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A Routing Protocol for Wireless Sensor Networks with Congestion Control

Qi Li[1], Zongwu Ke[2*], Duanfeng Xia[3], Yuxia Sun[4]
School of Computer Science and Technology, Hubei Normal University, Huangshi Hubei, China
Email: hbxfliqi2012@126.com, kezongwu@126.com, aimixia@163.com, 33311454 @qq.com

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ABSTRACT

This paper proposed a novel RED protocol which takes the node's energy into account depending on the length of the data packet. It also proposed a routing protocol for wireless sensor networks with congestion control which imitates the ant colony foraging behavior. Sensor nodes choose routings according to the pheromone density. The experiment result shows that the algorithm balances the energy consumption of each node. It mitigated congestion effectively with the proposed routing protocol.

Keywords: Wireless Sensor Network; Routing; Congestion Control

1. Introduction

Wireless sensor network is one of the key technologies in IoT. Many applications based on wireless sensor networks usually require real-time multimedia data [1], such as health-care system, target tracking, etc. In wireless sensor network, sensor node usually has small memory capacity, and the buffer resources used for routing are relatively few, but real-time multimedia has a large amount of data, a large number of multimedia data transfer to sink node via multi-hops, it's easy to generate congestion. Transmission delay generated by network congestion can't meet real-time requirement of multimedia data. As we know, the sensor node is usually powered by battery, node in congestion zone consumes huge energy, it would lead some nodes energy exhausted in a local network area, it also reduces the lifetime of the network [2].

Form the above discussion, the routing protocol of wireless sensor networks with large data traffic not only needs to find an optimized path, but also needs congestion avoidance and detection.

This paper studies routing protocol with congestion control in wireless sensor networks.

The remainder of this paper is organized as follows. Section 2 gives a brief overview of the related work. Section 3 presents an improved random early detection model. Section 4 presents a routing protocol for wireless sensor networks with congestion control. Section 5 discusses the simulation model and the experimental results. Section 6 concludes this paper.

2. Related Work

Congestion control is a strategy that is used to avoid network congestion and mitigate congestion. Wireless sensor networks are easy to generate congestion because of its constrained resource. Once network generates congestion, it would bring a lot of resources consumption. So it is necessary to use congestion control to avoid congestion in wireless sensor networks. Congestion control in wireless sensor networks usually have two types, end-to-end and hop-by-hop congestion control [3]. Congestion control includes congestion detection and congestion avoidance.

Congestion detection often relies on the buffer's occupation [4-7].Mohammad proposed the distinction service and congestion control strategy which is a kind of end-to-end type, based on priority rate in wireless sensor network multimedia, and used a strategy to avoid congestion which is similar to RED [6]. Bret Hull proposed a congestion control strategy which uses a combination of hop-by-hop flow control, rate limiting source traffic and a prioritized medium access control protocol [3]. Its basic idea is to set a congestion bit through different congestion detection methods. It will broadcast congestion information to the neighbor node if the node generates congestion. Its congestion detection method is to judge whether it will generate congestion using prediction method. This idea doesn't take different types of sensing data in sensor networks into account. When the size of the data packet is very small, the congestion node actu-

[*]Corresponding author.

ally can forward the packet. Omar Banimelhem proposed a wireless sensor networks' multi-path routing protocol with congestion control based on grid [7]. Its method to reduce congestion is monitoring the buffer through the master node. If a buffer occupies more than a threshold value, it broadcasts congestion information to the neighbor node. And choose two master nodes in grid, master node and secondary master node. When the master node produces congestion, it is a duty for secondary master node to route in order to reduce congestion.

3. Improved Random Early Detection Model

Random Early Detection (RED) is a congestion-avoidance mechanism. RED also known as random early drop, it will drop the packets with statistical probabilities based on the average queue size [8].

There are different data types in wireless sensor networks, and the length of every data packet is quite different from each other. Many sensed information, such as the temperature whose length of data packet only a few bytes. But the length of the multimedia data packets may occupy several K bytes, the RED protocol which is designed by the main idea of simple queue length can't meet the requirements of wireless sensor networks.

So, we design a novel random early detection model which is decided by the size of data packets.

