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Centralized congestion control routing protocol based on multi-metrics for low power and lossy networks

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Abstract

Owing to the unreliability of wireless link and the resource constraints of embedded devices in terms of energy, processing power, and memory size in low power and lossy networks (LLNs), network congestion may occur in an emergency and lead to significant packet loss and end-to-end delay. To mitigate the effect of network congestion, this paper proposes a centralized congestion control routing protocol based on multi-metrics (CCRPM). It combines the residual energy of a node, buffer occupancy rate, wireless link quality, and the current number of sub-nodes for the candidate parent to reduce the probability of network congestion in the process of network construction. In addition, it adopts a centralized way to determine whether the sub-nodes of the congested node need to be switched based on the traffic analysis when network congestion occurs. Theoretical analysis and extensive simulation results show that compared with the existing routing protocol, the performance of CCRPM is improved significantly in reducing the probability of network congestion, prolonging average network lifetime, increasing network throughput, and decreasing end-to-end delay.

Keywords LLNs, congestion control, multi-metrics, centralized way, routing protocol

1 Introduction

LLNs are composed of a large amount of wireless sensor nodes, whose memory size, processing power, and energy are extremely limited. In addition, considering the loss characteristic and instability of the wireless link, the existing routing protocols such as the Ad-Hoc on-demand distance vector (AODV) [1] and the dynamic source routing (DSR) [2] are not suitable for LLNs applications, because the energy consumption is beyond the demand. Therefore, a proactive distance vector routing protocol based on the IPv6 for LLNs (RPL) [3] is proposed by the routing over low power and lossy networks (ROLL) working group. With the emergence of LLNs, it has attracted extensive attention and research.

RPL is a tree like routing protocol that supports multi-point-to-point (MP2P), point-to-point (P2P), and point-to-multi-point (P2MP) traffic flows. It has a wide application scope such as building intelligence [4], health care [5], and environmental monitoring [6]. The characteristics and wide application range of RPL make it vulnerable to network congestion in emergency situations. Network congestion may lead to significant packet loss and end-to-end delay, increasing energy consumption and decreasing network throughput.

In wireless sensor networks (WSN), the network congestion control generally contains two parts; congestion detection and congestion avoidance [7]. However, currently there is no explicit mechanism to mitigate network congestion for LLNs. RPL usually adopts some parent selection mechanisms in the process of network construction, to select an optimal parent with good wireless link quality, less hop count or sufficient residual energy. Yet those parent selection mechanisms cannot effectively reduce the probability of network congestion. Moreover, they may cause ‘ping-pong’ effect in which a node changes its parent frequently when network congestion occurs. Currently, there are no specific schemes to completely avoid this issue. In addition, once

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the 'ping-pong' effect occurs in the process of congestion control, the network performance will be impacted severely and the network congestion cannot be mitigated effectively.

In this paper, we propose a novel network congestion control routing protocol based on multi-metrics (CCRPM) for LLNs. The main purpose of CCRPM is to reduce the probability of network congestion by considering multi-metrics such as the residual energy of node, buffer occupancy rate, wireless link quality and the current number of sub-nodes of candidate parent in the process of network construction. Simultaneously, it mitigates network congestion quickly and effectively using a centralized way based on traffic analysis by the congested node when network congestion occurs. In addition, a mechanism is proposed to avoid 'ping-pong' effect during the process of network congestion control.

The rest of this paper is organized as follows. Sect. 2 introduces the existing LLNs routing protocols and discusses the challenges and limitations of designing an efficient network congestion control routing protocol for LLNs. The system model and the problem description are presented in Sect. 3. In Sect. 4, we describe the proposed routing protocol CCRPM. Theory analysis and simulation results are displayed in Sects. 5 and 6, respectively. Finally, the conclusion and perspectives are given in Sect. 7.

2 Related work

In what follows, we divide the previous network congestion control schemes into two categories. One is the strategy of optimal parent selection in the process of network construction; the other is the mechanism of alternative path selection and rate adjustment. As shown in Refs. [8–11], the optimal parent selection strategy selects the optimal parent based on a single metric or several combined metrics. However, in the mechanism of rate adjustment [12–14] and alternative path selection [15–17], the children of the congested node reduce data packet transmission rate or find another path to forward data packet.

2.1 Process of optimal parent selection

As we all know, the choice of routing metric is extremely important for data packet transmission. At present, the ROLL working group has proposed a variety of routing metrics and constraints for LLNs. However, how to apply them to specific application scenarios flexibly remains to be studied.

The ROLL working group has defined two kinds of objective functions, including objective function zero (OF0) [8] and minimum rank with hysteresis objective function (MRHOF) [9]. The former only takes into account the hop count and the latter merely considers the expected transmission count (ETX) in the optimal parent selection process. Unfortunately, neither of them can make the load balanced. In Ref. [10], the residual energy of a node is chosen as the routing metric for optimal parent selection. However, a node with enough residual energy but poor wireless link quality might be selected as optimal parent, thus increasing the packet loss rate and the buffer occupancy of the source node. As a result, Refs. [8–10] cannot reduce the probability of network congestion effectively. Ref. [11] combines residual energy and ETX when selecting the optimal parent, but the probability of network congestion still cannot be reduced effectively on account of ignoring the buffer occupancy of node.

2.2 Process of alternative path selection and rate adjustment

Usually, the rate adjustment is adopted to mitigate network congestion. Refs. [12–14] propose various mechanisms and strategies to adjust the data packet transmission rate of source node to mitigate network congestion. However, those mechanisms and strategies may cause sharp decrease of network throughput and obvious increase of end-to-end delay, as well as increase of the probability of network congestion for other nodes in the network. Therefore, it cannot mitigate network congestion effectively by adjusting the data packet transmission rate of source node.

The standard RPL, a single path routing protocol, may easily lead to network congestion when there are large and rapid data packets caused by emergencies. It will bring significant packet loss and end-to-end delay. Therefore, Ref. [15] proposes a temporary multipath routing protocol during congestion over a path. The child halves its forwarding rate to the congested node and forwards the other half to the subordinate parent in the process of congestion mitigation. Nevertheless, it cannot mitigate congestion effectively if the packet transmission rate of the congested node is lower than the packet reception rate after carrying out the strategy of temporary multipath routing. Tang et al. [16] proposed a congestion avoidance multipath