Poster Abstract: Transmission Power Control in IPv6 Routing Protocol for Low-Power Wireless Network

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ABSTRACT

We present a transmission power control scheme for RPL, the IPv6 Routing Protocol for Low-power lossy network [9], that controls the routing topology to achieve load balancing in a low-power multihop wireless network. We show that higher-than-required transmission power results in congestion and load balancing problems under heavy traffic, and transmission power cannot be optimized for reliable packet delivery when equal power is used by all nodes. To address these issues, we propose an adaptive and non-uniform transmission power controlled RPL, called PC-RPL, that significantly improves the end-to-end packet delivery performance compared to the standard RPL.

1. INTRODUCTION

Low-power and lossy multihop wireless networks (LLNs) can be used in a variety of applications including smart grid AMIs [1][2], industrial monitoring [3], and wireless sensor networks [4][8][6]. In most LLN deployments, transmit(TX) power of each wireless device is selected based on a set of requirements such as transmission range, bit error rate, energy budget, and local regulations. In many cases, highest TX power within the required constraints is selected since users prefer longer range and better reception quality. Moreover, this TX power is used identically on all nodes for simplicity of configuration and management.

However, we argue that an LLN can achieve better packet delivery performance if we use an adaptive and non-uniform TX power strategy. If each node reduces its TX power to be just enough to maintain link connectivity to its next hop node, then the network as a whole will be able to reduce power usage without sacrificing performance. Moreover, this will decrease unnecessary contention to achieve better spatial reuse, and also help alleviate link congestion and facilitate load balancing. Although there has been many theoretical prior work on topology control via TX power control [7], there is little work that provides experimental evidence of its effectiveness on real devices using standard network protocols. Based on this idea, we investigate an adaptive TX power control scheme for RPL, the IETF IPv6 **R**outing **P**rotocol for **L**LN [9].

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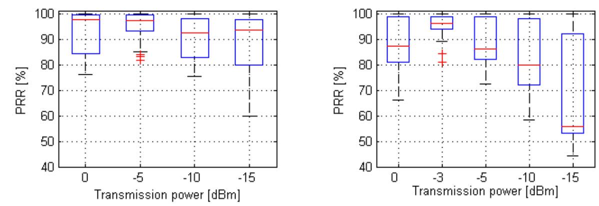

(a) 49-node testbed (b) 31-node testbed

Figure 1: PRR of each node using RPL

Using RPL as the basis, our experiments[1] have shown that (figures omitted for brevity) RPL experiences severe packet losses under heavy traffic due to link congestion and load imbalance. Furthermore, Fig. 1 shows that using maximum TX power is not optimal and smaller power can improve packet delivery performance, but also shows that PRR degrades rapidly when TX power is reduced too much. This is because as TX power decreases, the number of neighbor nodes (and thus link congestion) decreases, but at the same time hop distance increases, which may result in more congestion. This implies that a balance is needed to achieve optimum performance. In addition, tests on multiple topologies have proven that the best uniform TX power varies across topologies, and it is not possible to find one best power configuration for all deployments. Thus, we need a method that can find a good TX power configuration for a given topology at runtime, and better yet, this method should allow each node to find a good TX power autonomously in a distributed manner, thus relaxing the globally uniform constraint.

2. POWER CONTROLLED RPL

To overcome these challenges, we propose *'power-controlled RPL'* (*PC-RPL*). *PC-RPL* running at each node is designed to adaptively select its TX power and RSSI thresholds for topology construction, taking into account the congestion and load balancing status of the network. It does so by controlling the routing path towards the LBR and the local subtree size of the routing topology while maintaining good connectivity and reliability.

2.1 RSSI Threshold Control and Parent Selection

Fig. 2 describes *PC-RPL*'s RSSI threshold control algo-

[1]To study RPL in multihop LLNs, we conducted experiments on a 49-node WSN testbed using *BLIP* IPv6 stack and *TinyRPL* implementation within TinyOS 2.1.2.

