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Abstract—Equalizing energy consumption among sensor nodes within Wireless Sensor Networks (WSNs) is an important technique that can be used to prolong the network lifetime. Routing Protocol for Low Energy and Lossy networks (RPL) is a dedicated protocol for this type of networks of poor energy resources. In RPL there is only one routing metric that can be used at once in its Objective Function (OF); either reliability or saving energy of parent nodes. In the case of considering the reliability which is represented by Expected Number of Transmission (ETX) that will usually lead to unbalance energy distribution among nodes. On the other hand, when energy is being considered without taking into account the reliability of links, many packets might be lost. In this paper, an experimental study was conducted over two modified version of RPL that address issues of energy distribution among nodes with consideration of reliability network with less EXT. Cooja simulator was used for simulation purposes. The results obtained show that the distribution of energy consumption among nodes were achieved which in turn prolong the network lifetime.

Keywords- Internet of Things; Routing; energy; Wirless Sensor Network.

I. INTRODUCTION

Our lives witnessed a wide spread of applications for Internet of Things (IoT) in last few years. IoT applications vary from smart cites, smart homes, transport systems, healthcare systems, and many others. Many studies claimed that the societies in future will be completely connected to the Internet [1]. Smart objects, devices, and equipment would be connected into many inter-connected networks [2]. Wireless Sensor Networks (WSNs) is one of the key enablers for many of IoT applications [3]. The information that are collected by sensor nodes are exchanged with base station or sink node that in turn is connected to the outside world. Nodes in WSNs usually have limited energy resources because they usually run on batteries. Accordingly, prolonging lifetime of such type of networks is a great demand. Energy is a scarce resource in most WSN applications since charging of batteries is either not convenient or impossible and this impose efficient usage of nodes energy to lengthen the lifetime of the network [4]. Consequently, WSN protocols must be energy efficient.

Energy saving in WSNs is a dominant research topic. In addition, routing in WSNs is an important issue due its relation to the energy saving in WSNs. Routing aims to select the optimal path from source to destination within less time frame and less energy. For networks with poor energy resources a Routing Protocol for Low Energy and Lossy networks (RPL) was introduced with different metrics that can be involved in its Objective Function (OF). Mainly, there are two types of OF: Objective Function Zero (OF0) and Minimum Rank with Hysteresis Objective Function (MRHOF). In OF0, parent nodes will be chosen to achieve minimum hop count to the destination. On the other hand, MRHOF selects parent node so that Expected Number of Transmissions (ETX) will be minimized [5, 6].

There were many approach that have been proposed in the literature to develop other or modify these objective functions of RPL since the traditional RPL considers only one routing metric either reliability which is represented by ETX or the remaining energy of parent nodes. In the case when reliability is used, unequal energy distribution among nodes will occur. As a result, some nodes will exhaust their batteries faster than others. On the other hand, if energy is used as a routing metric without taking into account the reliability of path, many packets might be lost.

Many researchers consider lowest energy path as a routing metric but nodes in this path will exhaust its battery faster than the other nodes; because at each time the same path will be chosen as a route to the sink node. Eventually, the lifetime of network will be minimized because of unbalanced distribution of energy which leads to the network loses its functionality if one of nodes at least drained out its battery (communication with sink node is lost). In this paper, an experimental study was conducted over two modified version of RPL that address issues of energy distribution among nodes with consideration of reliability network with less EXT.

The paper is organized as follows. A background about RPL protocol is presented in section Two. Most recent RPLs improvement were discussed in section Three. A modified RPL implementation and experimental results and discussion are presented section Four. Finally, conclusion and future work are drawn in section Five.

II. RPL BACKGROUDND

There are many research themes in different areas of WSN in the past two decades, especially WSN routing protocols aiming at energy saving and WSNs reliability. Routing in WSN aims to select the optimal path from source to destination within less time frame and less energy. For networks with poor energy resources, the RPL was proposed by IETF workgroup with different metrics that could be used in the Objective Function (OF) [7, 8].

RPL is a distance-vector routing protocol design to operate on top of link layer mechanism targeting IPv6 networks [9]. RPL presents a mechanism to distribute messages over the dynamic formed network topology, which uses Trickle to optimize the distribution and messages and to increase the network lifetime.

