A Path Planning Method of Wireless Sensor Networks Based on Service Priority

Peng Li , Siya Xu*, Kang Sun, Xuesong Qiu, Feng Qi

State Key Laboratory of Networking and Switching Technology
Beijing University of Posts and Telecommunications
Beijing, China
penglee0214@163.com, xusiyaxsy@hotmail.com, sunkang, xsqiu, qifeng @bupt.edu.cn

***Abstract*—Life-time represents the effective survival time of network, which is significant when measuring the performance of wireless sensor networks (WSNs). Therefore, it is so important to extend network life-time by planning appropriate path based on energy consumption and remaining energy of wireless sensors. In this paper, a path planning method of WSNs based on service priority is proposed, and a customized Dijkstra algorithm is used to solve this problem. This method minimizes the total energy consumption of network while balancing remaining energy of all nodes in network, and through the sacrifice of network delay in exchange for extension of life-time. The simulation results show that our method not only prolongs network life-time compared to shortest-path algorithm but also improves network reliability.**

Keywords—WSNs, service priority, path planning, Dijkstra algorithm, load balancing

I. INTRODUCTION

The nodes of WSNs are small volume, low cost, and have ability to carry out knowledge. They are able to collaborate to complete a variety of monitoring and control tasks. WSNs is a kind of intelligent autonomous system, and this makes their application become very broad [1]. They are used in military, intelligent transportation, environmental monitoring, health and other fields widely. However, because of the impact of volume and environment, the energy of network is not inconvenient to add. Therefore, planning multi-hop path of WSNs reasonably, balancing network loads, and ultimately maximizing the entire network life-time become more and more important.

Energy efficiency of system is one of important factors of WSNs. Energy consumption of sensor nodes in network is mainly composed of three parts: sensing, data transmission and data processing. However, data transmission consumes much more energy than other energy events, so the way in which data is transmitted will affect the life of network directly. However, when studying the energy consumption of WSNs, the system's life-time is very important. Literally, the life-time refers to the life of network, that is, the time interval of network from birth to death. In this article, when the number of failed nodes exceeds a certain number, network is defined as death. The failed node refers to the node in WSNs whose energy is exhausted.

The energy of nodes in WSNs is limited and the energy consumed by data transmission between nodes is huge. So path planning is very effective for extending the life-time of network. To this end, many scholars have proposed relevant algorithm to solve this problem. Clustering or hierarchical routing is one of the most popular ways. LEACH [2] (Low Energy Adaptive Clustering Hierarchy) is one of the most common protocol. Its basic idea is to select cluster head node randomly, and distribute energy loads to each node evenly [3], so as to reduce energy consumption and improve survival time of network. Compared with general planar multi-hop routing protocol and static hierarchical algorithm, LEACH clustering protocol can extend the network life-time by 15%. PEGASIS [4] is an extension of LEACH, its basic idea is: nodes only need to communicate with their nearest neighbors [5]. Compared with LEACH, it reduces its overhead in the process of cluster reconstruction [6], and reduces the number of transceivers through data fusion, thus reducing energy consumption, compared with LEACH, PEGASIS can improve network life-time nearly two times, but their common disadvantage is that the protocol overhead is relatively large, and does not consider the actual state of node.

The contributions of this paper can be summarized as follows:

- Establishing a WSNs path planning model based on service priority to extend the life-time of network and improve its reliability.
- Proposing a customized Dijkstra algorithm to solve the established mathematical model.
- Designing an emulator based on path planning to evaluate the method designed in this paper.

II. SYSETEM MODEL

A. *Network model of WSNs*

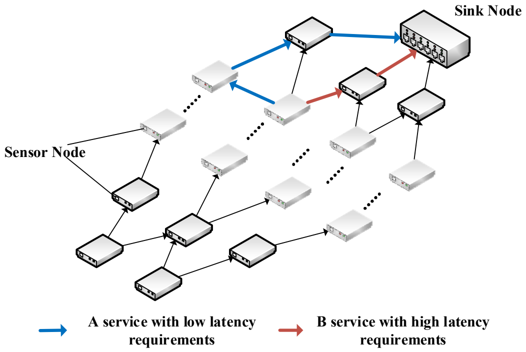

Figure 1. Wireless multi - hop sensor network model

Because nodes of WSNs are deployed in harsh environments or unmanned areas, their energy is generally supplied by batteries, and it is not easy to add, so an important criterion for measuring WSNs is their life-time. The data of which sensor detects may be varied, for example, in intelligent home system, they can be temperature,

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humidity, gas concentration and so on. It is hoped that once sensors detect gas concentration information, it can be delivered to mobile device as soon as possible, while other data such as temperature or humidity may be relatively slow to pass over. Therefore, the data detected by sensor nodes has different priorities, so how to achieve load balancing and how to improve network life-time in meeting delay requirements of service will be a question to be considered.

