Analysis and Optimization Strategy of Multipath RPL Based on the COOJA Simulator

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Abstract

The Routing Protocol for Low-power and Lossy Networks (RPL) is the standard IPv6 routing protocol designed by IETF, it is suitable for Low power and Lossy Networks (LLNs). However, the RPL network will suffer from network congestion, rapid consumption of key node energy and high packet loss rate in the case of heavy network load. In this paper, we propose a multipath routing optimization strategy for RPL, and carry out the simulation analysis of RPL and our proposal M-RPL with the COOJA Simulator. Simulation results show that our optimization strategy can handle well the situation of unstable links and network congestion, and reduce the average time delay of the network.

Keywords: *COOJA, RPL, multipath routing, optimization strategy.*

1. Introduction

Wireless sensor network (WSN) is composed of a large number of sensor nodes which has limited processing capacity and energy. The nodes often deployed in harsh environments for remote monitoring[1]. Low power wireless communication is an unreliable and uncertainty communication mode, because of the nodes can not be sure whether the receiving node has received the information. The network with such kind of transmission environment is called Low power and Lossy Network (LLN).

The routing protocols in LLNs must has good robustness and ability to handle well the changing quality of network links. Existing routing protocols such as Open Shortest Path First (OSPF) and Ad Hoc On Demand Vector (AODV) can not satisfy the requirements of LLNs. Therefore, the IETF Routing Over Low power and Lossy networks (ROLL) Working Group has designed and specified the Routing Protocol for LLNs (RPL) [2]. RPL is a single path routing protocol that a node transmit packets to the preferred parent. The network need to select links to build a new topology when the existing path failure. The repair and reconstruction of the topology will lead to the overall delay of the network. At the same time, the RPL network will suffer from network congestion, high packet loss rate and increased time delay in the case of heavy network load.

In this paper, we propose a multipath routing optimization strategy for RPL. The rest of the paper is organized as follows. Section II briefly summarizes the framework of RPL. Section III describes our proposed optimization strategy of RPL. Section IV presents the simulation results. Finally, Section V concludes the paper.

2. RPL Overview

RPL is a distance vector IPv6 routing protocol designed for LLNs, it constructs a topology as a Directed Acyclic Graph (DAG) that is partitioned into one or more Destination-Oriented DAGs (DODAG). In a network which using RPL may contain more than one RPL instance, each RPL instance has its own instance ID. An RPL node may join different RPL instances, but only belong to one DODAG within each instance. Each node has a rank value, which describes the relative location of the node in the DADAG [3]. The way how the rank is computed depends on the Objective Function (OF). Objective function identified by an Objective Code Point (OCP) that specifies the metrics and related functions used within the DODAG.

RPL specifies three ICMPv6 control messages [4] to construct and maintain a DODAG, they are the DODAG Information Object (DIO), the DODAG Information Solicitation (DIS) and the Destination Advertisement

Object (DAO). RPL provides mechanisms for multipoint-to-point (MP2P), point-to-multipoint (P2MP) and point-to-point (P2P) traffic. The root of the DODAG can collect data from other nodes by upward routes (MP2P), nodes can also receive packets from root by downward routes (P2MP). RPL routes are built according to an OF and a set of metrics and constrains. Up to now, the ROLL working group has specified two kinds of Objective Function, one is the Objective Function Zero (OF0) [5], the other is Minimum Rank with Hysteresis Objective Function (MRHOF) [6], which uses Expected Transmission count (ETX) as the default routing metric.

3. Proposed Design

In LLNs, the lossy links between devices are characterized by high loss rate and unstable. Therefore, this paper is mainly on the subject how to relieve network congestion and decrease the packet loss rate in a high-loading LLN with poor link quality.

We design a multipath routing protocol based on RPL, named M-RPL. It provides redundant links to improve the reliability of data transmission in the network, and increase network stability. Coupled with load balancing algorithm, we design a load balancing multipath mechanism with dynamic weight paths, to achieve the reduction of latency on the basis of load balancing.

The proposal M-RPL uses a dynamic adaptive routing scheme, constantly adjust the selection of the optical path based on the real-time situation of the network. It combine the link quality and the number of real-time transmission load of the node for dynamic multipath routing. This dynamic routing scheme can better adapt to the network capacity and provide a better network performance. The main idea is to dynamic adjust the selection of routes according to Expected Transmission count (ETX) and the number of packets the node transmits in a cycle time, and balance the network load according to the different link weights.