RPL forms a data structured called Directed Acyclic Graph (DAG) to establish bidirectional routes between sensors. RPL is essentially intended to exchange data between each (RPL) node and a particular node, called sink node. Sink node operates as a common transit point that bridges the WSNs with the IPv6 networks. RPL organizes its topology as Destination Oriented DAG (DODAG). DODAG is a tree-like structure with a root node. Each node in the tree (other than root node) has at least one parent with a role of relaying message to the root node. Message will be routed from leaves toward root node with no cycles of information. To enable leaves nodes from selecting their parents, parent nodes will send DODAG Information Object (DIO) message downward to possible children. Destination Advertisement Object (DAO) is sent upward in the graph and have information about reachable destination by sent node. DODAG Information Solicitation (DIS) will be sent in the case the DIO message did not reach node within a certain period of time. In the case of having more than one parent, the OF will choose between them, which will used in this paper as part of evaluation method in experimental results.

Numerous routing metrics have been projected to improve lifetime of network, to maximize the reliability, or to minimize the latency [10. 11,12]. In this paper, the focus more on the energy saving routing metrics targeting the improvement of the network lifetime.

III. RELATED WORK

The main motivation behind RPL is to select optimal path to the sink node. A typical RPL can consider only one routing metric at a time: Either hop count, ETX, or remaining energy. In [6] higher remaining energy of candidate parent node is considered as a routing metric. Considering energy consumption of node with neglecting the reliability of link which sometimes will lead to many packets losses, as a result many retransmissions will be required.

The authors in [7] recommended to use the best link quality as a routing metric, where nodes on the same route to the destination will be chosen every time. Consequently, nodes on this route will deplete their energies faster than other remaining nodes. As a result, network will lose its functionality of forwarding data to the sink node.

The authors in [13] presented an improvement of RPL that is based on considering both the ETX and residual energy of parent nodes as a routing metric. This combination achieved its target and prolonged the overall lifetime of network by 12% compared to traditional RPL. A composite energy aware node metric (RERBDI) was proposed in [14]. RERBDI rely on both the residual energy ratio (RER) of the nodes and a battery discharge index (BDI) during RPL routing decisions. However, they also defined a new objective function (OFRBE), which depends on both the composite node metric RERBDI and the sink quality metric ETX for node parent selection and rank computation, as a result network life time and packet delivery ratio were enhanced.

Two objective functions: Parent Energy Objective Function (PEOF) and PEOF2 were suggested in [4]. The two objective functions are based on ETX and residual energy of parent nodes. With one difference of considering residual energy of one hop parent node for PEOF and considering residual energy of all nodes along path to the destination for PEOF2. PEOF has a drawback, where optimization of energy distribution is local without considering overall energy of network. This is because it considers remaining energy of one hop parent. This problem is solved by PEOF2 because it takes into account the remaining energies of all parent nodes until reach sink node. In addition, good results of equalizing energy distribution among nodes was achieved; so that prolonging lifetime of network.

An improved version of RPL was introduced in [14], where RPL is based considering many factors such as: link quality, node energy, throughput, congestion detection factor, and data rate. A multipath scheme was proposed also to solve congestion problem. Good results of saving energy consumption, improving packet delivery ratio, and minimizing end-to-end delay was achieved.

An energy awareness routing approach was propose in [15], which is a cluster based WSNs. The approach is based on a clever policy of cluster head (CH) selection, remaining energy saving of the CHs and the intra-cluster distance for cluster members. To ease data routing and show some balance in energy consumption, authors used a directed virtual backbone of CHs is developed which is rooted at the sink.

A joint duty cycle scheduling algorithm was proposed in [16] which is an energy aware routing approach and also based on evolutionary game theory that is called DREG. the approach is based on make trade of tuning between energy saving and the network delay, to improve the the network lifetime. The paper is divided into the following sections: The scheduling approach is based on wakeup/sleep scheduling problem with multiple objectives is formulated as an evolutionary game theory or as in RPL objective function used in this paper. The, the evolutionary game theory is tuned to to find an optimal wakeup/sleep scheduling policy, based on a trade-off between network throughput and energy efficiency for each sensor in WSNs.

