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A CROSS-LAYER CONGESTION CONTROL STRATEGY IN WIRELESS SENSOR NETWORK

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Abstract

In wireless sensor networks (WSNs), the energy and function of sensor nodes are limited. Congestion occurs frequently in many to one and multi-hop transferring nodes. It can cause packets dropout, low energy efficiency, and long delay. The network congestion control is a key to improve the QoS of network. Most studies were carried out at the transport layer in congestion detection and rate adjustment mechanism, without considering the balanced combination in the multi-path routing and the variety application situations. In this paper, we present a Cross-layer Congestion Control (CLCC) Strategy in wireless sensor networks. It includes multi-path routing, rate adjustment, and application-oriented design. The multi-path routing can remove congestion of one node immediately by forwarding packets to other nodes. The rate adjustment can control congestion fundamentally. The application-oriented design is for the variety situations in wireless senor networks. Simulation results are also presented that show decrease in drop rate and stability in source rate.

Keywords: wireless sensor networks; cross-layer; congestion control; multi-paths routing

1 Introduction

Wireless sensor networks are deployed by a large number of cheap micro-region in the monitoring of sensor nodes. Each sensor node is integrated by data processing unit and communication module, which aims to percept, collect and process information of the coverage areas of network collaboratively [1]. With the maturity of theory and technology of WSN, its applications have expanded from military defense to environmental monitoring, traffic management, health care, business services and anti-terrorism disaster. People can get a lot of reliable information at any time, any place and any environmental conditions. At last, it can ultimately become a ubiquitous sensor technology [2].

Compared with the traditional Ad hoc networks, the energy of each sensor node is limited in wireless sensor networks. Communication capabilities and storage power are the greatest disadvantages of wireless sensor networks and the main factors restricting the routing protocol. Moreover, with the expansion of the network and increasing of application, the transmission performance will decline. The node starts to drop packets and enters the congestion state. Therefore, one of the most important targets in wireless sensor network is to manage data transferring and to avoid congestion as much as possible [3]. The congestion control strategy in traditional internet and Ad hoc networks is not suitable for WSN, because the network requirements and design objectives in WSN are different from that in traditional networks. The theory of internet is end to end, emphasizing all the controls based on the network terminal. The intermediate node is only responsible for forwarding data packets. While the WSN is a data-centric network and the topology of it is dynamic.

At present, most studies were carried out at the transport layer in congestion detection and rate adjustment mechanism. CODA [4] and Fusion [5] control local area congestion by adjusting the forwarding rate. Siphon [6] and IFRC [7] adjust the original rate to reduce network congestion fundamentally. These protocols have not considered the balanced combination in the multi-path routing and the application-oriented situation such as delay, reliability, priority and other requirements. In this work, we present a cross-layer congestion control strategy in wireless sensor network to control the congestion effectively.

The rest of the paper is organized as follows. We introduce the related work about congestion control protocol in wireless sensor networks in Section 2. We describe the cross-layer congestion control strategy in Section 3. Simulation studies are performed in Section 4. We give some conclusion and perspective to future works in Section 5.

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2 Related work

In this section we briefly describe some important methods of controlling congestion in the sensor network.

In [8], the authors proposed the event-to-sink reliable transport protocol (ESRT). ESRT is a novel transport solution developed to achieve reliable event detection in WSN with minimum energy expenditure. It includes a congestion control component that serves the dual purpose of achieving reliability and conserving energy. The algorithms of ESRT mainly run on the sink, with minimal functionality required at resource constrained sensor nodes. In [4], the authors proposed Congestion Detection and Avoidance (CODA) where several mechanisms were proposed to alleviate congestion. It includes receiver-based congestion detection, open-loop hop-by-hop backpressure and closed-loop multi-source regulation. The paper [9] proposed an energy-feedback based adaptive multi-path routing (EFAMP). It introduced minimum-hop-routing discovery strategy and negative-feedback based probability-forwarding strategy. In Fusion [5], authors investigate a mitigating congestion in WSN. They examine three techniques that span different layers of the traditional protocol stack: hop-by-hop flow control, rate limiting source traffic when transit traffic is present, and a prioritized medium access control protocol. Some protocols adjust the original rate to reduce network congestion fundamentally. Siphon [6] is based on a stargate implementation of virtual sinks that uses a separate longer-range radio network to siphon events to one or more physical sinks, and a mote radio to interact with the sensor field at siphon points. And IFRC [7] detects incipient congestion at a node by monitoring the average queue length, communicates congestion state to exactly the set of potential interferers using a novel low-overhead congestion sharing mechanism, and converges to a fair and efficient rate using an AIMD control law. Paper [10] did not consider the rate and proposed a congestion avoidance control mechanism for multiple paths routing protocol (MR-CACM). The network can avoid congestion by assigning traffic to different paths. The learning automata-based congestion avoidance algorithm was proposed in [11]. It would make the processing rate in the nodes equal to the transmitting rate, so that the occurrence of congestion in the nodes is seamlessly avoided.

