RPL Adaptation with Survivable Path Routing for IoT Applications

MANU ELAPPILA[1]
SOUMYA NANDAN MISHRA[1]
SUCHISMITA CHINARA[2]

National Institute of Technology Rourkela, Sundargarh, India

Abstract. Internet of Things (IoT) is a renascence of the Internet that gathers rapid momentum propelled by the evolutions in mobile and sensing devices, wireless communication and networking technologies, cloud computing, etc. IoT solutions are based on low power and lossy networks (LLN). LLN network consists of nodes having limited processing power, memory and battery capacity. The Routing Over Low Power And Lossy Networks(ROLL) group have developed a Routing Protocol for LLN (RPL). Network survivability is an absolute requirement in these scenarios. This paper tries to redesign the RPL protocol to work in congested and interfered network scenarios as in the IoT applications with fast-changing nature of the mesh-like network topology. The proposal modifies RPL to work like the survivable path routing (SPR) that maximizes the survivability of the links between the hops, reduces the energy disparity in the nodes, and avoids congestion at the relaying nodes. For selecting the next hop node, the rank calculation of RPL is done by using three factors called survivability factors (SF), i.e. SF_{energy}, $SF_{inerference}$, and $SF_{congestion}$. Simulation results show that the scheme works better regarding radio duty cycle, network delay and packet delivery ratio.

Keywords: IoT; RPL; Network Survivability; SPR, Energy Efficiency, SINR.

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1 Introduction

If a person is working in the kitchen, he/she may get reminded to take her medicine by blinking a lamp in front of her. When she forgot to have the tablet, the bottle cap goes online and act accordingly, also send a message to her physician to let him know. It can be a perfect example of a typical IoT application scenario. For this to happen, technologically many networking and computing mechanisms have to work together with a common objective, and many sensing and actuating devices have to get connected to the Internet backbone [1]. These small application networks are the instances of the low rate, low power wireless personal area networks or simply LLNs [8]. Protocols should be defined to meet the requirements and specifications that are unique to these cases [2, 3, 12]. The mesh structure is the typical network topology in these IoT application networks [10]. Protocol design should consider the highly dynamic nature of these mesh networks with fast-changing topology structures.

Wireless sensor nodes forming an LLN network have limited processing power, memory, and battery capacity. Traditional routing techniques cannot be well fitted in such topologies[17]. There are several routing protocols developed for IoT based scenarios that work on reliable data transmission from source to destination. RPL [19] is one of the IoT based routing protocols which is designed for low power and lossy networks.

The routing process in RPL starts by forming a Destination Oriented Directed Acyclic Graph(DODAG) topology containing a single root known as DODAG root [13]. Networks can have more than one DODAG's, each identified by a unique DODAG ID. The root broadcasts a DODAG Information Object(DIO) message in the network. Upon the reception of these DIO messages, nodes calculate their rank based on the objective function used in the protocol [16]. RPL nodes choose their parent based on the objective function and the routing information in the DIO message. Nodes use Destination Advertisement Object(DAO) control message to send the destination information upward to the root [7]. RPL uses the Trickle algorithm to decrease the network setup time by reducing the number of control messages transmitted while constructing the DODAG topology [9]. The existing RPL considers only one single routing metric, i.e., either hop count[15] or Expected Transmission Count(ETX)[5] to select a path for data transmission. However, considering only a single metric do not satisfy all the QoS requirements for different applications.

In [18], an energy balancing multi-path RPL modification is presented. It uses node and link metrics to redesign the parent node selection strategy. An energy-equalizing multipath data distribution based RPL for latency reduction is proposed in [20]. B. Mohamed et al. proposed an objective function [11] which chooses a path having a high transition probability. The transition probability is calculated by taking two metrics into account, i.e., transmission delay and residual energy. However, it did not consider the ETX metric for detecting lossy links. So, it may result in choosing inefficient routes. The authors in[14] have combined four routing metrics namely ETX of the link, REC of the link, RANK of a node and minimized delay metric, to select the most optimal path for data transmission. However, the energy consumption of the node has not been taken into account for studying the network lifetime of nodes. The state-of-the-art rank calculation techniques are not considering the survivability metrics of the network in their objective functions. In IoT application networks, it is essential to prolong the topology lifetime and sophisticated services. Hence the rank calculation process and the next hop selection strategy should include the path, link, and node survivability factors into consideration.

