nodes, it will be tell it's parent node that can not reach the node V_j.

Step 6. If the parent node of the node V_i receives the message from the node V_i that can not reach the node V_j, the node will repeat the above topology maintenance algorithm to find the FS or adjust its transmission power. So the node will check its FS first, and check whether there are other nodes to replace the node V_i. If there are, the node needs not to adjust its transmission power. If there is not, the node will judge increase its transmission power 1.5 times or directly increase the power to the maximum based on the above strategy.

Specific judgment methods of step3 are as follows:

Modified the formula (1) as follow:

$$\mathrm{r}_i = \sqrt[a]{\frac{P_i}{C}} \tag{16}$$

If adjusted the transmission power of the node V_i to the current 1.5 times, the communication radius of the node V_i is $\mathrm{r}_i^{'}$:

$$\mathrm{r}_i^{'} = \sqrt[a]{\frac{1.5 * P_i}{C}} \tag{17}$$

The transmission power was increased 1.5 times, the communication radius was increased $\Delta\mathrm{r}$:

$$\Delta\mathrm{r} = r_i^{'} - r_i = \sqrt[a]{\frac{1.5 * P_i}{C}} - \sqrt[a]{\frac{P_i}{C}} \tag{18}$$

The node V_i moves with the current speed v_j and the movement distance is *d*, the time required is $\Delta\mathrm{t}$:

$$\Delta\mathrm{t} = \frac{\Delta\mathrm{r}}{|\upsilon_j - \upsilon_i|} \tag{19}$$

The node V_i make a judgment before it adjusts the transmission power. If the node V_i adjusts the transmission power to the current 1.5 times, the failure relay node V_j is still or not in its own communication range. When the node V_i transmits the "*Live*" message, but the node V_j dose not receive it. Assuming that the relay node V_j is just outside the edge of the communication radius of the node V_i. As shown in Fig. 3(a). The node V_i dose not receive the feedback message from the relay node V_j after the time t_0. The node V_j continues to move. If the node V_i adjusted its transmission power to the current 1.5 times and then transmits the "*Live*" message to the node V_j. After the time t_0, the V_i still dose not receive the feedback message from the relay node V_j. It shows that the node V_j has been moved out of the $\mathrm{r}_i^{'}$. As shown in Fig. 3(b). The time that node V_j moves the distance $\Delta\mathrm{r}$ with the relative velocity $|v_j-v_i|$ can be calculated by the formula (19). the node V_i judges the whether adjusted its transmission power to the current 1.5 is effect need two "*Live*" messages, and the time interval is $2t_0$. So directly compare the size of the $2t_0$ and Δt. If $\Delta t > 2t_0$, it shows that the node V_j is still in the communication radius of the node V_i after the node V_i adjusted its transmission power to the current 1.5 times. That is to say the node V_j haven't had time yet to move the distance Δr, it can receive the next "*Live*" message from the node V_i and feedback it. If $\Delta t < 2t_0$, it shows that the node V_i adjusts its transmission power to the current 1.5 times has no effect at this time, the node can adjust the current transmission power to the P_{max}.

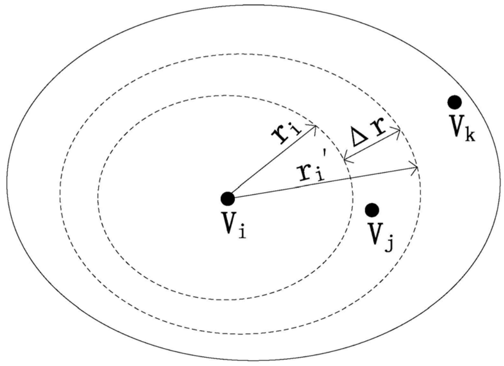

Fig. 3. (a) The node V_i adjusted its transmission power to the current 1.5 times

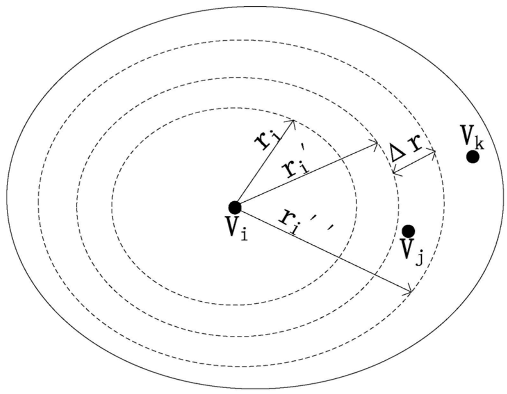

Fig. 3. (b) The node V_i adjusted its transmission power to the current 1.5 times

The flow chart of the PCTMA algorithm as shown in Fig. 4.

