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A WSN Routing Algorithm based on Transmission Cost

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Abstract

In order to solve the energy consumption problem of wireless sensor networks (WSNs) and ensure network performance, a new WSN routing algorithm based on Transmission cost is proposed. The algorithm comprehensively considers the effectiveness of node energy and the balance of traffic and constructs the transmission cost function based on energy cost and load index. Sensor nodes calculate the transmission cost of neighbor nodes and select the node with the lowest transmission cost as the next hop. The simulation results show that the algorithm significantly reduces the network's total energy consumption and has good real-time and reliability.

Keywords

Wireless Sensor Network; Transmission Cost; Routing; Energy.

1. Introduction

A wireless sensor network composed of many sensor nodes connected in a wireless self-organizing manner has been widely used [1]. The routing algorithm determines how nodes relay and route data packets, which directly affects the energy consumption and performance of the network. Most of the traditional routing algorithms start from the effectiveness and equilibrium of network energy consumption [2, 3], generally for limited node energy, and do not consider the impact of node distribution and the unevenness of network traffic on the performance of routing algorithms. However, in some WSN applications, such as electricity information collection [4], the collected data stream has the characteristics of periodicity and large traffic, which often causes the network load to exceed the network's transmission capacity, leading to network congestion. Therefore, because of the specific characteristics and performance requirements of WSN, it is very necessary to design a routing protocol that considers network energy consumption and traffic balance [5].

Based on the above analysis, we propose a WSN routing algorithm based on transmission cost. The algorithm considers the effectiveness of node energy and the traffic balance and constructs the transmission cost function based on energy cost and load index.

2. System Model

2.1. Network Model

Sensor nodes periodically perceive environmental information and transfer data hop-by-hop to the sink node. To simplify the network model, we make the following assumptions:

(1) Sensor nodes are randomly deployed in a monitoring region;

(2) The sink node is deployed in a fixed location;

(3) The signal transmitting radius of each node is R.

(4) Each node calculates the approximate distance from the sending node to itself based on the received signal strength

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2.2. Energy Consumption Model

This paper adopts the same wireless communication energy consumption model as the literature [6]. When the sensor node transmits *l* bit data, and the transmission distance is *d*, the energy consumed is:

$$E_{tx}(l,d)=\begin{cases} l \bullet E_{elec}+l \bullet E_{fs} \bullet d^2, d<d_0 \\ l \bullet E_{elec}+l \bullet E_{mp} \bullet d^4, d \geq d_0 \end{cases} \tag{1}$$

The energy consumed by the receiving node is:

$$E_{rx}(l)=l \times E_{elec} \tag{2}$$

wherein, $d_0=\sqrt{E_{fs}/E_{mp}}$. E_{elec} represents the energy consumed by the circuit processing unit *bit* of data. E_{fs} represents the energy loss using the free space model. E_{mp} represents the energy loss using multi-path fading.

3. Algorithm Description

In a wireless sensor network, to reduce network energy consumption and ensure network performance, it is necessary to match the effectiveness of node energy consumption and the balance of traffic. This paper defines energy cost and load index, thus ensuring efficient energy use and achieving an optimal match between energy consumption and network traffic balance.

3.1. The Energy Cost

The energy consumption of nodes is an important indicator for designing and evaluating the performance of the WSN routing algorithm. Therefore, considering three factors: the distance from the current node to the sink node, the distance to the neighbor node, and the distance from the neighbor node to the sink node, we construct the energy cost function.

The energy cost is the ratio of the energy consumed by the node *i* sending data to the node *j* to the actual distance to sink, i.e.:

$$EC_{ij}=\frac{E_{tx}(l,d(i,j))}{d(i,s)-d(j,s)} \tag{3}$$

$E_{tx}(l,d(i,j))$ represents the energy consumed by the node *i* sending *l* bit data to the node *j*. $d(i,j)$ is the distance from node *i* to node *j*. The smaller EC_{ij} , the greater the probability that the node *j* will be selected as the next-hop. The formula (3) is normalized as follows:

$$EC_{i,j}=\frac{EC_{i,j}-\min EC_{i,k}}{\max EC_{i,k}-\min EC_{i,k}} \quad k,j \in FN(i) \tag{4}$$

$FN(i)$ represent the nodes that are closer to the sink node than *i* among the neighbors of node *i*.