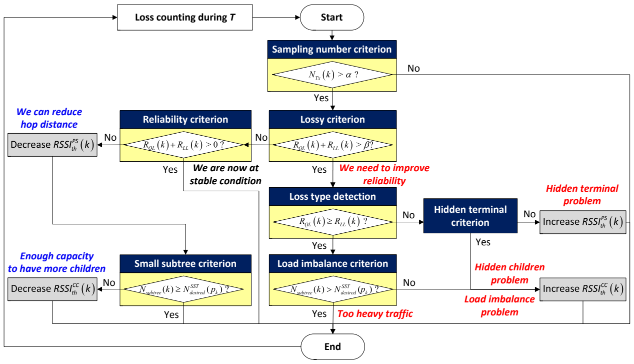

Figure 2: RSSI threshold control algorithm

rithm. Key idea is to have a *'reference RSSI'* value of obtained from reception of DIO messages, and two thresholds for controlling the parent selection and children attachments. $RSSI_{th}^{PS}$ is the *'parent selection RSSI threshold'* that a node maintains and uses for parent selection. $RSSI_{th}^{PS}$ is increased to select a parent with better signal strength when a node is experiencing severe link losses, and it is decreased to select a farther away parent in a hope to reduce hop distance when its link reliability is good. $RSSI_{th}^{CC}(k)$ is the *'children control RSSI threshold'* maintained by each node k, and used by its neighboring nodes for parent selection. $RSSI_{th}^{CC}(k)$ is increased to detach far-away children nodes when a load balancing action is required, but otherwise it is decreased to attract children and provide shorter path length. With these two added constraints, parent selection process of *PC-RPL* is a straight-forward extension of the standard RPL.

However, queue losses can occur even in a load balanced network if traffic rate is too high. In this case, increasing $RSSI_{th}^{CC}(k)$ will only increase hop distance and worsen the performance. To resolve this, we use the desired number of grandchildren nodes (of node k) $N_{desired}^{SST}(k)$, for each child node of node k where $N_{desired}^{SST}(k)$ is calculated from the number of its one hop children nodes and the total subtree size. Node k detects load imbalance when it experiences high queue loss rate and its subtree size $N_{subtree}(k)$ is larger than $N_{desired}^{SST}(p_k)$ received from its parent node.

2.2 Transmission Power Control

After each parent change to parent node p_k, a node k configures its *data packet transmission power* to p_k as,

$$power^{data}(k) = power^{DIO} - \left(RSSI_{\mathrm{ref}}(p_k) - RSSI_{thresh}^{default}\right)$$

where $RSSI_{thresh}^{default}$ is set to the default clear channel assessment threshold. It further adapts the transmission power according to transmission results (successes and failures). Then, this $power^{data}(k)$ allows the node k to use minimum TX power to reach its parent p_k in order to improve spatial reuse without loss of reliability.

3. EVALUATION

We have evaluated the performance of *PC-RPL* on a testbed and compared it against standard RPL and QU-RPL [5]. Preliminary results (Fig. 3) show that *PC-RPL* provides dramatic PRR improvement over RPL, and *PC-RPL* outperforms the best case of RPL and QU-RPL with any uniform TX power. This confirms that the use of non-uniform TX power can achieve better packet delivery performance than using any equal TX power for all nodes. More importantly, *PC-RPL* achieves this performance improvement automatically without requiring a system designer to manually select the transmit power. Finally, Fig. 4 plots a snapshot of the TX power settings selected by each *PC-RPL* node during an experiment. It shows not only that *PC-RPL* constructs a multihop network with heterogeneous TX power, but also that it reduces TX power by -6.21dBm on average while achieving better packet delivery performance.

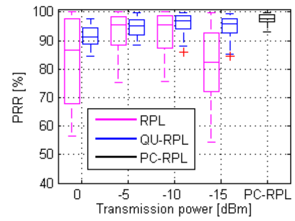

Figure 3: *PC-RPL* vs. RPL PRR comparison at different TX power

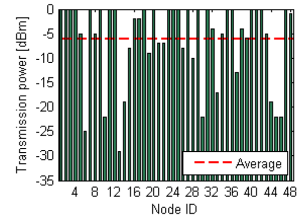

Figure 4: TX power of each *PC-RPL* node during an experiment

4. CONCLUSION

In this poster, we presented an adaptive and non-uniform transmission power control scheme for routing protocol in low-power wireless networks. We were motivated by the fact that a uniform transmission power configuration can be improved for better packet delivery performance. We proposed *PC-RPL* that tackles the congestion and load balancing problem in LLNs by controlling the subtree size of the routing topology via transmission power and RSSI threshold control. Our preliminary evaluation showed that *PC-RPL* alleviates packet losses and achieves significant improvement in end-to-end packet delivery performance compared to standard RPL.

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