4.3 Maintenance Mechanism Based on Event Triggering

With the adjustment of the node's transmission power and the change of the communication radius, the node's movement and the failure node due to energy depletion, the FNS and FS may be changed. In this paper we define two events for these situations: *Join i(j)*, *Leave i(j)*. Nodes take different maintenance strategies according to different events they detected.

Join i(j). When the node V_i detects the beacon from the node V_j for the first time. It shows that the node V_i detected a new neighbor.

Leave i(j). when the node V_i hasn't detected the predetermined beacon from the node V_j. It shows that the node V_j has out of the communication range of the node V_i, or the node V_j has left the network, or the node V_j has became the failure node due to energy exhausted.

Maintenance strategies for the two events:

(1) When the node V_i detects the event *Join i(j)*, the node V_i will first to find it's FS(i) and FNS(i), then check whether there are other nodes satisfy the condition(5) (6) can become the relay nodes of the node V_i and the node V_j. If there are, updating the FNS(i) and FS(i) according to the above strategies. Meanwhile check the node V_j can or can not be the relay node for the others. If can, update the FS(i).

(2) when the node V_i detects the event *Leave i(j)*, the node V_i according to the above strategies and the flow chart shown in Fig. 4 for topology maintenance.

If the node detects two events both occurred, it is executed in sequential order.

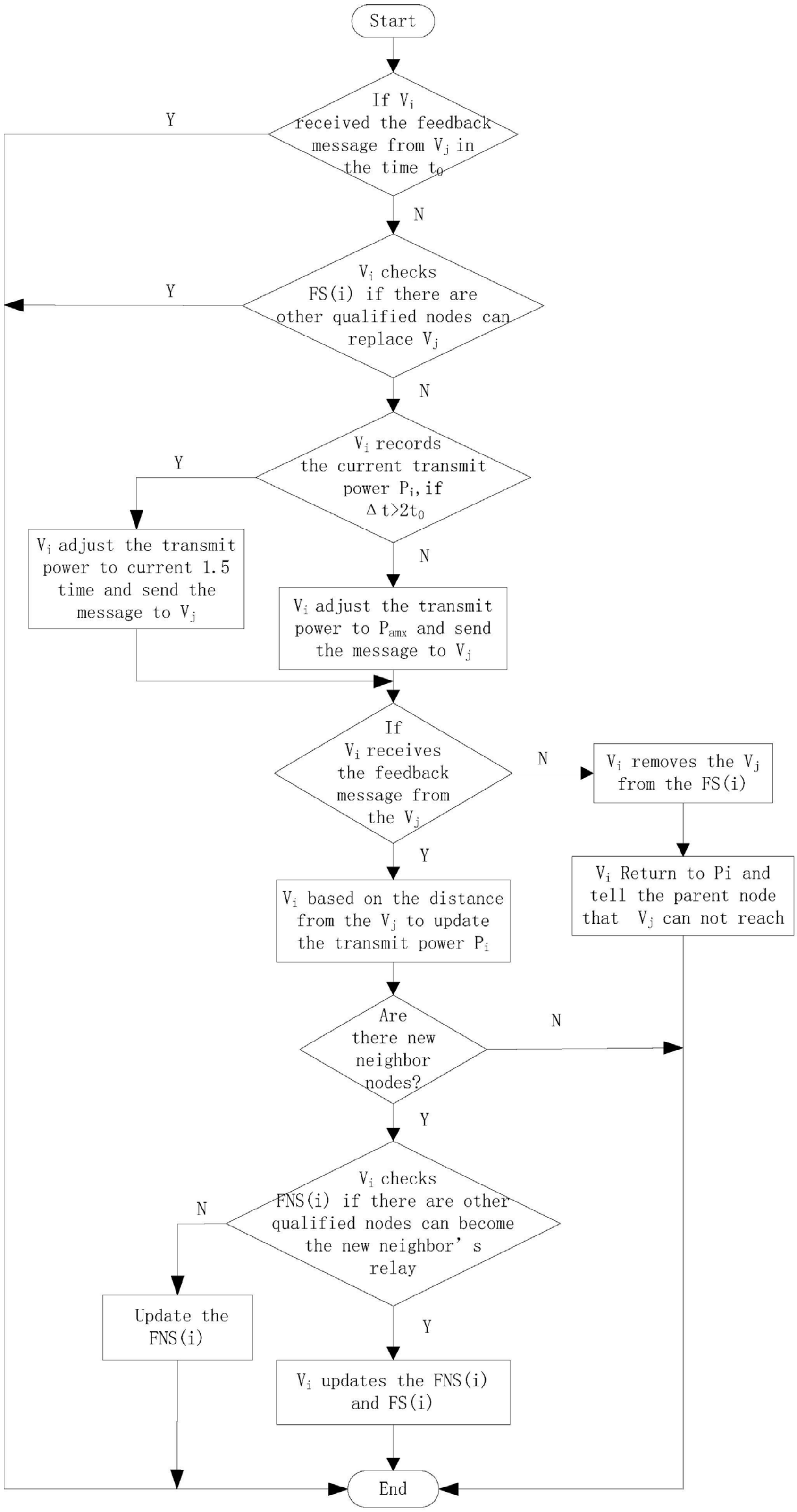

Fig. 4. Flowchart of the PCTMA algorithm

5 Simulation Experiment and Result

We use OPNET to carry out the simulation in this paper and NAPC algorithm, XTC algorithm were selected for comparison. The performance indexs that average transmission power, link connectivity and the number of live nodes in the network are compared with the PCTMA algorithm.

