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

Minghong Lin, Hyung-Sin Kim, and Saewoong Bahk

Department of Electrical and Computer Engineering, Seoul National University and INMC, Korea

mhlim@netlab.snu.ac.kr, hskim@netlab.snu.ac.kr, sbahk@snu.ac.kr

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 industrial applications such as upcoming Smart Grid service also require LLNs to deliver very high rate traffic. In this paper, we investigate the effect of transmission power control on the performance of routing protocol for LLNs (RPL) at heavy traffic load through testbed experiments. Our study shows that, unlike LLNs in low rate applications, packet delivery performance at heavy traffic load first increases and then decreases with transmission power. It reveals that design of a power control mechanism has potential to improve the performance of LLNs in large scale industrial applications.

Keywords— RPL, low power and lossy networks, transmission power, reliability

Ⅰ. Introduction

Traditionally, low power and lossy networks (LLNs) have considered low rate traffic where use of maximum transmission power can maximize performance by minimizing relay burden and hop distance. Power control has been considered for energy saving rather than performance improvement [1]. However, large scale industrial applications such as upcoming Smart Grid service incur heavy traffic near the root node even though each node generates low rate traffic. It may incur significant amount of link congestion. Our question is: "*use of maximum transmission power still provides the best performance in such a scenario?*"

To investigate this, we study the effect of transmission power on the performance of LLNs constructed by routing protocol for LLN (RPL) [2] at heavy traffic load. Our observations show that, as transmission power increases, packet delivery performance first increases but decreases again. That is, transmission power has potential to be optimized for further improvement of packet delivery performance. To the best of our knowledge, this is the first experimental study which considers the impact of transmission power on RPL-based LLNs.

The remainder of the paper is organized as follows. Section Ⅱ introduces the experimental environments and Section Ⅲ shows the experimental results. Finally, Section Ⅳ concludes this paper and gives some future research directions.

Ⅱ. Experimental environments

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 and deliver data packet to the root node with traffic rate of 40 packets per minute (ppm). This incurs traffic load of 1200 ppm for the root node.

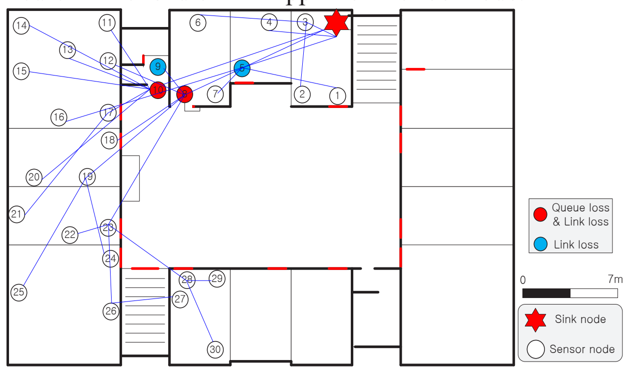

Fig. 1. Test-bed topology map with a snapshot of routing paths given by RPL.

Ⅲ. Experimental Results

A. Packet loss rate

Fig. 2 shows the average packet loss rate of all 30 nodes with varying transmission power. Packet loss rate is used to quantify how reliably a protocol can deliver packets to the destination. The experimental results indicate packet loss rate first decreases but increases again while increasing transmission power. We can see that use of too small transmission power (e.g., -15dBm) decreases network reliability. Interestingly, use of maximum transmission power (i.e., 0dBm) also degrades packet delivery performance. When transmission power is -5.5dBm, we obtain the best performance. Based on this observation, we confirm that transmission power has potential to be optimized in a large scale industrial application which incurs heavy traffic near the root node. We further investigate the reasons of packet loss in the next subsection.

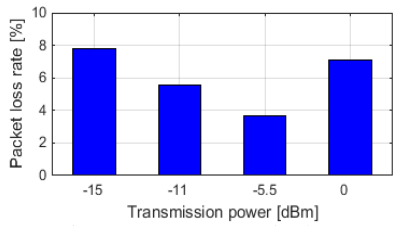

Fig. 2. Tx. power vs. Packet loss rate.