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3.2. The Load Index

We define the load index to balance the traffic load on the network. The load index LI_j of node *j* is determined by the current queue length Q_j of node *j*'s buffer and the maximum length $Q_{\max}$ of the buffer, as follows:

$$LI_j = \frac{Q_j}{Q_{\max}} \tag{5}$$

According to formula (5), when $LI_j = 1$, the buffer of the node *j* is full, and congestion will occur. $LI_j < 1$ indicates that the node *j*'s traffic load is lighter, and the possibility of congestion is less.

3.3. The Transmission Cost Function

The smaller the energy cost of a node, the better it is for data forwarding. The formula (5) directly reflects the node's ability to forward data from the point of view of balancing network traffic. For simplicity and ease of processing, we define the following transmission cost function:

$$TC_{ij} = \alpha EC_{i,j,k} + (1-\alpha) LI_j \tag{6}$$

wherein, α is the adjustment parameter, and $0 \le \alpha \le 1$, the general value is 0.8.

3.4. Route Selection

The implementation of the routing algorithm proposed in this paper can be divided into the following steps :

Step 1: Node *i* takes the maximum communication distance *R* as the radius and determines the forward neighbor node set $FN(i)$.

Step 2:Node *i* calculates the energy cost $EC_{i,j}$ of each forward neighbor of node *i* based on formulas (3) and (4).

Step 3: The load index LI_j for each forward neighbor node is obtained based on the formula(5).

Step 4: Bring the results in steps 2 and 3 into formula (6), node *i* calculate the transmission cost value of each forward neighbor node. Then, select the next-hop node based on the formula (7).

$$j = \min(TC_{ij}), j \in FN(i) \tag{7}$$

Step 5: When the sink node is included in the neighbor node, the data is sent directly to the sink node to complete the data transfer.

4. Simulation Results and Analysis

In order to verify the validity of our algorithm, we use MATLAB 2019 to simulate the algorithm. In the simulation, the nodes are randomly and evenly distributed in a square area with a side length of 100m. The specific simulation parameter settings are shown in Table 1.

We choose three indicators to measure the algorithm's performance: total network energy consumption, packet loss rate, and average routing hops. In the simulation, the algorithm in this paper is compared with the Min-hop algorithm [7].

Table 1. Simulation Parameters

Parameter	Value
The size of the region	$100 \times 100m^2$
The number of nodes	100~300
Sink location	(50, 50)
The transfer radius	30m
Size of a data packet	2048 bit
Simulation time	100 round
E_{elec}	$50nJ / bit$
E_{fs}	$10\,pJ / bit / m^2$
E_{mp}	$0.0013\,pJ / bit / m^4$

4.1. The Total Network Energy Consumption

It can be seen from Figure 1 that as the scale of the network increases, the total network energy consumption is getting higher and higher. However, because the algorithm in this paper considers the energy cost of nodes when routing, its total energy consumption is lower than that of the Min-hop algorithm. Thus, our algorithm realizes the effectiveness of network energy consumption.