B. Mathematical model

N nodes in network model are numbered, and all nodes are named $Node_i (i = 1, 2, ..., N)$, each node contains two attributes: location $P(x, y)$ and remaining energy E_{left} , randomly set a node $Node_{obj}$ as sink node, all nodes no matter what path to forward, and finally enter $Node_{obj}$ for processing. When service with low delay requirements choosing its route, it is possible to achieve load balancing by sacrificing delay (from blue path to red path in Figure 1), but still satisfying the conditions of delay constraint and making loads of whole network more balanced, finally, it can improve the reliability of nodes and extend network life-time.

Objective function is the life-time of whole network. If average residual energy of all nodes is larger, and the available time of battery is longer, and network life-time is longer. And if total energy consumption of network is larger, network life-time shorten, so life-time is proportional to average residual energy of nodes, inversely proportional to total energy consumption of network, so objective function is:

$$T_{life} = \frac{\overline{E_{left}}}{E_{total-\cos t}} \tag{1}$$

$$\overline{E_{left}} = \frac{1}{N}\sum_{i=1}^{N} E_{left} \tag{2}$$

$\overline{E_{left}}$ is the average residual energy of all nodes.

The energy required by sending node to send λ bits of data is [7]:

$$E_{send} = \lambda(E_0 + \varepsilon d_{ij}^{indic}) \tag{3}$$

The energy consumption required by receiving node to receive λ bits of data is [8]:

$$E_{receive} = \lambda E_0 \tag{4}$$

E_0 is a fixed value, it is related to physical properties of node itself, so E_0 is same for all nodes.

So total energy consumption of network is:

$$E_{total-\cos t} = \sum_{i=1}^{N}(\lambda * (2E_0 + \varepsilon d_{ij}^{indic})) \tag{5}$$

d_{ij}^{indic} is Euclid Distance of node i and its next jump node j, d_{ij}=P_i-P_j $= \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$, *indac* is an indicator vector.

$$indac = \begin{cases} 2, d < d_0 \\ 4, d > d_0 \end{cases} \tag{6}$$

d_0 is the threshold of d , $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon}}$, ε is power amplification factor of multipath attenuation channel model, and ε_{fs} is power amplification factor of free energy attenuation model, therefore:

$$T_{life} = \frac{\frac{1}{N}\sum_{i=1}^{N} E_{left}}{\sum_{i=1}^{N}(\lambda * (2E_0 + \varepsilon d_{ij}^{indic}))} \tag{7}$$

Assume that there are M kinds of services transmitted in whole network, denoted as $\{B_1, B_2, ..., B_M\}$ respectively, and their delay limits are $\{T_1, T_2, ..., T_K\}$. And their relationship is $T_1 < T_2 ... < T_K$.

The actual delay of service must be less than or equal to delay limit, and different kind of service may have same delay limit. So, the constraints of delay are:

$$T_x \le T_k^x (x = 1, 2, ..., M, k = 1, 2, ..., K) \tag{8}$$

Assuming that $T^{ave} = T_{queue} + T_{process} + T_{transmission}$ is a fixed value, $T_{queue}, T_{process}, T_{transmission}$ are queuing delay, processing delay and propagation delay of same kind of service respectively, so we can transform delay constraint into the constraint of hops:

$$H_x \le H_x^{\max} = \frac{T_k^x}{T_x^{ave}} (x = 1, 2, ..., M) \tag{9}$$

$\eta_{reload} = \frac{E_{left}^{\max}}{E_{left}^{\min}}$ is used to measure load balancing of WSNs. where η_{reload} is definitely a number greater than or equal to 1, the closer to 1 indicates that remaining energy of all nodes is closer and the loads of whole network is more balanced. Every time load factor is calculated, it must be less than the last calculated value:

$$\eta_{reload} < \eta_{reload}^{last} \tag{10}$$

The remaining energy of each node is constantly updated:

$$E_{left}^{'} = E_{left} - \lambda(2E_0 + \varepsilon d_{ij}^{indic}) \tag{11}$$