First we give a method of calculating the average data length in the present buffer with the weighted average method.

$$AvgDataLen=(1-Weight)\times AvgDataLen + Weight\times SampleDataLen \quad (1)$$

Where SampleDataLen is the data length which is detected in the present buffer, AvgDataLen is the weighted average length. The current sample value is sampling when a package is completely received.

The drop probability function of RED is definite as follows:

Suppose the size of the sensor node's buffer is max buffer size, set two thresholds to control the drop probability.

If $AvgDataLen\le MinBufferThreshold$, the sensor node accepts data directly, that is, $p=0$.

If $MinBufferThreshold < AvgDataLen\le MaxBufferThreshold$, the sensor node drops following data packet with probability p.

If $AvgDataLen > MaxBufferThreshold$, the sensor node drops following data packet with probability $p=1$.

That is, if average data length is smaller than $MinBufferThreshold$, it doesn't take any measure; if average data length is between $MaxBufferThreshold$ and $MinBufferThreshold$, it drops the following data packets with probability p; if average data length is longer than $MinBufferThreshold$, it drops the packet directly.

The sensor nodes in wireless sensor networks are usually powered by battery. If the sensor node is used excessively, it will bring energy exhaustion. The network is easy to become invalid. It will lead to reduce lifetime in wireless sensor networks. When the node's residual energy is low, it will drop data actively. It will inform the sender to choose other nodes with high energy to transmit data.

It gets the abandon rate P with the energy factor e based on the traditional RED model.

$$TempP = Maxp\times\frac{AvgDataLen-MinBufferThreshold}{MaxBufferThreshold-MinBufferThreshold}\times e \quad (2)$$

$$P=\frac{TempP}{1-Datalen\times TempP} \quad (3)$$

$DataLen$ is the size of the data packet coming in the node which is not discarded, while the size of average data between the two threshold.

$$Maxp={}^{1}\!/_{32}=0.03125$$

The energy model uses hierarchical mechanism:

$$x\in[0,1], e=2^{6-\lceil 6x\rceil} \quad (4)$$

x represents the ratio of the residual energy and the maximum energy

Assume the $MinBufferThreshold$ is 500 KB and the $MaxBufferThreshold$ is 1000 KB, the drop probability is shown as **Figure 1**:

4. A Routing Protocol for Wireless Sensor Network with Congestion

Routing protocols in wireless sensor networks have been researched widely. Generally, routing protocols are divided into table-driven routing protocols and on-demand

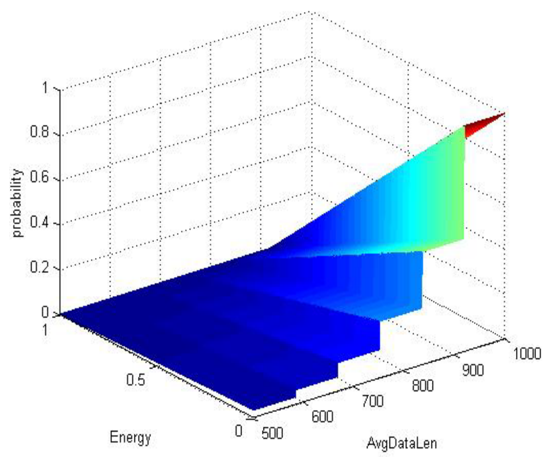

Figure 1. Drop probability with energy.

routing protocols. General routing protocols in wireless sensor networks don't take congestion control into account.

Some routing protocols using ant colony algorithm have been studied [9-11]. This paper proposes a novel routing protocol of wireless sensor network which imitate ant colony foraging behavior. Ants usually leave pheromone on the path when looking for food and they always follow the path with high pheromone density in order to find an ideal path. To imitate the ants' habit, we maintain a routing table in each node. All neighbor nodes' pheromone density Q_n of a node store in this routing table. When a node prepares to send data, it chooses the next hop with probability P_n shown as follows:

$$P_{\mathrm{n}}=\begin{cases}\dfrac{Q_n{}^{\alpha}\cdot\eta_{\mathrm{n}}{}^{\beta}}{\sum\limits_{s\subset No\_Visited(t)}Q_n{}^{\alpha}\cdot\eta_{\mathrm{n}}{}^{\beta}}, s\in No\_Visited\\ 0, s\in Visited\end{cases}$$

where, η_{n} is inspiration function, it represents the ratio of The residual energy and the total energy, that is

$$E_r/E_t$$

α is the important degree factor of pheromone, indicating the importance of pheromone in the process of choosing the next hop.