In this work, we are trying to adapt the RPL with our previous work the energy efficient survivable path routing protocol (SPR) [4]. Real-time communications are addressed where there are multiple nodes send their sensed data packets to the base station at the same time. Since the RPL by definition is made suitable for modifications, the proposal tries to maximize the survivability of the links between hops, to reduce the energy disparity in the nodes and to avoid congestion at the relay nodes. The rest of the paper is organized as follows. Section 2 explains the details of the proposed work in which the adaptation of RPL with the survivable path routing technique is described. Analysis of simulation results and the comparison with other objective function methods are given in section 3. And finally, section 4 concludes the paper.

2 RPL adaptation with SPR.

The proposed algorithm is a multi-path technique as opposed to the basic RPL. RPL is a single path routing protocol in which, each node saves only the best possible node as the parent. The next hop node towards the root is that parent, and the packets are forwarded to that node. But we modify the RPL functionality such that, each node stores the information about all the possible paths towards the root. If a node receives a DIO message from an upstream node, it will save the rank value according to that parent. When another packet is received, it also stores the rank according to that particular node as in [6]. The rank calculation is done by using a routing metric defined as the Path Choosing Factor (PCF) that is a function of three terms called Survivability Factors (SF), i.e., $\mathrm{SF}_{\mathrm{energy}}$, $\mathrm{SF}_{\mathrm{interference}}$, $\mathrm{SF}_{\mathrm{congestion}}$. The next hop node is selected which has the maximum value for the PCF among all the possible paths toward the root.

$\mathrm{SF}_{\mathrm{energy}}$ (SF_E) is called the path survivability factor which is a metric that describes the survivability of the whole path from the next hop node up to the root. $\mathrm{SF}_{\mathrm{energy}}$ is defined as the ratio of the minimum of the available energies of all the nodes along the path, to the total energy cost to transmit a packet up to the root (base station). Suppose $n_1 - n_2 - n_3 - n_4$ is the path from a node n_0 to the root n_4. Here, node n_1 is the next hop and n_2 is the second hop from n_0 and etc. Let a_1, a_2, a_3, a_4 be the respective available energies and C_{1-2}, C_{2-3}, C_{3-4} are the corresponding energy cost to transmit a packet between two hops. Then for node n_0,

$$SF_{energy} = \frac{min\left(a_1, a_2, a_3, a_4\right)}{C_{0-1} + C_{1-2} + C_{2-3} + C_{3-4}} \tag{1}$$

$\mathrm{SF}_{\mathrm{interference}}$ (SF_I) is called the link survivability factor which is a metric that has information about the interference on the link between a node and its next hop node. Signal to Interference plus Noise Ratio (SINR) is the best such metric to consider. Equation 2 shows the definition of $\mathrm{SF}_{\mathrm{interference}}$. Here $p(T_{e_i})$ is the transmission power of the transmitter T_{e_i} on the link e_i. $G\left(T_{e_i}, R_{e_i}\right)$ is the path gain between the transmitter and receiver of the edge e_i. And $I_f\left(e_i\right)$ is the interference plus ambient noise around the receiver R_{e_i}.

$$SF_{interference} = \frac{G\left(T_{e_i}, R_{e_i}\right) p\left(T_{e_i}\right)}{I_f\left(e_i\right)} \tag{2}$$

$\mathrm{SF}_{\mathrm{congestion}}$ (SF_C) is called the node survivability factor which is a metric that includes information about