4. Performance Evaluation

4.1 Simulation Environment

We simulated the basic RPL and our proposed M-RPL under COOJA [7], a well-known simulator available under Contiki operating system [8]. Contiki is a lightweight, open-source, highly portable, multi-tasking operating system. Contiki is specially designed for low-power and memory-constrained devices, it is an efficient event-driven simulator dedicated to WSN. Contiki includes an IPv6 stack with 6LoWPAN support, as well as ContikiRPL, an implementation of basic RPL. COOJA is a flexible Java-based simulator designed for WSNs running Contiki OS. In contrast to other simulators, COOJA enables simultaneous simulation at many levels combining low-level simulation of hardware and high-level behavior in a single simulation. It allows nodes instantiation using real code compiled for actual hardware [9].

We deploy 20 normal nodes and a sink node in the simulation scenario, the sink node located at the edge of the network. The simulated platform is Tmote Sky. We used the Unit Disk Graph Medium (UDGM) as the radio model with a 50m transmission range and a 100m interference range.

4.2 Network Performance in the case of different inter-packet interval

Set the transmit and receive probabilities to 85%, test the network performance in the case of different inter-packet interval when using basic RPL and M-RPL. We focus on (1) Packet Reception Number (PRN) of root node per unit time, (2) average number of packet loss, (3) packet loss rate, (4) average time delay.

As is shown in Figures 1-4, when the inter-packet interval is short (i.e. 1s and 2s), there are a large amount of data packets transmitting in the network, which will lead to network congestion and increased conflicts and packet loss. The data packets can not be transmitted to the sink node in time, the PRN of basic RPL is much smaller than expected. M-RPL relieves the network congestion by multipath and load balancing when the inter-packet interval is short, and reduce the times of re-transmission. Therefore , in contrast to basic RPL, the network using M-RPL not only has a less packet loss rate, but also has a lower time delay. The result in Figure 4 demonstrated the effectiveness of the optimization strategy in the aspect of reducing delay.

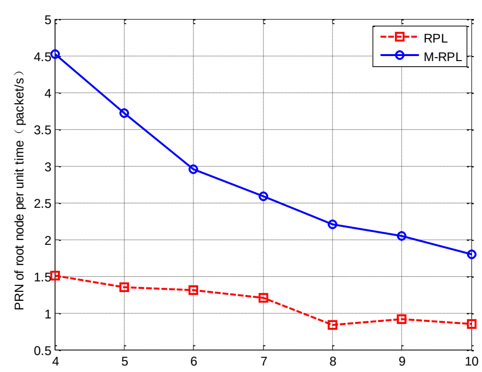

Fig. 1: PRN in the case of different inter-packet interval

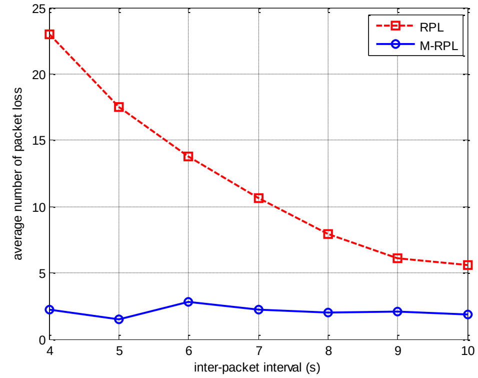

Fig. 2: average number of packet loss in the case of different inter-packet interval

