A Routing Algorithm based on Dynamic Weight of the Wireless Sensor Network

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Abstract—**The wireless sensor network routing strategies determine the lifetime and the energy consumption of the sensor networks. An algorithm on calculating the approximate maximum network lifetime is presented by establishing the wireless sensor network routing strategy planning model. Through the simulation, the amount of information acquired during the network lifetime could account for 98.2% of the maximum possible quantity. Meanwhile, the network energy consumption also gets reduction by controlling the weight coefficient.**

Keywords-wireless sensor network; routing strategy; planning model; dynamic weight

I. INTRODUCTION

The wireless sensor network (WSN) [1-3] is regarded as the primary one of the 10 world changing transformative technologies. WSNs are mainly studied on the extent to monitor the physical space by the sensors, which reflect the quality of "sensing service" provided by the network, ensure the space resources well distributed in order to accomplish the tasks better, such as environment awareness, information acquisition and effective transmission. In some special working condition, energy is limited without supplement, which is the key restrict of the wireless sensor network lifetime [4-6].

It is critical to take into consider of the energy consumption when designing the WSNs routing strategies. Shah *et al.* [7] proposed a multi-path energy routing mechanism, aiming at the energy limitation of the points in the network and partial topology information obtained to the points. This method provides several paths from the source point to the end, and balances the energy consumption in the whole network by means of endowing every edge with probability [8-9], to achieve the optimal objective of prolonging the network lifetime. In this paper, we establish a planning model of routing strategy with the real sensor network, propose an algorithm based on dynamic weights, and obtain the approximate maximum network lifetime which is verified by the simulation results.

II. WIRELESS SENSOR NETWORK MODEL

A. Sensor Network

In a wireless sensor network, there are always one or more base stations for receiving the information of the whole network, and several sensors as the network nodes for sensing and transmitting information. Each sensor transmits the sensed information to the around, thus the sensors within the effective range could receive and transmit them with their own information together.

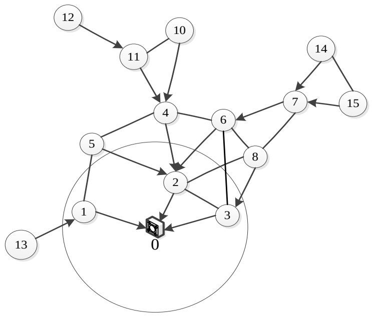

Figure 1. Wireless sensor network.

Fig. 1 demonstrates a wireless sensor network with only one base station and each sensor as a node, in which the information can be transmitted through the link from one node to another. The arrow direction in the figure indicates the current routing strategy. As the only sink node in the network, the base station, identified as node 0, can get the location information of sensor nodes in the scene through the localization algorithm. The base station calculates the node's routing strategy according to the network topology, and then broadcasts routing information to the nodes in the scene. The network lifetime is essential to be optimized on the basis of the maximum work load efficiency.

There are many indices used to measure the working proficiency in a sensor network, such as:

- Node failure: it is due to energy consumption or that the node no longer has any path to transmit information to the base station.
- Network efficiency (η): it is the percentage of sensors that provide information to the base station in the network during the unit period.
- Sensor network service lifetime (T_{net}): it is the lifetime of the first failure node in the network, that is, the working time length with 100% network efficiency.

B. Assumptions

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To make further analyses, assumptions are supposed as follows in consideration of the reality:

- Assume that the sensors in the network are almost the same, the initial energy of each sensor node is Q_0;
- Assume that the sensor network is a random uniform network, and once the sensor position is determined they cannot move anymore;
- Assume that the sensors collect and transmit information in accordance with the time period, all the sensors can transmit the information collected and received selectively in one period;
- Assume that the amount of information collected in one time period is always the unit s;
- Assume that the energy consumption to transmit one unit of information s is always q_{t}, and comparative to the transmission consumption, the reception and collection consumption are negligible.

C. Inputs

It is given that the wireless sensor network $G=(V,E)$, while V is the set of sensor nodes, $N=|V|$ is the total number, E is the edge set. There is only one base station.