3 Cross-layer congestion control

Firstly, we establish a multi-path routing network from the source node to sink node. Then the cross-layer information will be shared in the state frame which is sent to upstream node to publish and update the congestion information of the node. The upstream node records the information of many downstream nodes and selects the downstream node to forward packets according to the congestion information and the requirement of the application. It can control congestion and meet the needs of application layer effectively.

3.1 Routing establishment

Sink node broadcasts the RREQ command frame to the whole network. The frame records the number of hops through the routing nodes. Its initial value is 0. The node which has received the RREQ frame updates the hops of routing node (n_r to n_{r+1}) in the frame, and then performs the operation under the following two conditions.
1) For the first time—if the node (A) first time receives the RREQ frame, do the template as follows.
Set: Set the updated value as the smallest hops to Sink and add the node (B) ID from which node (A) receives the RREQ in the routing table. So the node (B) will be downstream node when node (A) forwards data to Sink.
Forward: Node (A) forwards the RREQ to other neighbors.
2) If the node (A) has been received RREQ before—do the template as follows.
Compare: we compare the value of hops in the frame (n_r) with the current value of the minimum hops (n_i) in routing table.
If (n_r>n_i), then drop the RREQ frame directly.
If (n_r<n_i), then delete the information of all downstream neighbors in the routing table, add the node (B) ID from which node (A) received the RREQ in the routing table, and update the minimum hops n_i to n_r.
Forward: Node (A) forwards the RREQ to other neighbors.
The maximum number of downstream nodes recorded in routing table is MAX.
Based on the rules above, the multi-path network will be established between source node and sink node. It is shown in Figure 1.

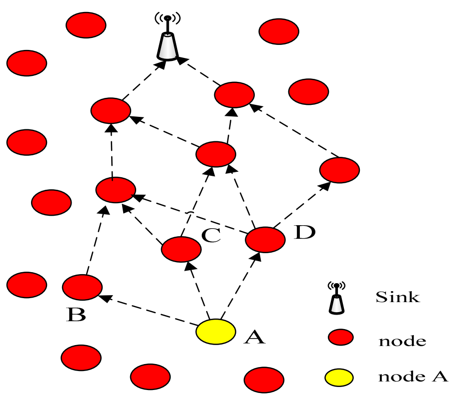

Figure 1 Multi-path routing

3.2 Congestion detection

Accurate and efficient congestion detection plays an important role in congestion control of sensor networks. There are two main use of the current congestion measure: the buffer occupancy (BO) and listening to the channel load. Buffer occupancy is a very simple detection method. This method only views the buffer and costs very small price. While the method of listening the channel load needs to detect the status of channel load frequently. Therefore, the cost of energy is too large. In this paper, we select the first method to detection the congestion.

3.3 Share and report cross-layer congestion

The idea of cross-layer information shared is integrating the information of physical layer, data link layer, network layer, transport layer and application layer into one frame. We can use this frame to exchange information and establish some connection to allocate the network resources and to control congestion efficiently. It is shown in Figure 2.

Protocol layer	Shared information
application layer	reliability delay priority
transport layer	data rate
network layer	routing information
data link layer	congestion state
physical layer	

Figure 2 Cross-layer information

There are two ways of reporting congestion. One is expressly notices. The advantage of it is the speed of diffusion. The other is piggybacked to the ACK frame. And the advantage of it is low costs. We use the first way to integrate the shared information into the state frame.

3.4 Congestion control

The congestion control includes forwarding mechanism and rate adjustment mechanism.

1) Forwarding mechanism—When a routing node i receives a packet, it doesn't always forward the packet to a fixed node, but selects a downstream neighbor node j in its routing table as the next hop randomly. The probability (P_{ij}) of selecting the downstream neighbor j is related with the congestion degree of j . The congestion degree C is calculated as:

$$C = \frac{k(1-\mathrm{BO})}{2^n} \tag{1}$$

In the formula, k and n are the adjustment factors. The initial value of n is 0. The formula of the probability (P_{ij}) of selecting the downstream neighbor j is as follows.

$$P_{ij} = \frac{C_j}{\sum_t C_t} \tag{2}$$

The mechanism can change the probability of forwarding packets adaptively according to the congestion information of downstream nodes. It is shown in Figure 3.