IV. SIMULATION AND EXPERIMENTAL RESULTS

Our methodology is based on the energy-efficient oriented routing algorithm similar to what have been proposed in [13]. As mentioned before the main idea is to study the effects of objective functions in RPL on energy consumption and trying to have an equal distribution of energy among node in WSN. The modifications implemented in RPL involve altering the objective functions.

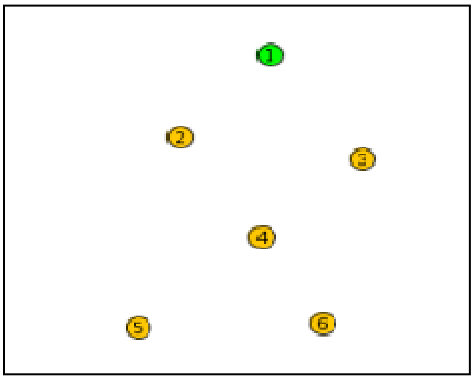

Fig. 1: WSNs Topology

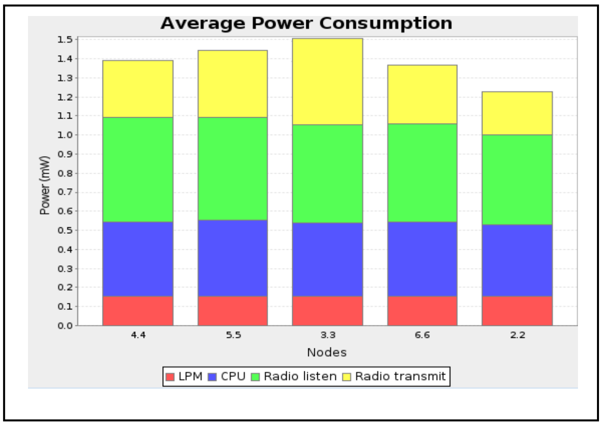

Fig. 2: Average Power Consumption

The ETX will be reduced by changing the ETX_SCALE constant from 100 to 1000. Altering this constant through equation (1) will reduce the overall new_etx value. The experiments show that link quality is improved.

$$
\begin{aligned}
new\_etx = & ((uint32\_t)recorded\_etx \\
& * ETX\_ALPHA \\
& + (uint32\_t)packet\_etx \\
& * (ETX\_SCALE \\
& - ETX\_ALPHA)) \\
& / ETX\_SCALE
\end{aligned} \quad (1)
$$

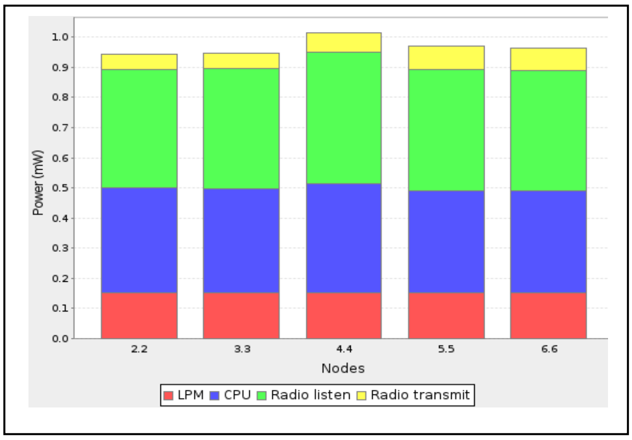

Fig. 3: Average Power Consumption based on new_etx

We used Cooja simulator under Contiki 2.7 operating system to implement two modified RPL versions and evaluate the energy consumption. The first WSN topology used is illustrated in Fig. 1. The experiment simulation time was 23 hours.

Fig. 2 show the average power consumed at each node. As we can see that the average energy consumption of the nodes vary between 1.2 to 1.5. Moreover, the min and max consumption value are for the nearest two nodes for the sink. This means that the energy consumption is not balanced among nodes in the network.

Table 2: Average energy with ETX, received packets and lost packets of network in figure3.