To sum up, the mathematical model is:

$$Maximize: T_{life} = \frac{\frac{1}{N}\sum_{i=1}^{N}(E_{left}^{last} - \lambda * (2E_0 + \varepsilon d_{ij}^{indic})}{\sum_{i=1}^{N}(\lambda * (2E_0 + \varepsilon d_{ij}^{indic}))} \qquad (12)$$

$$where, d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

$$s.t.: \begin{cases} H_i \le H_i^{\max} = \dfrac{T_k^i}{T_i^{ave}} \begin{Bmatrix} i = 1, 2, ..., M \\ k = 1, 2, ..., K \end{Bmatrix} \\ \eta_{reload} < \eta_{reload}^{last} \\ \eta_{reload} = \dfrac{E_{left}^{\max}}{E_{left}^{\min}} - 1 \ge 0 \end{cases} \qquad (13)$$

III. ALGORITHM DESCRIPTION

A. *Customized Dijkstra algorithm*

The shorter distance will cause energy consumption smaller. Therefore, first step of this paper is to select the shortest path, which can guarantee the minimum energy consumption of network and extend network life-time. But every time choosing next hop, we need to judge the load balancing conditions, if the shortest path does not meet the conditions of load balancing, then selects path which is a little longer than the shortest path, which can make remaining energy of all nodes is more balanced, thereby extending network life-time.

B. *Algorithm steps*

The implementation of path planning based on customized Dijkstra algorithm is as follows:

Step 1: At first, V_A and V_B contain only source, $V_A = V_B = \{v\}$, and the distance of v is zero. U contains the other vertices except v, $U = \{\text{other vertices}\}$, if v has a side with vertex u in U, then $<u, v>$ has a normal weight, and if u is not the adjacency of v, then the weight of $<u, v>$ is ∞.

Step 2: Select a vertex w with the smallest distance to v from U, add w to V_A (the selected distance is the shortest path length of v to w), add the other adjacency to V_B set, and sort all distances.

Step 3: Change the distance of each vertex in U with w as a new point of consideration. If the distance from source point v to vertex u (through vertex w) is shorter than original distance (not through vertex w), then modify the distance value of vertex u, and the modified distance value plus the weight of edge. The vertices sorted in V_B set are taken as intermediate points and same operation is performed.

Step 4: Repeat step 2 and 3 until all vertices are included in V_A and V_B sets.

Step 5: Choose next hop of current node from V_A.

Step 6: After selecting next hop, calculate the energy consumption and residual energy of node. If load balancing constraint is satisfied, return to step 5; if it is not satisfied, select next hop of current node from V_B. If it is still not satisfied, repeat until meeting the load balancing conditions, and then return to step 5. When next hop is destination node, it ends.

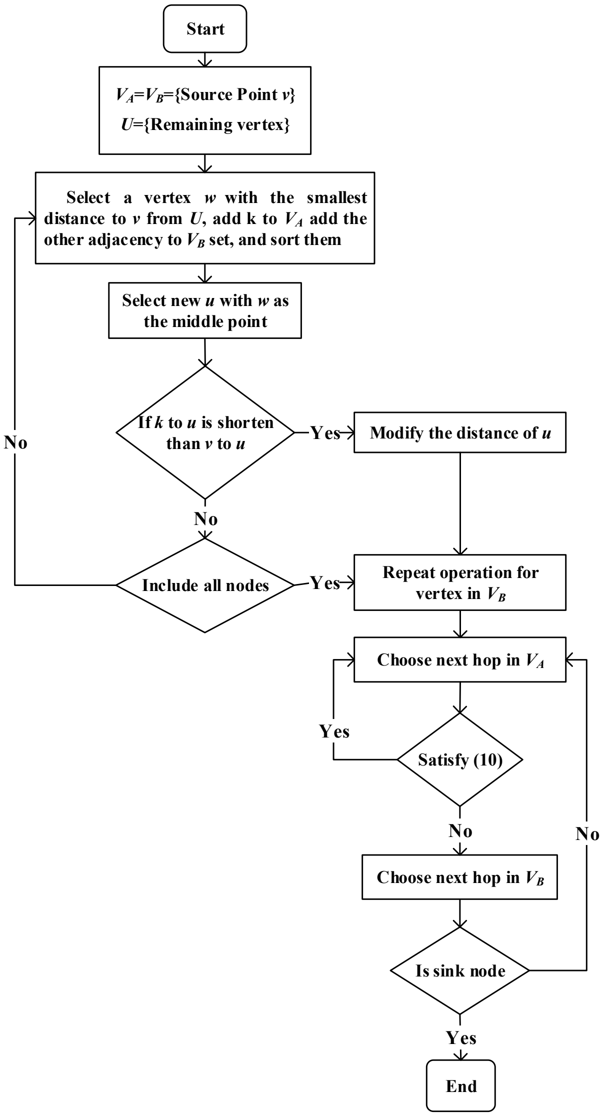

Figure 2. Algorithm flowchart

IV. SIMULATION RESULTS AND ANALYSIS

A. *Simulation environment settings*

There are 200 nodes in our simulation scene, the initial energy of each node is 1000J, the maximum transmission radius is 30m, and the arrival rate of packet can be set to be 1bps, 5bps and 10bps. There are two kinds of service, and the delay limit is 100ms and 200ms respectively.