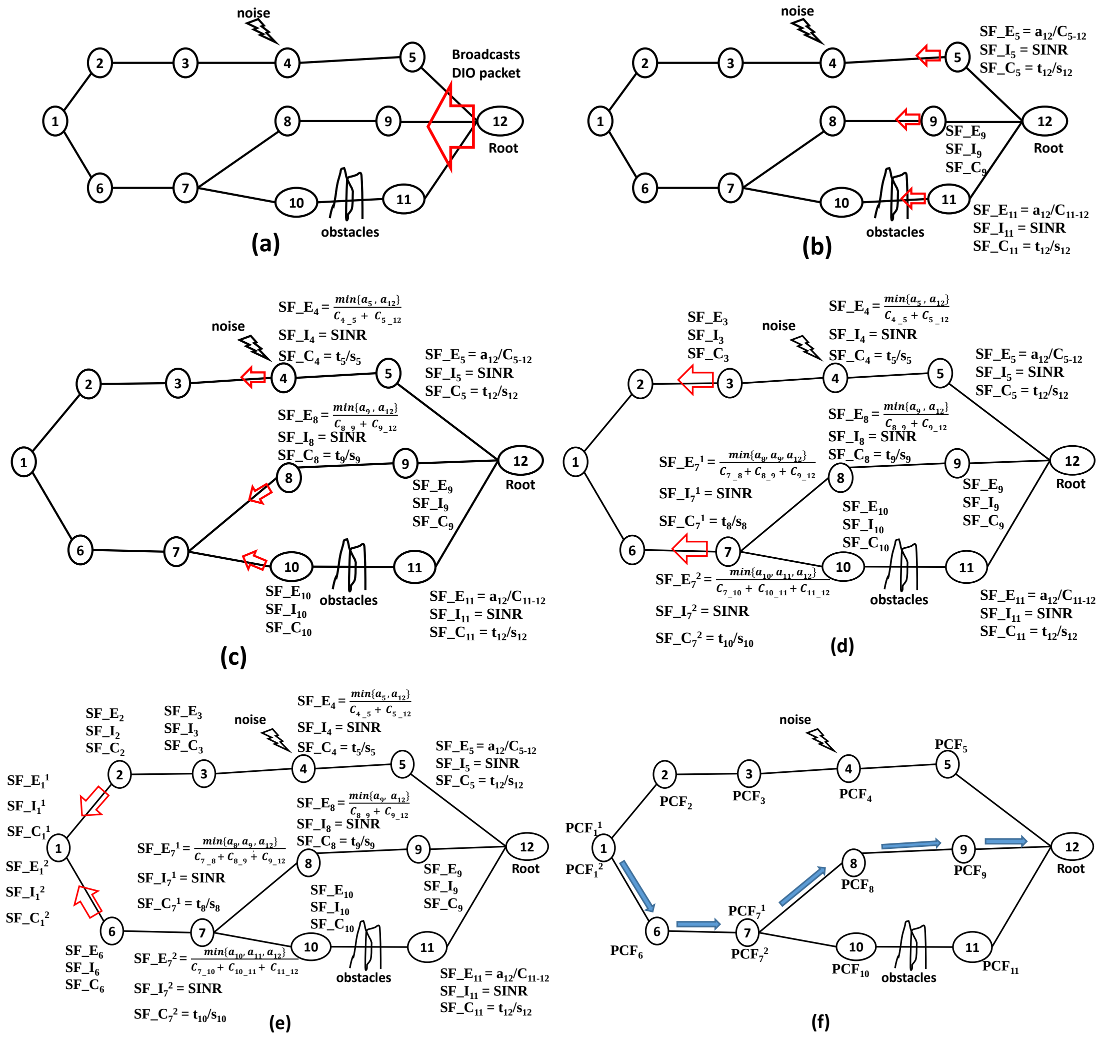

Figure 1: The process of the route set up by the construction of DODAG and the calculation of PCF by its three components

the congestion level of the next hop node. Equation 3 shows the definition of $SF_{congestion}$ where t_i is the input traffic rate of the node n_i, i.e., the number of packets flows into the network interface queue of a node (both application packets and relayed packets). And s_i is the output service rate, i.e., the number of packets flows out from a node to the channel.