β is the important degree factor of inspiration function, indicating the importance of inspiration function in the process of choosing the next hop. No_Visited tells node set that the current node didn't visit. Accordingly, Visited tells node set that the current node has visited.

Suppose that there is only one sink node in wireless sensor networks. If a node is in the condition of initialization, the neighbor nodes' pheromone densities in its routing table are all zero.

When the node prepares to send data, it needs to initialize its routing table, initialize method as **Figure 2**:

Step 1: The source node send a path-finding packet to all neighbor nodes, the path-finding packet contains source node identification.

Step 2: If the next hop has completed initialization, find the next hop by P_n, and record this path in the path-finding packet; Else Initialize this node

Step 3: If it is not a sink Go to Step 2; Else Send back all paths' pheromone density to source node

Figure 2. The algorithm of initializing the routing table.

Sink node calculates source's neighbor nodes' pheromone density in its routing table according to the hop count on each path, the formula is as follows:

$$Q_n=(1-\frac{hopcount(n)}{\sum hopcount(n)})\times Q \tag{5}$$

where $hopcount(n)$ represents the hops on each path, Q is a constant number.

If a neighbor node doesn't appear in the routing table sent back by sink node, it shows that this node can't reach sink node, we set its pheromone density zero.

The routing table updating strategy is defined as follows:

A protocol is proposed to transmit data hop-by-hop which is similar to stop-wait-protocol in this paper.

A volatile factor ρ is used to change the pheromone density, pheromone density on current path volatile with ρ and the pheromone density will be updated with $\Delta\tau_t$ after finding a path, that is,

$$Q_i=(1-\rho)Q_i+\Delta\tau_t, 0<\rho<1 \tag{6}$$

where Q_i represents the pheromone density of the node i.

It sets a timeout timer in this protocol. When a node sends a data packet, it waits for the confirm message from the next hop. If a node receives a confirm message from the next hop, it indicates that the node sends data packet successfully. It updates the nodes' pheromone densities in the current node routing table with the following method.

$$\Delta\tau_t=\begin{cases}Q, t=i\\ 0, \ \ others\end{cases} \tag{7}$$

If it times out, reduce the pheromone density with the following method:

$$Q_i=\frac{Q_i}{2^k} \tag{8}$$

where k presents the number of timeout. This method can reduce the congestion node's energy sharply and it can guarantee the validity of the routing.

5. Experimental Results

In this paper, it simulates this routing algorithm using the topology of network shown in **Figure 3**. In the topology, there are three sensor nodes S_1, S_2, S_3, three routers r_1, r_2, r_3 and a sink node. A sensor node $S_i(i=1,2,3)$ sends data packets to the sink node via router $r_i(i=1,2,3)$. The network topology is shown in **Figure 3**.

In the experiment, the sensor node sends data with the speed of 100 bytes per second. Set 500KB as the MinBufferThreshold and set 1000KB as the MaxBufferThreshold. Assume that the initial energy of r_1, r_2, r_3 are $E_{r1}=9, E_{r2}=12, E_{r3}=10$.

In the first experiment, it uses both traditional RED protocol and the proposed RED protocol to watch on the condition of drop probability. When taking traditional RED protocol, three nodes all select the router r_2 to send data packet. The drop probability increases to maximum value and keeps it. In the proposed protocol, three nodes all select the router r_2 at first. The drop probability in r_2 will increase if there is congestion. Then, dropped data will find other nodes to send .The energy in the proposed RED protocol uses equation.(4)..

The first experimental result is shown in **Figure 4**, G1 is the drop probability curve by the algorithm of RED, and the drop probability rises until the maximum and keeps it. When it takes the proposed protocol, the node drop data with some probability if there is congestion. The dropped data selects some other node, so the drop probability of the current node reaches a certain value at first, and then it decreases tending to a small probability.

In the second experiment, it uses traditional routing protocol and the proposed routing protocol to watch on the energy consumption condition.