In terms of the i^{th} node, v_i, and the j^{th} node, v_j, it exists $v_i, v_j \in V$, $(v_i, v_j) \in E$, and both v_i, v_j are in the transmission range of each other, which means they are the one-jump neighbors. N_i is the neighbor nodes set of the i^{th} sensor node, the element amount of which is n_i, and the element amount of base station is n_0. Thus, each sensor collects information and transmits to base station by direct or multi-jump path in every time period.

D. Outputs

The routing strategy of data transmission in each time period is the output result, specifically speaking, the working states of all nodes, the essential data volume collected, the essential data volume received, the data volume sent out, and the data transmission lines from node to node.

E. Constraints

1) The transmission distance of each sensor is restricted with their transmission energy. According to the effective radius r of each sensor to transmit information, two points are assumed to be connected when their distance is within the range r.

2) It consumes energy to send information for each node, the period energy consumption of the i^{th} node is regarded as $\mathrm{d}Q_i$:

$$\mathrm{d}Q_i = \left(\sum_i x_{ij} + s_j\right) q_{\mathrm{t},j} \tag{1}$$

where x_{ij} is the information amount transmitted directly from the i^{th} node to the j^{th} node and sent forward by the j^{th} node, and s_j is the information amount collected by the j^{th} node, that is the energy consumption to transmit the unit of information by the j^{th} node.

3) The initial energy of each sensor is Q_0, thus:

$$\int_{T_{\mathrm{net}}} \mathrm{d}Q_i \le Q_0 \tag{2}$$

F. Optimization Objective

The optimization objective of the model is the lifetime of the network T_{net}:

$$\max\left(T_{\mathrm{net}}\right) \tag{3}$$

III. MODEL SOLUTION

A. The Algorithm Based on the Dynamic Weight

Obviously, during the whole lifetime of the network, the maximum information amount of network is a constant value, not changing with the multi-jump strategy.

$$S_m = n_0 Q_0 s / q_t$$

where n_0 is the sum of sensor nodes adjacent to the base station, Q_0 is the initial energy of each sensor, q_{t} is the energy consumption of sensor to transmit one unit information s, and the energy consumption of reception and collection can be neglected.

S_m is the maximum amount of receiving information during the network lifetime T_{net}. Supposing that the reception information during T_{net} is $\mathrm{S_T}$, and thus the effective information ratio is $\lambda = \mathrm{S_T}/\mathrm{S_m}$. That is, T_{net} is longer when λ is larger.

Due to the difficulty of calculating the maximum lifetime T_{net} and the routing strategy, it is necessary to design an algorithm to find the better solution for the planning model, and make the indirect answer T'_{net} is near the optimal solution T_{net}.

Thus, one algorithm of sum weight based on dynamic weight and Dijkstra algorithm [10] maximizes T_{net}.

Step 1: Determine the nodes of network. The coordinate information of the i^{th} node (x_i, y_i) is given to the base station, while the base station is always in the center of the network. Once the distribution has done, the location of the base station and sensors barely changed any more.

Step 2: Construct the network. To verify the connectivity of every point, in accordance with the effective radius of the information transmission of each sensor, it is deemed to be connected when the distance between two nodes is within the range. That is:

$$\sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} < r \tag{4}$$

where $i, j = 1, 2, \cdots$, $i \neq j$, all weights are the same.

Step 3: Draw up routing strategy. One of the shortest paths is found as the next routing strategy by Dijkstra algorithm.

Step 4: Calculate the sum weight. After verifying the connectivity of each node (e.g., the links depicted in Fig. 1), construct the network and find the shortest path to base station from each node by the Dijkstra algorithm (shown as the directed links). Sensor 2 consumes its energy soon, after the death of which, the information of sensor 12, 11, 10 and 4 can be transmitted to the base station through sensor 6 or 5. This kind of information transmission scheme doesn't consider into the reasonable distribution of energy, which decreases the efficiency of the whole sensor network from 100% sharply. Without any improvement, the efficiency will come down constantly, and raise the energy consumption for the same amount of information. Thus, it is necessary to introduce a strategy where sensor 5 and 6 can transmit their information to the base station through sensor 1 and 3, respectively, at the beginning of the next cycle to the base station, thereby saving the energy of sensor to maintain the information transmission of nodes 2, 4, 10, 11, and 12 (if sensor 2 died, the node information transmission path will grow longer).