$$SF_{congestion} = \frac{t_i}{s_i} \tag{3}$$

At every node, the next hop node is selected from its routing table based on the path choosing factor. PCF is the weighted sum of the above three factors as in equation 4, where α, β, and γ are the weighting coefficients.

$$PCF = \alpha \times SF\_E + \beta \times SF\_I + \gamma \times (1 - SF\_C) \tag{4}$$

Figure 1 shows the process of the route set up. During this phase, each node will become a part of any DODAG in the network and find out all possible paths towards the root. Root node initiates the set up by broadcasting a DIO message. When a child node receives this packet, it calculates the rank of the path through that particular parent. For the rank calculation, the three factors of the PCF are determined first. If there are multiple paths possible for an intermediate node, it stores the rank information separately for all the paths towards the root. During the communication phase, data packets are forwarded according to the stored results. At each node, the best possible route is selected according to the PCF. The path that has the highest rank is chosen for relaying packets towards the destination. Other objective functions in the literature for rank cal-

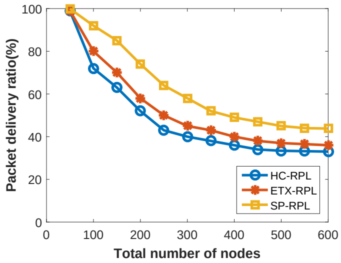

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Figure 2: Packet delivery ratio

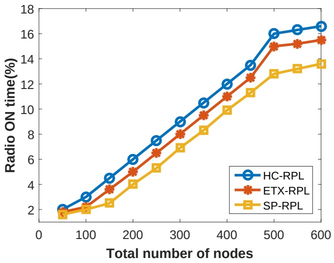

Figure 3: Average radio ON time

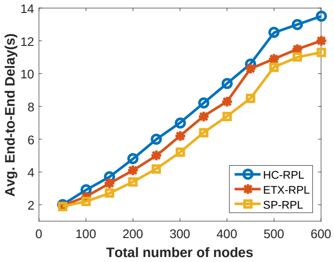

Figure 4: Avg End-to-End Delay

culation (ex: ETX, Hopcount, etc.) are performing by minimizing the rank. But in our proposed algorithm, we calculate the rank by maximizing the PCF. The path that has the highest rank (i.e., maximum PCF) among all the available options is chosen for communication.

3 Experimental Results and Analysis

Simulations are done in cooja simulator by using Contiki OS [21]. The proposed model is evaluated in comparison with the existing variants of RPL protocol, i.e., objective functions OF0 and MRHOF. Deployment area is fixed as 100m X 100m in all simulations. The network size is changed from 100 to 600 nodes to study the performance of the proposed technique in different interference and scalability levels. The total number of nodes are spanned across different DODAGs of sizes below 30 nodes. These small subnets are grounded to their corresponding RPL border routers. The proposed protocol SP-RPL that uses PCF in equation 4 as the routing metric is compared with HC-RPL that uses OF0 objective function with hop count as the routing metric and ETX-RPL that uses MRHOF objective function with expected transmission count (ETX) as the routing metric.

Figure 2 shows the comparison of the packet delivery ratio in three approaches. The SPR adapted RPL (SP-RPL) outperforms the other protocols in all the simulations. The performance is evaluated by changing the number of nodes in the network. To study the effect of interference caused by other nodes on the links, the number nodes those transmit the application packet at the same time instant is also varied from 1 to 10 percent of the total network size. If the channel is more prone to disturbances, nodes have to enhance the transmission power to maintain the signal quality. And the size of the interface queue also increases as the packet collisions increase that may lead to overflow. Hence, by considering interference, energy and congestion factors together, the proposed algorithm is capable of reducing the packet drops in the relay nodes.

In figure 3, it is observed that the radio ON time is lesser for the new protocol as compared to the existing approaches. Radio ON time is defined as the duration of time the radio transceiver of a node be in the ON mode during the total span of simulation. Here the value is taken as the average of the radio ON times of all nodes in the network. When packets are not transmitted successfully, then the node would not get a positive acknowledgment from the receiver, and hence that node will keep doing retransmission. As the packet transmission become successful, the radio transceiver goes to the low-power idle mode. Therefore, the radio ON time can be used as a performance metric to compare the protocols.