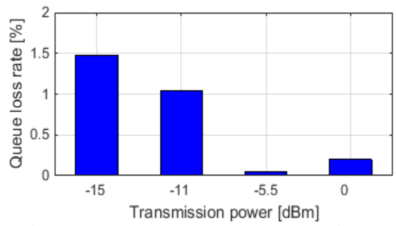

Fig. 3. Tx. power vs. Average queue loss rate.

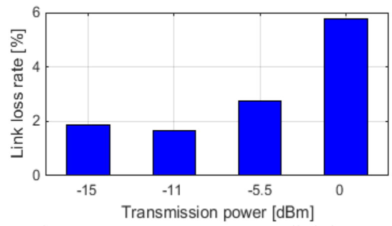

Fig. 4. Tx. power vs. Average link loss rate.

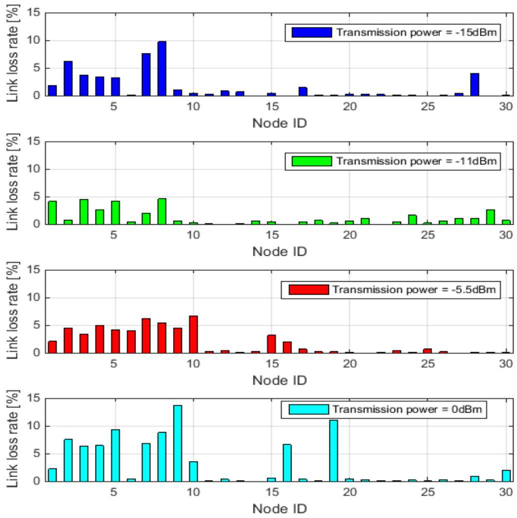

Fig. 5.Tx. power vs. Link loss rate of each node.

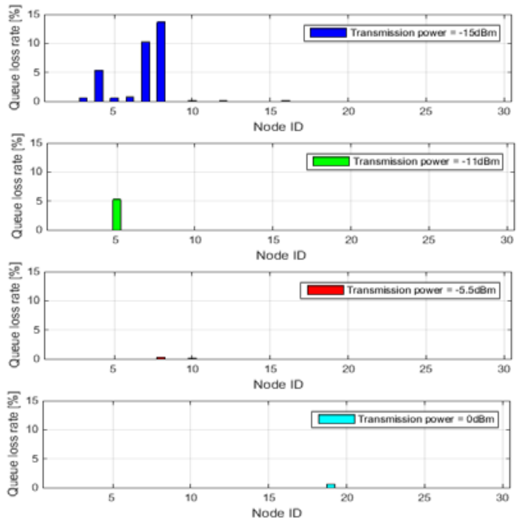

Fig. 6. Tx. power vs. Queue loss rate of each node.

B. Queue loss and link loss

We divide the reasons of packet loss into the following two aspects: queue loss and link loss. We first analyze queue loss 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.

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.

Overall, we confirm that trade-off between link and queue loss makes packet loss rate have a convex curve according to transmission power.

C. Per node analysis

We further investigate the characteristics of queue and link loss by per node analysis. Fig. 5 and Fig. 6 depict link and queue losses of each node with varying transmission power, respectively. Observing the experiment results, we find out that link and queue losses are significantly unbalanced among nodes, which shows the load balancing problem of RPL [3]. Furthermore, queue loss occurs at the nodes which experience severe link loss. 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. Conclusions

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. Our observation gives an intuition that design of a new mechanism which allows each node to adaptively control its transmission power according to its own queue and link losses possibly improves performance of LLNs in large scale industrial applications.

Ⅴ. Acknowledgement

This research was supported by the MSIP (Ministry of Science, ICT & Future Planning), Korea, under the C-ITRC (Convergence Information Technology Research Center) (IITP-2015-H8601-15-1001) supervised by the IITP (Institute for Information & communications Technology Promotion)

Ⅵ. References

[1] S. Lin, et al., “ATPC: adaptive transmission power control for wireless sensor networks,” in Proc. ACM SenSys, Nov. 2006.

[2] T. Winter, “RPL: IPv6 routing protocol for low-power and lossy networks,” 2012.

[3] H. –S. Kim, J. Paek, and S. Bahk, “QU-RPL: Queue utilization based RPL for load balancing in large scale industrial applications,” in *Proc. IEEE SECON*, June 2015.