Transmission Power Control for Large Scale Industrial Applications in Low Power and Lossy Networks

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Abstract— Transmission power is an important factor which impacts on routing topology in low power and lossy networks (LLNs). LLNs have been designed for low rate traffic where use of maximum transmission power is the best choice for performance maximization since it results in reduced hop distance and transmission overhead. However, large scale applications require LLNs to deliver very high rate traffic. In such large scale applications, the nodes which are near the root node will incur heavy traffic even though each node generates low rate traffic. As a result, it will cause severe link congestion. In this paper, we propose a simple power control mechanism, which allows each node to adaptively control its transmission power according to its own link and queue losses to solve load balancing problem. Experimental results indicate that our proposal significantly improves the packet delivery performance by balancing the traffic load within a routing tree. We show performance improvement through experimental measurements on a real multihop LLN testbed running RPL over IEEE 802.15.4.

Keywords— RPL, wireless sensor networks, transmission power, load balancing, low power and lossy networks.

I. INTRODUCTION

RPL is an IPv6 routing protocol for low power and lossy networks (LLN), which is one of the most common protocols that fit the various requirements of LLNs [1][2]. Since LLNs usually deal with low rate traffic, RPL-based multi-hop LLNs have used maximum transmission power to minimize relay burden and hop distance with large transmission range and low packet error rate. However, current LLNs start to consider large scale applications such as SmartGrid where the root node experiences heavy traffic even though each node generates low rate traffic. These new applications make us have a research question as below: Is the use of maximum and equal transmission power for all nodes still the best choice for heavy traffic delivery?

There are lots of power control researches on LLNs [4][6][7][8]. Many transmission power control mechanisms in LLNs use a single transmission power for the whole network, rather than making full use of configurable transmission power provided by CC2420 [7][8]. Kim et al constructs an asymmetric transmission power-based network where the root node uses much higher power than low power nodes, but all low power nodes still use an equal power [9]. Some other researches take the configurable transmission powers into consideration in LLNs [4][5]. However, all of them do not consider power control in an RPL-based LLN.

In this paper, we try to solve the load balancing and congestion problem of RPL by transmission power control. The experimental results indicate that proposed method significantly improves packet delivery performance. To the best of our knowledge, this is the first experimental study which considers the impact of transmission power control on RPL-based LLNs.

The remainder of the paper is organized as follows. Section II introduces the experimental environments and section III describes the load balancing problem of RPL by showing the pre-research experimental results. Section IV proposes power control mechanism and Section V gives the performance comparison between standard RPL and proposed method. Finally, Section VI concludes this paper.

II. EXPERIMENTAL ENVIRMENTS

We deploy a network testbed in the office building as depicted in Fig. 1. There are 30 LLN sensor nodes and one root node which is marked with the red star. Each node is a telosB cloned device which employs CSMA and a FIFO transmit queue size of 10 packets. We make all the sensor nodes generate upward data packet (from a child node to the root node) with traffic rate of 40 packets per minute (ppm). This incurs traffic load of 1200 ppm for the root node. Each node uses CC2420 radio and transmission power from -15dBm to 0dBm.

We make all nodes use the same transmission power to send DIO message or deliver data packet at the experiments. In order to use the stable link, we only do the experiments at night time. Because there are too much interferences in day time. The protocol stack is like this. In routing layer, we use RPL protocol, in MAC layer, we use CSMA, and in physical layer, we use IEEE 802.15.4.

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III. LOAD BALANCING PROBLEM OF RPL

In this section, we show the experimental measurement study of RPL within high traffic condition. We divide packet losses into two types; queue losses and link losses, and consider packet loss rate, queue loss rate, and link loss rate as performance metrics.

A. Packet loss rate

Fig. 2 shows the average packet loss rate of all 30 nodes with varying transmission power. The experimental results indicate packet loss rate first decreases but increases again with transmission power. That is, transmission power has potential to be optimized for further improvement of packet delivery performance. We further investigate the reasons of packet loss by dividing it into queue loss and link loss.

B. Queue loss rate

Queue loss rate is the number of queue losses divided by the number of packet transmission requests at IPv6 layer. We analyze queue loss rate using Fig. 3, which shows the average queue loss rate for different transmission power level. It shows that queue loss rate decreases as transmission power increases since hop distance and relay burden of each node decrease with transmission power.

C. Link loss rate

Link loss rate is the number of packet losses divided by the number of packet transmission requests at link layer. We move onto link loss analysis using Fig. 4, which illustrates average link loss ratio across different transmission power. We find out that link loss rate increases with transmission power due to packet collisions. We confirm the reason by counting average number of neighbors with varying transmission power. As transmission power increases, each node has more neighbors, which incurs congestion at link layer.