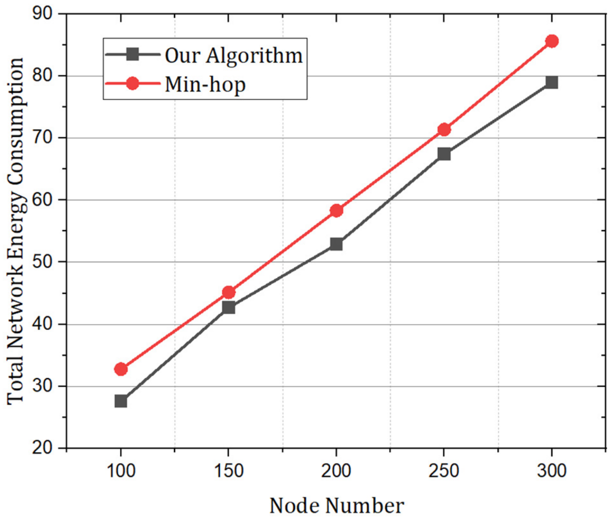

Figure 1. Comparison of the total network energy consumption

4.2. The Packet Loss Rate

Data transmission reliability is an important performance indicator of WSN, and the packet loss rate can reflect the network's reliability. It can be seen from Figure 2 that the algorithm in this paper has the lowest packet loss rate. Min-hop algorithm only considers minimizing the number of hops. Therefore, there is more congestion in the process of data transmission, increasing the packet loss rate. The algorithm in this paper constructs a load index based on the queue length. It takes the traffic load of the node into account for routing selection, which greatly reduces the possibility of congestion and significantly reduces the network packet loss rate.

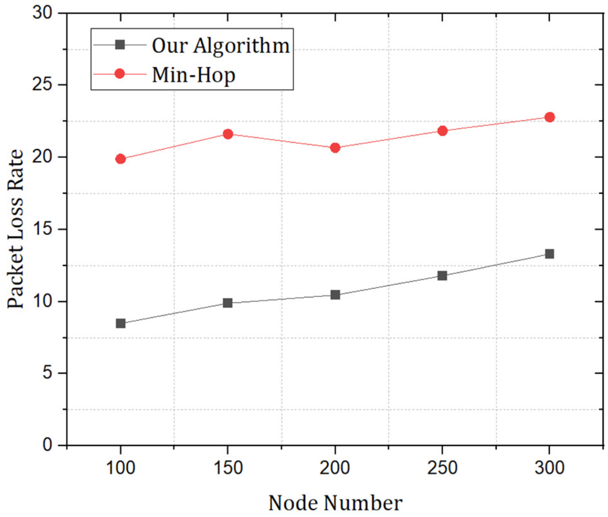

Figure 2. Comparison of the packet loss rate

4.3. The Average Routing Hops

The routing hops reflect an end-to-end delay. It can be seen from Figure 3 that as the number of nodes increases, both Min-hop and the average number of hops of routes in this algorithm show an upward trend. Thus, although the Min-hop algorithm aims to reduce the number of hops, the number of hops in a single data packet is less. However, because it is easy to cause congestion, the average number of hops is higher than the algorithm in this paper. Thus, our algorithm relieves network congestion, although the delay of a single data packet may increase, the overall average routing hops is lower.

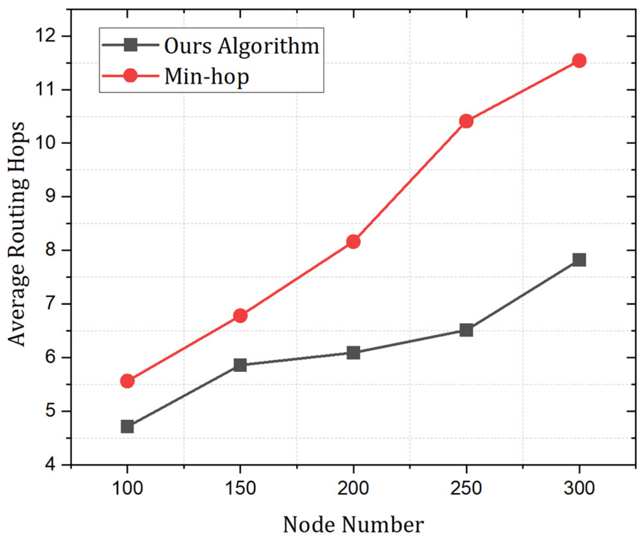

Figure 3. Comparison of the average routing hops

5. Conclusion

Combined with the characteristics of WSN, a routing optimization algorithm based on the transmission cost is proposed. The algorithm introduces energy cost and load index to construct transmission cost function from the point of view of reducing the total network power consumption and balancing the network traffic load. The simulation results show that the routing algorithm can effectively reduce the network's total energy consumption and reduce the network packet loss rate.

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