It is proposed here that the weight L_{ij} is based on the remaining energy of two nodes connected by the link and the energy consumption of each node:

$$L_{ij} = \alpha k_i + \beta \big/ Q_{re_j} \tag{5}$$

where α, β are constants as the weighted coefficient, $\alpha > 0$, $\beta > 0$, and $\alpha + \beta = 1$, means the weight of the information transmission path from sensor i to sensor j, k_i means the sum of information transmitted by sensor i, and Q_{re_j} means the remaining energy of sensor j.

On account of the larger change range of Q_{re_j}, its inverse value may inundate the value of k_i, thus L_{ij} should be amended further:

$$L_{ij} = \alpha k_i + \beta \frac{K_{\max} Q_{re_{\max}}}{K_{\max}\left(Q_{re_j} - q\right) + Q_{re_{\max}}} \tag{6}$$

where $K_{\max}$ means the maximum amount of the transmission information in a time period for the whole network, and $Q_{re_{\max}}$ means the maximum remaining energy of sensors in a time period for the whole network.

Step 5: Judge the failure of nodes. After the failure of nodes, it is considered that the weight from that node to any other node is infinite, and information is no longer transmitted to other nodes or the base station, then it comes to the end. If there is no nodes failure, get back to step 3.

The flow chart of the whole algorithm is shown in Fig. 2.

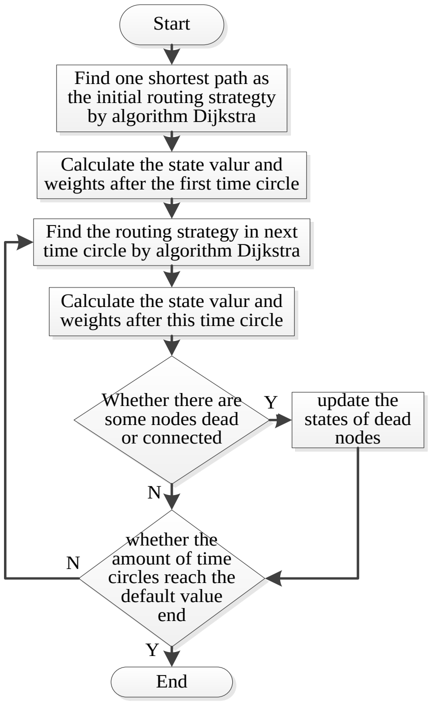
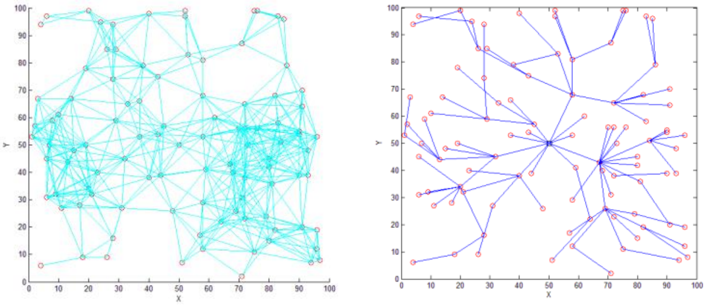


Figure 2. Flow chart of the algorithm based on the sum of dynamic weights

B. *Simulation*

Supposing that there are $N = 100$ sensors in the $Z = 100\text{cm} \times 100\text{cm}$ area (the coordinate data are given), and they are distributed uniformly while the base station is in the center of the scene $(50, 50)$. The initial energy of the sensor node is $Q = 1000\text{J}$, and the energy consumption of information transmission is $q = 1\text{J/bit}$. There is no energy consumption for sensors to receive information, and the energy consumption in one time period is $s = 1\text{bit}$, the communication radius of the node is $r = 20\text{cm}$. Nodes transmit information to the base station periodically.

(1) Construct the network after the determination of connectivity, as shown in Fig. 3.