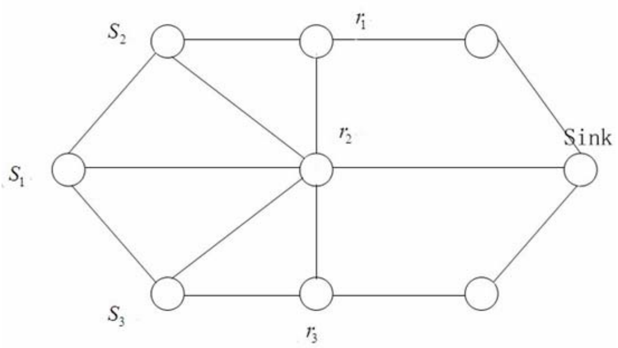

Figure 3. The topology of network.

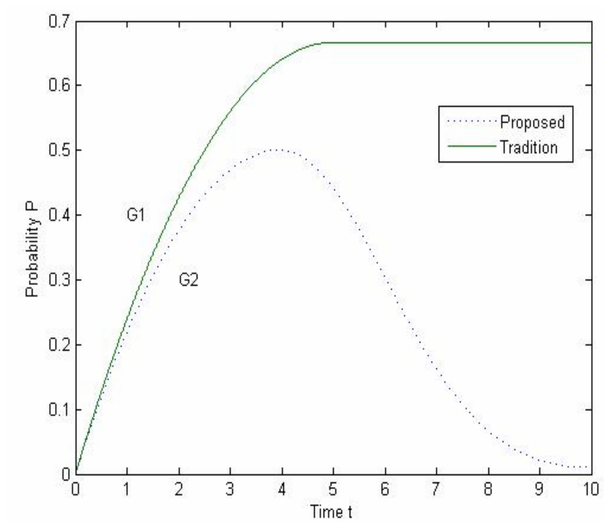

Figure 4. Drop probability in traditional RED vs. proposed RED.

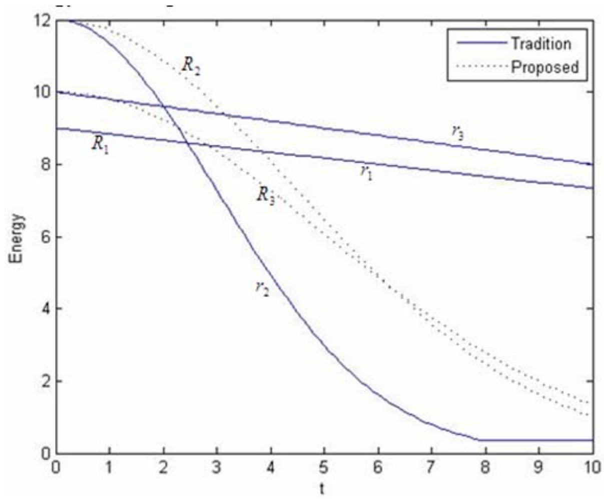

Figure 5. Energy consumption in proposed routing protocol vs. traditional.

When taking the traditional routing protocol, three nodes S_1, S_2, S_3 all choose the router r_2, so the energy of r_1 nearly doesn't change and the energy of r_3 nearly doesn't change either. The energy of r_2 changes as the curve r_2 shown in **Figure 5**. The energy of the router r_2 reduces sharply because three nodes all choose the router r_2. When the energy of the router r_2 reaches a certain value E_0, it keeps this value, the energy of the router r_2 tends to be E_0 When taking the proposed routing protocol, S_1, S_2, S_3 choose routes r_2 at first. Once it generates congestion in router r_2, router r_2 will drop data with a certain probability p_0, and the dropped data will choose the router r_3. So the router r_3 could consume some energy. The energy of S_2 changes as the curve R_2 in **Figure 5**, and the energy of S_3 changes as the curve R_3 in **Figure 5**.

From the analysis of the drop probability and energy above, using the improved model could reduce the drop probability and reduce congestion effectively. Meanwhile, the energy state of the node which generated congestion before has an improvement. All of the data don't choose a unique node, so that it can reduce the energy consumption.

6. Conclusions

This paper proposed a routing protocol of wireless sensor networks with congestion control. The routing algorithm simulates the ant colony foraging behavior.

The RED protocol takes the balance use of energy into account. The experiment shows that the protocol could avoid congestion and mitigate congestion effectively. Meanwhile, it could prolong the network's lifetime.

The following research work is to compare this protocol with general wireless sensor network routing protocol by simulation and study the characters of the protocol.

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