D. Per node analysis

We further investigate the characteristics of queue and link loss by per node analysis (figures are omitted for brevity). We find out that link and queue losses are significantly unbalanced among nodes, which shows the load balancing problem of RPL. The correlation between link and queue loss allows each node to self-detect whether it suffers from congestion, regardless of its transmission power. Lastly, we observe that the nodes which experiences severe link and queue loss ratio vary according to transmission power. It shows that transmission power control heavily impacts on routing topology and has potential to enhance congestion problem.

IV. TRANSMISSION POWER CONTROL MECHANISM

As we has shown in last chapter, RPL has load balancing problem in all scenarios. In order to solve this problem, we try to use transmission power control mechanism, which allows the congestion node to reduce its transmission power, hence, it can detach its children nodes.

Power control mechanism works like below. First, we count loss during every time period of t by using a timer. According to the loss, we calculate LossRate, which can be obtained through loss divided by total transmission number. If LossRate is bigger than $\delta$, which denotes reliable criterion that we can preset according to different environments and requirements, we will go back to the timer. If current performance is better than before, we then will check whether MySubTreeSize is bigger than NeighborSubTreeSize. If MySubTreeSize is bigger than NeighborSubTreeSize, power index will be decreased by one, otherwise, go back to the beginning. If LossRate is lower than $\delta$, we will return to loss counting stage. Each node runs transmission power control mechanism independently.

Each node is a TelosB clone device which supports CC2420. When dealing with the different 32 output transmission power levels that CC2420 supports, we set the maximum transmission power level to 31, which indicates 0 dBm, and the minimum transmission power level to 7 in our experiments, which is -15 dBm. We discard transmission power index form 6 to 0, because they are too small to send data packet in real test-bed environment that has different kinds of obstacles.

V. EXPERIMENTAL RESULTS

In this chapter, we analyze the performance of proposed method obtained from a multithop LLN test-bed, and compare it with standard RPL.
A. Queue loss rate

We observed that proposed method reduces the queue loss ratio significantly as shown in Fig. 6. This reveals that our proposed power control mechanism has a critical impact on load balancing, and as a result, proposed method could provide lower queue loss compared to standard RPL. Proposed method dramatically reduces the traffic load of the nodes which have many children, while only slightly increasing those to nearby nodes. This is because proposed power control mechanism detaches its children nodes by reducing transmission power.

B. Link loss rate

Fig. 7 compares the average link loss ratio of different transmission power in standard RPL with proposed method. We observe that in standard RPL, link loss rate increases when increasing transmission power due to packet collisions, however, under transmission power controlling, link loss rate turns out to be the lowest. We find out that the nodes which have many children suffer link loss seriously. As transmission power increases, transmission range will increase hence each node has more neighbors, which incurs congestion at link layer. In order to solve this problem, proposed method allows each node reduces its children number by controlling its transmission power adaptively according to its own congestion condition. Therefore, traffic congestion of the most constrained node is reduced at the same time while only slightly increasing other nodes traffic. Next, we will talk about packet loss rate in detail.

C. Packet loss rate

Fig. 8 depicts packet loss rate of the real-world sensor network test-bed under different transmission power settings. When using power control mechanism, packet delivery performance is much better than the performance of standard RPL under the same configuration. This is because in standard RPL, some sensor nodes are so heavily congested that even increasing the transmission power cannot alleviate the congestion caused by load imbalance. Proposed method helps reduce congestion essentially by balancing the workload among sensor nodes. As a result, packets will not be queued or collided in some sensor nodes for a long time.

VI. CONCLUSIONS

In this paper, we have provided an understanding of the performance trade-off relation between transmission power and queue and link losses. Through testbed measurements, we have verified that packet delivery performance at heavy load first increases and then decreases with transmission power. That is to say, the use of maximum transmission power in RPL cannot provide the best performance. To achieve balanced workload distribution among nodes in large scale low power and lossy networks, we have designed a lightweight power control mechanism based on the standard RPL protocol, which allows each node to adaptively control its transmission power according to its own queue and link losses. Load balancing and congestion condition are jointly considered to control transmission power for maximizing packet delivery performance. We show performance improvement through experimental measurements on a real mutihop LLN testbed running RPL over IEEE 802.15.4 in comparison to the standard RPL protocol. Test-bed experimental results show that the proposed power control mechanism performs much better than standard RPL protocol in terms of load balancing and packet delivery performance.

VII. FUTURE WORKS

This is our initial work which focuses on showing that LLNs have a power control issue when delivering heavy traffic. Our simple power control algorithm is enough to reveal the power control problem. But, design of a more effective power control mechanism is still an interesting future work.

REFERENCES