5.1 Simulation Scenarios and Parameters Setting

The simulation scene parameter settings are shown in Table 3.

Table 3. Simulation parameter

Parameter item (unit)	Configuration data
Network coverage area (m^2)	1000×1000
Network simulation time (s)	1000
Number of nodes	40
The maximum communication radius of the node(m)	100
The maximum transmission power of the node(mW)	50
The moving speed of the node (m/s)	[0,25]
E_{elec} (nJ/bit)	50
ε (pJ/bit/m^2)	100
The size of the data packet(Byte)	512

5.2 Simulation Results and Analysis

The relationship between average transmission power and the number of mobile nodes in the network is shown in Fig. 5. The figure shows that the average transmission power of XTC, NAPC, PCTMA algorithms are decreased with the number of nodes in the network increases. Because with the increase of the nodes in the network, the qualified relay node will be increased. So the node can reduce the transmission power. In addition, for the same number of nodes, the average transmit power of the PCTMA algorithm is smaller than XTC, NAPC. Firstly, in the first part of the PCTMA algorithm, the qualified relay nodes were selected based on the energy model. Each node is as far as possible to send data with minimum transmit power. Secondly, when the node detects lost contact with one of its neighbor, nodes are not blindly increase the transmission power in the PCTMA algorithm. But first to check the FS whether there are other nodes can replace the failure node. Then judgment which way should be adopted to increase the transmission power to maintain connectivity with the network. Furthermore the new nodes join the network are taking into considered. For the new nodes the PCTMA algorithm can further save energy through judging whether update FNS and FS.

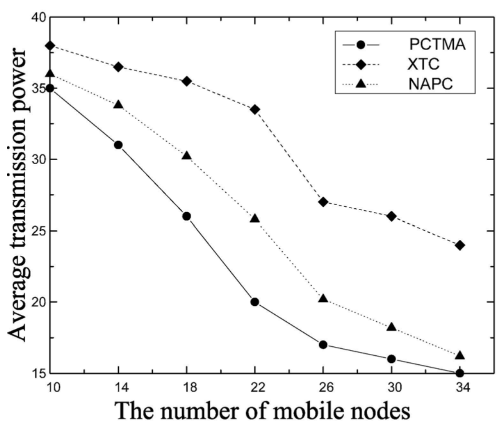

Fig. 5. Average transmission power

The relationship between the node speed and the connectivity degree of the network is shown in Fig. 5. The figure shows that the connectivity degree is decreased with the node speed increased. Because node speed increases, displacement per unit time is increased. The node more easily move out of other node's communication range, the connectivity degree of the node will drop. From the Fig. 6, for the same move speed, the connectivity degree of the PCTMA algorithm is larger than other two algorithms. Because the power adjustment prejudging mechanism was used to repair the network in the PCTMA algorithm. And the PCTMA algorithm also considers that when the node increases its transmission power there may be other nodes become the new neighbors. The new neighbors may become the relay nodes. This helps to improve the connectivity of the network.

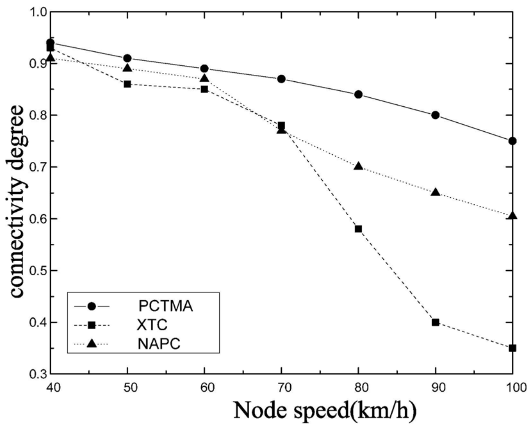

Fig. 6. The connectivity degree of the network

The relationship between the numbers of live nodes in the network and the simulation time is shown in Fig.7. The figure shows that with the simulation time increased, the numbers of live nodes in the network is decreased. But for the same simulation time, the numbers of live nodes in the network for PCTMA algorithm is more than XTC algorithm and algorithm NAPC. It is more effectively to save energy because of the energy model was used in PCTMA algorithm. Besides, in topology maintenance, PCTMA algorithm is not blind to increase nodes transmit power. But first to check the FS whether there are other nodes can replace the failure node. Then judgment which way should be adopted to increase the transmission power to maintain connectivity with the network. More importantly, the PCTMA algorithm defines two events to maintain the topology. The nodes according to the different event adopt the different maintenance strategies. And this helps to improve network performance.