Node	Energy	ETX	Received packets	Lost packets
2	1. 454	24	13	0
3	0. 955	16	13	0
4	1. 426	24	13	0
5	1. 906	16	13	0
6	1. 184	25	14	0
7	1. 5	16	12	0
8	1. 325	24	13	0
9	1. 97	16	13	1
10	. 952	40	12	1
11	1. 076	32	14	1
12	1. 398	24	14	0
13	1. 173	32	15	0
14	1. 128	40	13	0
15	1. 243	32	13	0
16	1. 091	40	12	0
17	1. 210	35	15	0
18	1. 263	42	14	0
19	1. 055	32	14	0
20	1. 485	24	13	0

Fig. 3 show the new results after applying the new ETX_SCALE and change it from 100 to 1000. In the new results, we can see that most of the nodes consumption are within 0.1 mW rather than with 0.3 mW in Fig. 2. Moreover, the nearest two nodes to the sink have approximilty equal consumption. The average energy, ETX, received packets and lost packets are also shown in table 1. Please note that the lower value of energy consumption are due to lower simulation time not due to new_etx value. As seen in table 1, the experiments shows that packet delivery with 100% ratio which mean zero packet loss. The new ETX of node 2 and 3 are reduced to 16 regarding this change.

In the following experiment, we changed the topology as shown in Fig. 4. Before we provide the new results we discuss the location of the sink between Fig. 1 and Fig. 5. In Fig. 1, node 4 has the greater power consumption because it is the intermediate node between all nodes. Nodes 5 and 6 need to transmit to node 4 in order to reach sink node, also node 4 needs to choose which is next hop to reach sink. We can achieve an improvement to this situation by changing the position of sink node to be as in Fig. 5. In this case the power consumption of all nodes is nearly equalized as Fig. 6 shows.

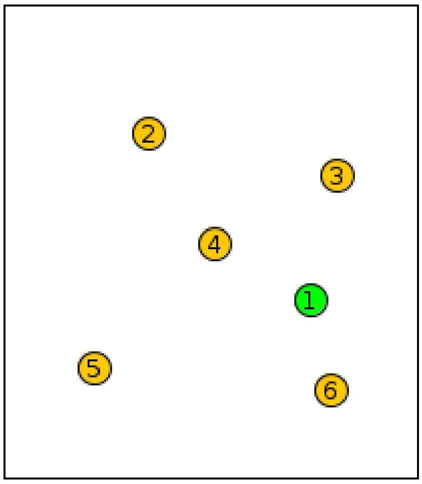

Fig. 5: The modified topology of Fig. 1

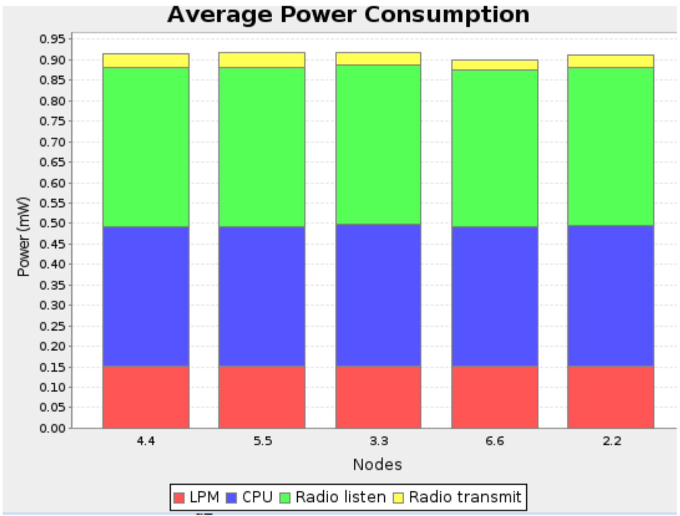

Fig. 6: Average power consumption for the topology of Fig. 5

One other development was to reduce value of ETX_ALPHA of new_etx equation to 40 instead of 90, and let the ETX_SCALE remaining the same as its original value. This change was applied to the topology of figure (2). We noticed that the power is nearly equalized among node 2 and 3 as figure (9) illustrates.