B. *Simulation result and analysis*

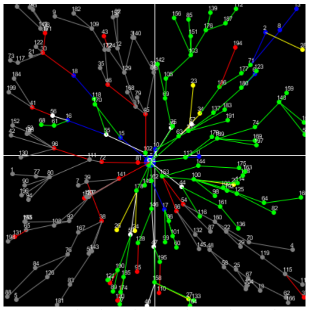

Figure 3(a). Path simulation based on shortest path

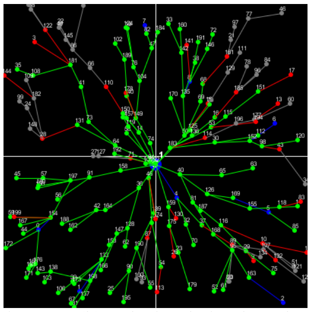

Figure 3. (b)Path simulation based on LEACH

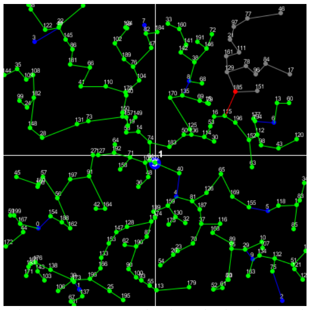

Figure 3. (c) Path simulation based on service priority

The above three figures are path simulation based on the shortest path, LEACH, service priority, and sink node is in the center of map, surrounded by sensor nodes, each sensor node can spontaneously generate data packets. Green node indicates that current node's energy is not exhausted, and its data can reach sink node. Gray node indicates that current node's energy is not exhausted, but its data can't reach sink node. Red node indicates that current node is exhausted and dead. The blue service is a relatively low priority service.

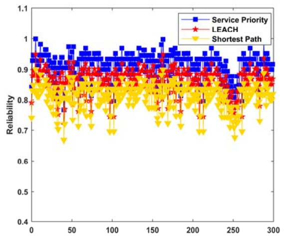

Figure 4(a). Simulation results of reliability when arrival rate is 1bps

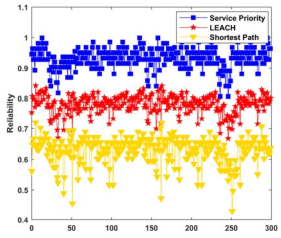

Figure 4(b). Simulation results of reliability when arrival rate is 10bps

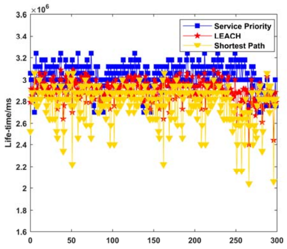

Figure 5(a). Simulation results of life-time when arrival rate is 1bps

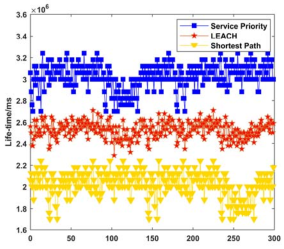

Figure 5(b). Simulation results of life-time when arrival rate is 10bps

Figure 4 and Figure 5 are simulation results of reliability and life-time at different arrival rate respectively. In Figure 4(a) and Figure 5(a), the arrival rate is set to be 1 bps, so the loads of network are very small. We can see that the influence of different algorithms on life-time and reliability of network is not so obvious, and the life-time and reliability of network are relatively high. In Figure 4(b) and Figure 5(b), the arrival rate is set to be 10 bps, which indicates that the loads of network are relatively large and a lot of data needs to be allocated path to sink node at the same time. Note that our method is designed based on service priority, so it will choose appropriate path according to the priority of data. It means that low priority services should choose longer paths, and seldom compete the shortest path with high priority service, so they have more reasonable ways to deal with heavy loads. As a result, in the case of more loads, our proposed method can have better network reliability and longer life-time.

V. CONCLUSIONS

In order to maximize the life-time of WSNs, this paper designs a path planning method based on service priority and it is sloved by customized Dijkstra algorithm. Our method chooses the shortest path from optional paths to balance the remaining energy of all nodes, and can prevent the emergence of dead nodes to extend network life-time. Simulation results show that the proposed method extends network life-time compared with the traditional shortest path strategy, and improves network reliability. Furthermore, with the increase of service type and arrival rate, our method will be more effective.

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