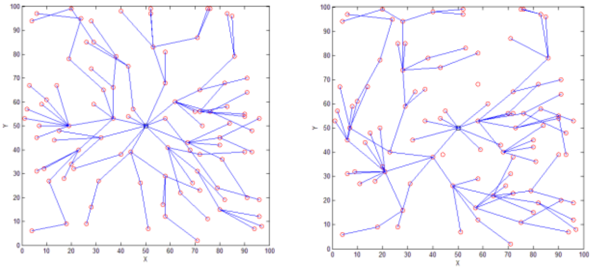
(a) Connectivity graph of the sensor network instance

(b) Initial routing strategy graph

Figure 3. Simulation result

(2) Supposing that the initial weight value is always 1, find one of the shortest path as the initial routing strategy by Dijkstra algorithm, as shown in Fig. 3.

(3) Calculate the value of k_i and Q_{re_j}, and get the edge weight value. In accordance with the new weight, find the routing strategy in next period by Dijkstra algorithm (during the simulation realization, α=0.01, β=0.99, the reasons are given later). According to the above algorithm in flow chart, some of the routing strategies are shown as Fig. 4.



(a) Routing strategy after one iteration

(b) Routing strategy after the first node failure

Figure 4. Routing strategy graphs

It is shown in Fig. 5 that the relationship of the constant weight of simulation and the value of η based on the dynamic weight to the period amount.

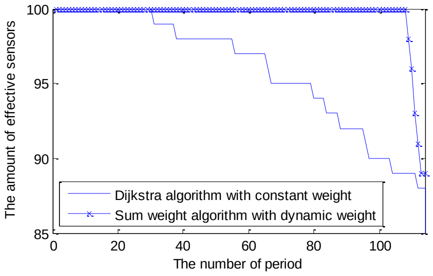


Figure 5. The relationship between η and the period number

Fig. 5 demonstrates that the optimal lifetime T'_{net} of the network can be calculated by the wireless routing network algorithm based on dynamic weights to some degree, T'_{net}=108, and the effective information ratio is λ=98.2%.

The whole energy consumption ratio μ is that the sum of energy consumption accounts for the sum of initial energy.

It is shown in Table 1 about the relationship of the network lifetime T'_{net}, the energy consumption μ and α, β.

TABLE I. THE RELATIONSHIP OF T_{net}, μ AND α, β

NO.	α	β	T'_{net}	μ
1	0	1	106	0.2986
2	0.01	0.99	108	0.3015
3	0.1	0.9	108	0.3125
4	0.3	0.7	107	0.3187
5	0.5	0.5	105	0.3235
6	0.7	0.3	92	0.3301
7	0.9	0.1	67	0.3353
8	0.99	0.01	67	0.3429
9	1	0	57	0.3542

Make comparison from Fig. 1 about the value of T_{net} and μ with different α, β:

(1) When $\alpha = 0.01$, $\beta = 0.99$ and $\alpha = 0.1$, $\beta = 0.9$, T'_{net} is the maximum value, it is assured sufficiently about the maximum cover of the network. μ is less when $\alpha = 0.01$, $\beta = 0.99$ than $\alpha = 0.1$, $\beta = 0.9$. Thus, the above model solutions are all adopted the strategy when $\alpha = 0.1$, $\beta = 0.9$.

(2) With the decrease of β, the influence of remaining energy has less proportion in the sum weights value. When the network topology changes, the optimization ability of the sensor with small remaining energy is less, which can easily lead to a premature end of one sensor consume the energy too early, the value T'_{net} will be reduced. In this way, the information transmitted from this node will be transmitted by other ways, and the energy balance is broken, which causes big energy waste and enlarges the value of μ.

IV. CONCLUSION

This paper establishes the wireless sensor network model to find the solution of routing strategy, and puts forward an algorithm to calculate the maximum lifetime of the network, which obtains the approximate optimal solution. Through the simulation, the effective information rate obtained during the approximate optimal network lifetime reaches 98.2%, and under the control of the weighted coefficient, it is obtained that the network routing strategy guarantees the maximum network lifetime and the minimum energy consumption.

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