Figure 4 shows the average end-to-end delay of the packets received at root nodes. It can be observed from the figure that, the proposed protocol works better to make the packet reach at the destination early. It chooses the less interfered nodes in the path selection or relaying packets towards the destination. It minimizes the collision in the relay nodes and also selects the less congested node to reduce the queueing delay at the hops. Hence, the new algorithm experiences decreased end to end delay for the packets. It can work well in delay constrained networks since it achieves QoS measure also.

Figure 5 shows the node-wise power consumption of a single DODAG in the network for simulations of the three protocols. There is a 12.32% improvement in the average consumed power among the nodes for the proposed protocol as opposed to the existing ones. In figure 6, graphs for the radio duty cycles of nodes are depicted. SP-RPL experiences a 19.36% decrease in duty cycles of the nodes. Moreover, the bar graphs are nearly in the same range for the proposed protocol which suggests that all nodes experience duty cycle and hence consumed power almost equally. That is the idea of network survivability.

4 Conclusion

Routing data over a network comprising of a large number of energy constrained nodes is a significant challenge faced by IoT routing protocols. The devices in these networks are contingent to interfere with each other since they are using radio transceivers and wireless medium for communication. Hence, the routing protocol should consider the link quality, survivability of paths according to the energy disparity and the possible node level congestion before selecting a node for the next hop. These factors are used for the rank calculation and hence for the routing choice selection of the proposed adaptation of RPL with the survivable path routing protocol. Simulation results suggest that the proposed protocol works in the direction of reducing the discrepancy in power consumption and radio duty cycles of nodes, attaining lesser packet drops and reduced network delay as compared with the existing algorithms.

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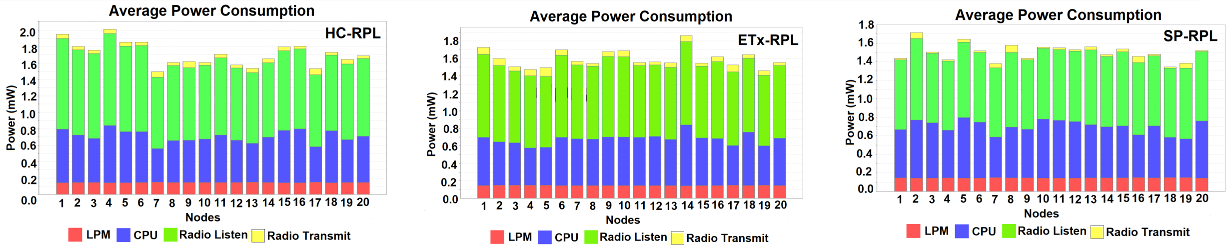

Figure 5: Average power consumption (in low power mode (LPU), processing mode (CPU), and radio listen and transmission) of nodes in the network

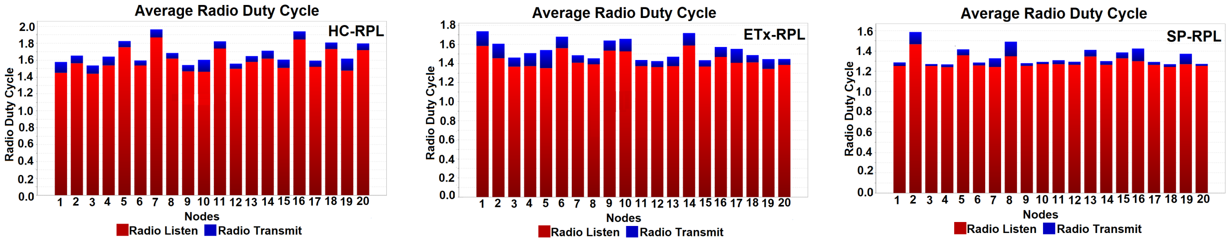

Figure 6: Average radio duty cycle of nodes in the network

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