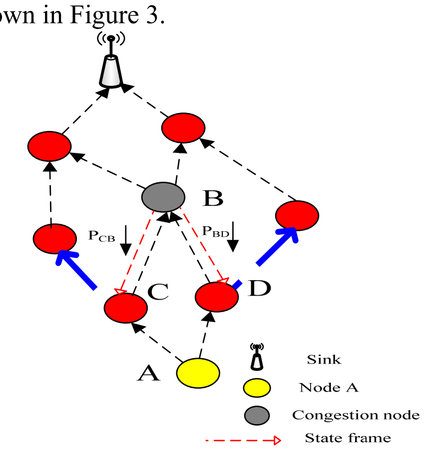

Figure 3 Forwarding mechanism

2) Adjustment mechanism—The specific algorithm of adjustment is as follows.

Step 1: When congestion occurs, the adjustment factors of probability n will update to n+1. Then the congestion degree C will reduce greatly. The probability of selecting it to be the downstream neighbor is also reduced. At the same time, the rate adjustment will change the rate R_c to $R_c/2$.

Step 2: When the congestion removes, the adjustment factors of probability n will reset to 0. The probability of selecting it to be the downstream neighbor will also increase. And the rate adjustment will change the rate R_c to $R_c+\Delta R$.

3.5 Application-oriented

1) High reliability—When the position of reliability in the state frame is 1 in the state frame, the application need high reliability information. Then the adjustment factor K of congestion node will set 0. The probability of selecting it forwarding packets is 0, too. The other idle nodes will forward these packets to ensure the reliability.

2) Low delay—When the position of delay in the state frame is 1 in the state frame, the application need low delay transmission. Then the adjustment factor K of congestion node will set 0. The rate of sending to other nodes will change to the maximum.

3) High priority—When the position of priority of the state is 1 in the state frame, This frame will be sent to next hop firstly. If the state of the node is congestion, it will drop the low priority packets.

4 Simulation results

To assess the performance and effectiveness of the algorithm, Simulation studies were performed using the NS (network simulator)-2. We compared the LBMR with ESRT in drop packets rate and source rate. A summary of the simulation parameters set in our experiments is presented below.

1) Simulation Time: 30 seconds.
2) Seed for generation of random numbers: 2.3.
3) Terrain dimension:200m*200m.
4) Number of nodes: 100.
5) The initial rate:100packets/s
6) MAC protocol: 802.15.4

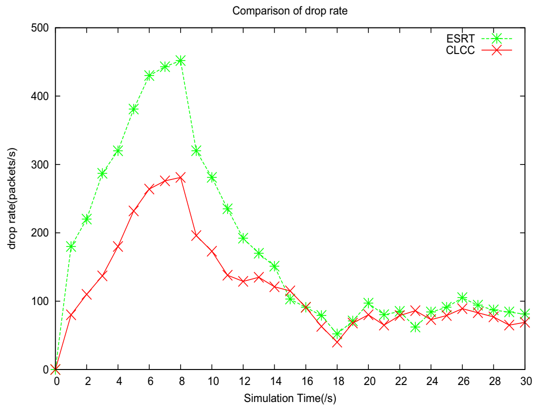

Figure 4 Comparison of drop rate

As is evident from Figure 4, the drop rate in CLCC algorithm is much lower than that in ESRT algorithm. When the network just starts running, the drop rate in ESRT is very high. It is because the strategy of single sink to the source rate adjustment can't reduce send rate according to network capacity in time. While with the help of multi-path routing balancing the load and the adjustment algorithm, CLCC can control the congestion more effectively.

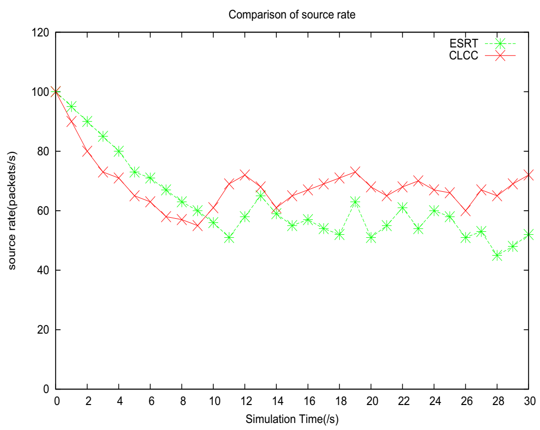

Figure 5 Comparison of average source rate

Figure 5 shows that the source rate in CLCC algorithm is higher than that in ESRT algorithm in most of the time. In CLCC algorithm, each node can send packet to many nodes and adjust the probability adaptively. Therefore, the average of the source rate has remained relatively stable after period of time.

5 Conclusions

This paper introduces a cross-layer congestion control strategy in wireless sensor networks. In this algorithm, each node has multiple downstream nodes to be transmitted. The probability of forwarding nodes and the rate of sending packets can be dynamically adjusted by the congestion state. We have compared the performance of the CLCC with the ESRT. The evaluation shows that CLCC has a better performance and can control congestion effectively. Our future work is mainly in two aspects. One is to improve CLCC with the MAC protocol. The other is to try to use this kind of adjustment mechanism in network diagnosis and observe whether this mechanism has advantages..

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