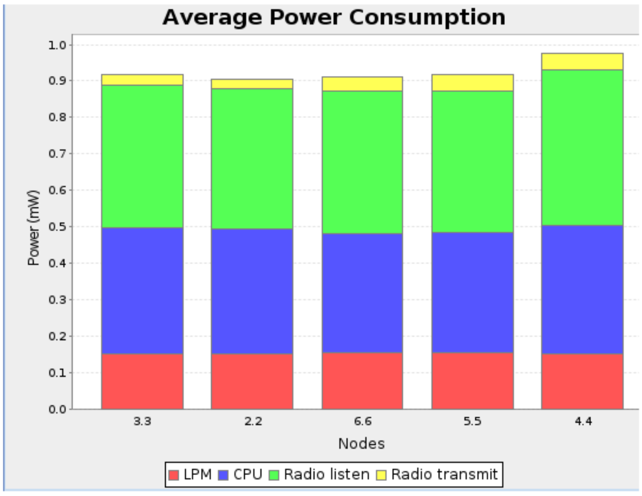

Fig. 7: Average Power Consumption after changing the etx_alpha to 40

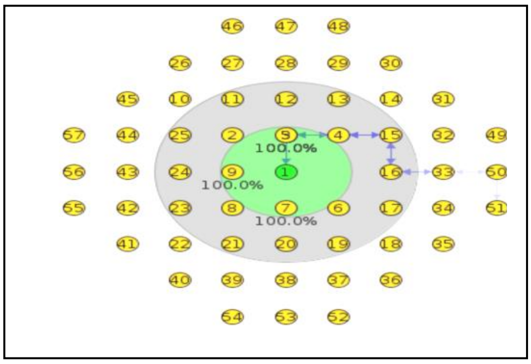

Fig. 8: Symmetric Network with 57 nodes

In the following experiment, we used similar topology as used in [4] to be able to compare our results to their results. The topology consists of 57 nodes, with node 1 is sink node, where network is symmetric illustrated in Fig. 8.

Changing preferred parent is occurred when min-diff between ETX of two candidate parents is more than threshold value (from 10 to 20), where node will not change to the best parent node, and ETX value will increased. The experiment shows that there will be many transmissions and retransmissions with increasing of energy consumption. Alternatively, Threshold value was set to 2. In this case, the min-diff is always greater than (PARENT_ SWITCH_THRESHOLD_DIV) value. Thus, node will always choose the best parent. In one hand, there is no lost packets. The packet delivery ratio is 100%. On the other hand, many parent switching occurred to select best parent in all times. As a result, ETX is high and also the energy consumption is high too as seen in Fig. 9. In accordance to save energy, which can be slightly reduced by setting threshold value for example to 9. This will reduce lost packet and increase packet delivery ratio with an acceptable energy consumption.

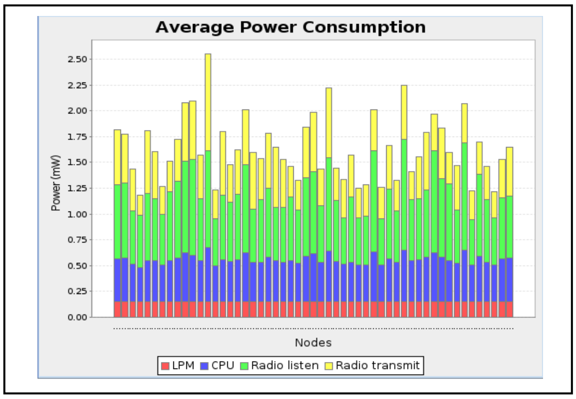

Fig. 9: Average Energy consumption With Threshold 2

V. CONCLUSION

Energy saving in WSNs is an imperative issue due to limited energy resources of nodes with WSNs. RPL is a dedicated protocol for WSNs which considers only one routing metric at a time either reliability represented by ETX or remaining energy of parent nodes. Researchers tried to combine both of them in one routing metric as a development to RPL. In the case of reliability, which is used without considering energy consumption of nodes, there will be unbalance in energy distribution among nodes in network. Although, if energy is considered without looking to the reliability, the packet delivery ratio will not be improved. In this paper, an experimental study was conducted to evaluate two RPL modified algorithms through coordination the objective function to equalize energy distribution among nodes in WSNs. As noted, the value ETX_SCALE and ETX_ALPHA of new_etx equation, and THRESHOLD lead to efficient energy through equalizing energy distribution among nodes in WSNs. Threshold value proved that can used to improve reliability through increasing packet delivery ratio in WSN.

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