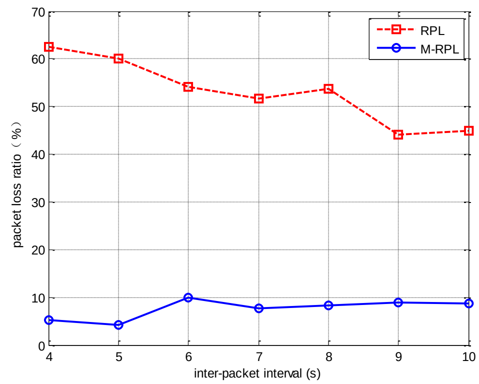

Fig. 3: packet loss ratio in the case of different inter-packet interval

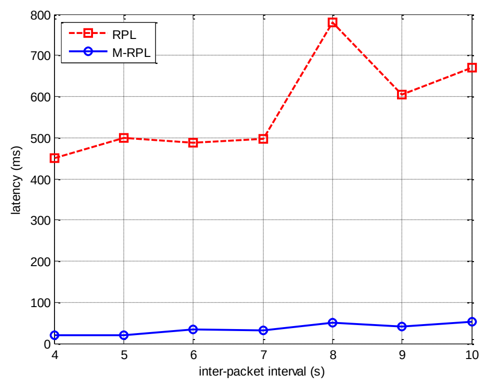

Fig. 4: latency in the case of different inter-packet interval

4.3 Network Performance in the case of different link quality

Set the inter-packet interval is 4s, the transmit probability (TX) to 100%, test the network performance in the case of different receive probabilities (RX) when using basic RPL and M-RPL.

As is represented in Figure 5,6 and 7, M-RPL can handle well the situation of different degrees of lossy links, and reduce the average time delay of the network. When RX ratio is low, the link quality is poor, the re-transmission due to failure to send or receive causes network congestion and packet loss, and decrease the PRN of root. The proposed M-RPL has better performance in PRN, packet loss and latency compared with basic RPL.

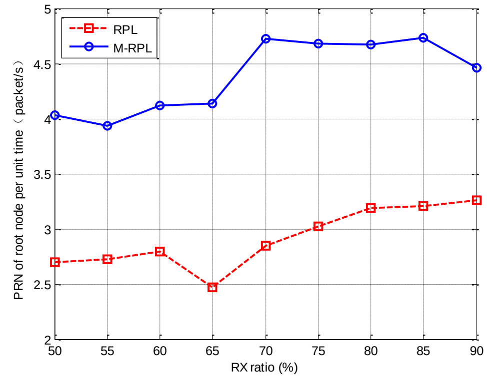

Fig. 5: PRN in the case of different RX ratio

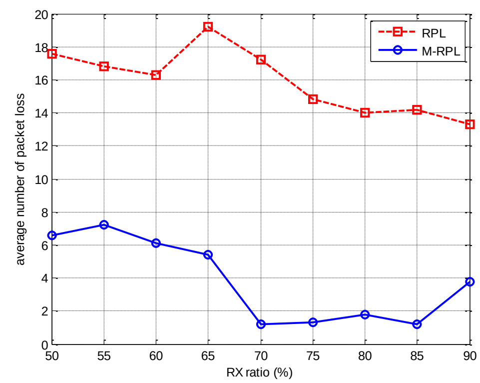

Fig. 6: average number of packet loss in the case of different RX ratio

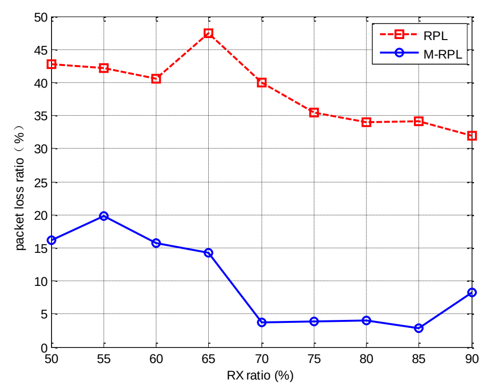

Fig. 7: packet loss ratio in the case of different RX ratio

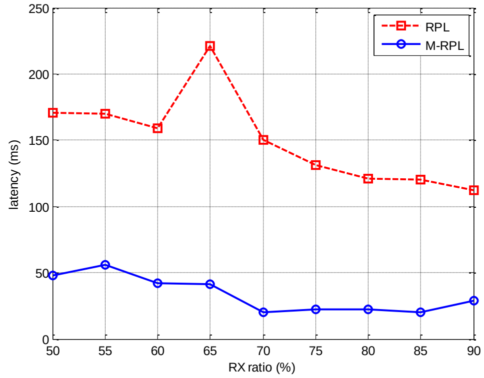

Fig. 8: latency in the case of different RX ratio

5. Conclusion

In face of the problems of RPL in LLNs, we proposed a multipath routing optimization strategy for RPL, named M-RPL. Simulation results show that our optimization strategy can handle well the situation of unstable links and network congestion, reduce the packet loss ratio and average time delay of the network, and significantly improve the performance of LLNs.

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