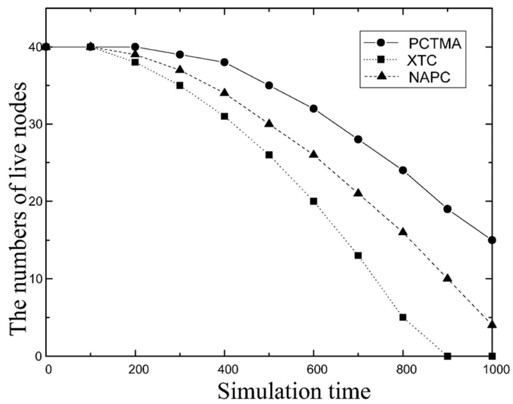

Fig. 7. The numbers of live nodes in the network

6 Conclusions

This paper we proposed a power control based on the topology maintenance algorithm PCTMA. The PCTMA algorithm is mainly aims at the node mobility, some nodes joining and exiting the network, node failure that may cause the mobile wireless sensor network topology changes. Both theoretical analysis and simulation results show that the PCTMA algorithm can save energy more effectively, maintain the network topology and prolong the life cycle of the network compared with existing topology maintenance algorithms. PCTMA algorithm is different from the current topology maintenance algorithm based on topology reconstruction. Through adjust the nodes transmission power to the proper size to maintain the network topology. The next step will be based on the status of the nodes in the network and how to further reduce the overhead of topology maintenance to optimization algorithm.

References

[1] P.M. Wightman, M. Labrador, Topology maintenance: extending the lifetime of wireless sensor networks, Latin America Transactions IEEE 8(4)(2010) 469-475.

[2] A. Shahid, H.K. Qureshi, A survey on topology maintenance techniques to extend the lifetime of wireless sensor networks, in: Proc. Communications in Computer & Information Science, 2013.

[3] M.S.G. Premi, U. Nivetha, B. Martin, S.M. Shaby, Route maintenance in set routing using FLT for mobile wireless sensor networks, in: Proc. International Conference on Science Engineering and Management Research, 2014.

[4] S.R. Rajeswari, V. Seenivasagam, Secured energy conserving slot-based topology maintenance protocol for wireless sensor networks, Wireless Personal Communications 87(2)(2016) 1-24.

[5] D. Cheng, G. Fei, Z.L. Fen, A topology maintenance algorithm used for wireless sensor networks, in: Proc. Fourth International Conference on Multimedia Information Networking and Security, 2012.

[6] M. Aparna, A new method for controlling and maintaining topology in wireless sensor networks, International Journal of Computer Networks & Communications 6(4)(2014) 91-98.

[7] J.X. Niu, W. Guo, Link state prediction based topology maintenance in multi-channel MANET, in: Proc. the IEEE International Conference on Signal Processing Communication and Computing (ICSPCC), 2013.

[8] M. Bala Krishna, M.N. Doja, Swarm intelligence-based topology mmaintenance protocol for wireless sensor networks, Iet Wireless Sensor Systems 1(4)(2011) 181-190.

[9] K. Kunavut, A novel adaptive topology control in mobile ad hoc networks based on connectivity index, in Proc. International Conference on Intelligent Informatics and Biomedical Sciences, 2015.

[10] Z. Shen, Y. Chang, C. Cui, X. Zhang, A topology maintenance algorithm based on shortest path tree for wireless ad hoc networks, Journal of Electronics & Information Technology 29(2)(2007) 323-327.

[11] J. Liu, B. Li, Distributed Topology Control in Wireless Sensor Networks with Asymmetric Links, GLOBECOM, San Francisco, 2003.

[12] R.R. Yin, B. Liu, X.C. Hao, An energy efficient topology maintenance scheme for wireless sensor networks, Journal of Information and Computational Science 8(13)(2011) 2815-2822.

[13] R.Y. Song, Reseach on topology control algorithm for mobile sensor network, [dissertation] Nanjing: Nanjing University of Posts and Telecommunications, 2012.

[14] R. Wattenhofer, A. Zollinger, XTC: a practical topology control algorithm for ad hoc networks, in: Proc. 18th International Parallel and Distributed Processing Symposium, 2004.

[15] J.L. Cao, Y. Jun, L.L. Wang, Z. Ren, An energy-efficient clustering routing protocol for wireless sensor networks, Journal of Chongqing University of Posts & Telecommunications 26(2)(2014) 150-154.