An Energy-Efficient and Reliable RPL for IoT

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***Abstract*—Routing Protocol for Low-Power and Lossy Networks (RPL) is an IPv6 routing protocol that is standardized for the Internet of Things (IoT) by Internet-Engineering Task Force (IETF). RPL forms a tree-like topology which is based on different optimizing process called Objective Function (OF). In most cases, IoT has to deal with low power devices and lossy networks. So, the major constraints of the RPL are limited power source, network life time and reliability of the network. OFs depend on different metrics like Expected Transmission Count (ETX), Energy, Received Signal Strength Indicator (RSSI) for route optimization. In this work, the ETX and Energy based OF have been evaluated in terms of energy-efficiency and reliability. For one sink and nine senders, the simulated average power consumption is 1.291 mW and 1.56 mW respectively, for ETX OF and Energy OF. On the other hand, the average hop count for ETX OF is 1.89, which is 3.01 for Energy OF. Thus, ETX OF is more energy-efficient but it is not reliable as it takes fewer hops with long distances. Moreover, it does not take load balancing and link quality into account. However, Energy OF is more reliable due to short hops, but it is not energy efficient and sometimes it might take unnecessary hops.**

***Index Terms*—RPL, OF, ETX, RSSI, IoT**

I. Introduction

RPL is the standard networking protocol for IoT. It is designed for IPv6 devices, which is a distance-vector tree-based scheme. RPL works on IEEE 802.15.4 standard with the adaptation layer of 6LoWPAN. RPL works well with communication Protocol like ZigBee and also can be deployed directly to the IoT applications like [1]. RPL forms Destination Oriented Directed Acyclic Graph (DODAG), which is a tree-like topology having leaves at the edges. All the nodes that are included in DODAG are anchored to a single sink node called DODAG root. These DODAGs are collectively called DAG which covers the whole network. Fig. 1 depicts a DAG with one DODAG only.

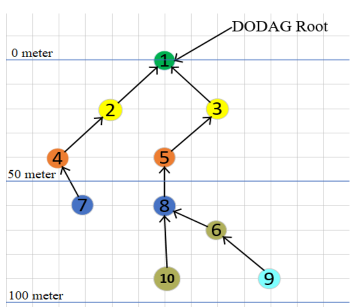

Fig. 1. DODAG with single root

OF determines the routing path in a DODAG by defining the routing metrics, optimization objectives and related functions. There are two OFs standardized by IETF– Objective Function Zero (OF0) and Minimum Rank Hysteresis Objective Function (MRHOF). OF0 uses minimum hop-count to find the route to the root, whereas MRHOF uses ETX as the metric for route optimization [2].

II. Related Works

Mahmud et al. propose improved RPL for better reliability and energy-efficiency of the network [3]. It uses ETX as the routing metric and maintains an RSSI of -86 dBm to reach saturated packet data ratio. It also achieves energy-efficiency with the transmission power control algorithm. However, this protocol does not address the load balancing and the problem due to network congestion. In case of denser network, both OF0 and MRHOF choose long hops, which may restrict the network creating network bottleneck. Sanmartin et al. solves this problem by choosing standard deviation of the ETX of each node as the routing metric [4]. It improves the reliability, energy consumption, latency and life-time of the network but it does not take the link quality and load balancing into consideration. Zhao et al. propose an energy-efficient region-based RPL (ER-RPL) with an aspect of getting energy-efficient data delivery and maintaining reliability [5]. It divides the whole region into few smaller sections. In ER-RPL only a subset of nodes takes part in the route discovery process instead of all the nodes as like most routing protocols. It shows better performances in packet data ratio, hop count, normalized overhead and energy consumption in compared to traditional RPL and Point to Point (P2P) RPL.

III. Simulation and Evaluation of RPL

ETX and Energy are two important metrics for OF. Both ETX and Energy based OF have been evaluated with simulations. Tmote sky mote is used for simulations and they are done in Cooja simulator. Tmote sky supports IEEE 802.15.4 and consists of RF CC2420 transceiver and MSP430 micro-controller. One sink node and nine sender nodes are used in the simulation. The sender nodes are randomly placed as depicted in Fig. 1 for both the scenarios. For evaluation the deployed region is divided into two equal areas. The sink is located on the 0 m line and nine sender nodes are located on the region from 0 m to 100 m line. The senders which are located in the range of 0 m to 50 m are relatively closer to the sink and termed as closer nodes. The senders which are located in the range of 50 m to 100 m are termed as distant nodes. Comparison of the average power consumption for ETX based OF and Energy based OF are depicted in the Fig. 2 and Fig.

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3 respectively for closer nodes and distant nodes. The power consumed by any node in RPL can be broken down into four sectors- (i) Transmit power (Tx power) (ii) Receive power (Rx power) (iii) CPU power (iv) Low Power Mode (LPM) power. In energy based OF, the average power consumption by a node is 1.56 mW whereas the ETX based OF consumes 1.291 mW per node. So, it is evident that the ETX OF is more energy efficient than that of Energy OF.

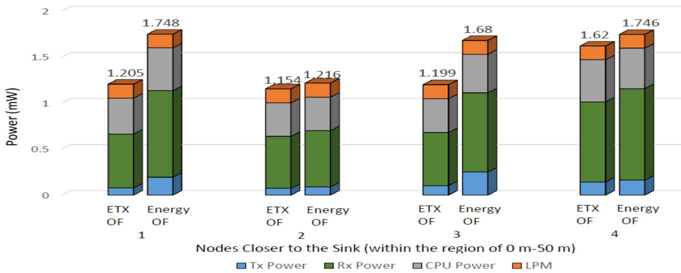

Fig. 2. Comparison of average power consumption for closer nodes

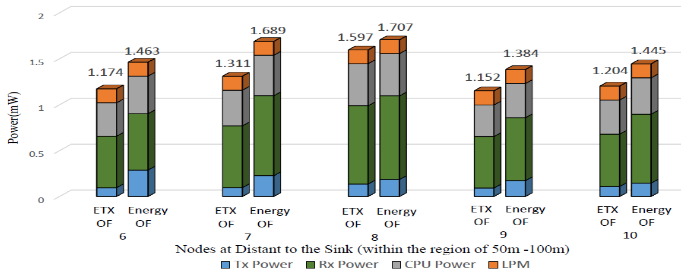

Fig. 3. Comparison of average power consumption for distant nodes

For the closer nodes, average difference of the consumed power between ETX OF and Energy OF is 0.304 mW and for the distant nodes, it is 0.25 mW. Thus, with the increase of the distance of the senders from the sink, energy efficiency of the Energy OF increases in comparison to the ETX OF. The simulated average hop count for ETX OF is 1.89, which is 3.01 for Energy OF. Fig. 4 shows the sensor graph with hops from each sender to the root for both ETX OF and Energy OF. In ETX OF, the highest number of hop is 3, taken by sender nodes 9 and 10. On the contrary, in Energy OF sender nodes 6, 8 and 9 take the highest number of hop which is 5. The ETX OF always takes the path with the lowest ETX total, thus may end up taking less number of hops with long distances. ETX OF does not take the link quality (in terms of RSSI) into account. Thus these long hops may degrade the reliability of the network by decreasing the throughput. The long hops in dense networks may also create the network bottleneck.

The percentage break down of the power consumption of both ETX OF and Energy OF are depicted in the Table 1. Even though the percentage of Tx and Rx power of Energy OF is higher than that of ETX OF, the percent LPM and CPU power consumption in Energy OF is lesser than that of ETX OF. This happens because Energy OF always chooses the next hop which consumes lower energy, thus end up taking

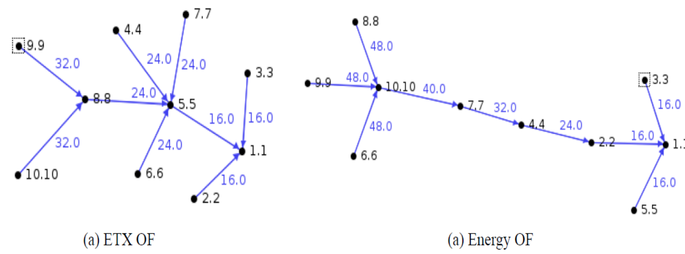

Fig. 4. Network graph showing number of hops to reach root

TABLE I
PERCENT BREAK DOWN OF ENERGY CONSUMPTION FOR ETX AND ENERGY OF

ETX OF		ENERGY OF	
Tx Power	7.99%	Tx Power	12.17%
Rx Power	50.07%	Rx Power	51.47%
LPM Power	11.15%	LPM Power	9.63%
CPU Power	30.18%	CPU Power	26.72%

more number of hops with smaller distances in any route in compared to the ETX OF. Though Energy OF increases the reliability of the network by discarding long hops but it decreases the energy efficiency. It may also take unnecessary long routes. So none of the OFs can offer both reliability and energy efficiency at the same time.

IV. Conclusion

The evaluation of the ETX OF and Energy OF showed that none of them can ensure both the energy-efficiency and reliability at the same time. The ETX OF is more energy-efficient than Energy OF. But it does not take load balancing and link quality into account. On the contrary, Energy OF takes the least amount of energy in every hop but takes more number of hops in total to reach the root. It is power-hungry and may also take longer routes unnecessarily. Thus, we expect to propose a hybrid OF which is based on both ETX and Energy. It expects to do the load balancing and eliminates the chance of network bottleneck. The reliability and network life-time are also likely to be improved with better link quality in terms of RSSI.

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