DOI: https://doi.org/10.33103/uot.ijccce.19.1.9

Routing with Energy Threshold for WSN-IoT Based on RPL Protocol

Sarah Ammar Rafea[1], Abdulkareem Abdulrahman Kadhim[2]
[1] *College of Information Eng., Al-Nahrain University, Baghdad, Iraq.*
[2] *College of Engineering., Al-Nahrain University, Baghdad, Iraq.*
sara.ammar@coie-nahrain.edu.iq, abdulkareem.a@coie-nahrain.edu.iq

Abstract— Internet of Things (IoT) enables things to have connectivity through the internet. The number of things is growing fast and has to be uniquely identified through the Internet to communicate with other things. In Wireless Sensor Networks (WSNs) each node can be considered as a thing. WSN node resources are very limited due to the need to communicate using low power and usually through unreliable links. Such limitations need an energy efficient routing protocol. WSN is considered as a type of Low power and Lossy Network (LLN). The routing protocol for low power and lossy network (RPL) is being adopted for LLN and has been standardized to enable connectivity of WSN over IoT. RPL constricted a topology similar to tree topology. Nodes in RPL optimized its path using an objective function (OF). OF depends on different node/link metrics in the optimization process. In this paper, an Energy Threshold RPL (ETRPL) protocol is proposed. ETRPL depends on a new objective function to enhance energy consumption of RPL protocol by taking into account the remaining energy of the preferred parent node. ETRPL is implemented using Cooja simulator. The results show that ETRPL provides an increase in the remaining energy of at least 87.4% for a small area with high number of nodes. ETRPL also performed better with regards to Time Delay, Packet Reception Ratio, and the number of dead nodes in a small area. For a large area, the performance is not encouraging. Thus the proposed ETRPL protocol is useful for IoT networks with relatively small areas.

Index Terms— Routing protocols, Wireless sensor networks, Internet of Things, RPL, objective function, Cooja.

I. INTRODUCTION

IoT is a technology that enables the intelligent objects (things) to collect and exchange data through the internet in the existing network infrastructure for different purposes. Things refer to any physical object with a device that has its own IP address and can connect to a network to send/receive data via network. According to CISCO estimation, the number of connected devices with each other through IoT will increase to about 50 billion devices by 2020 [1]. These huge number of devices need to be connected by an efficient routing protocol to guarantee prolonged life time of the IoT network.

WSNs distribute hundreds to thousands of inexpensive micro-sensor nodes in their areas, and these nodes are fundamental parts of IoT. The sensor nodes in WSNs are small devices, low-cost and low-power, equipped with limited sensing, data processing, and wireless communication capabilities [2,3,4]. The main goal when developing a routing protocol for WSNs is the reduction of energy consumption for each node [5]. WSNs are types of LLNs which are resource constrained in terms of battery life time, memory and processing power [6]. In March 2012, IETF standardized a routing protocol to implement IoT over WSN called routing protocol for low power and lossy network (RPL)

Received 22 Sep 2018; Accepted 4 Dec 2018
 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

[7]. RPL is a proactive protocol based on ipv6 to accommodate huge number of things because ipv4 is not enough to uniquely identified things. RPL is designed to meet requirements of wide range of applications such as smart city applications, industrial applications, medical applications,…etc [8,9]. RPL used an objective function to select the optimal path. This objective function should be designed to satisfy the target of application. The objective function can use the link metrics and node metrics to specify cost for each path [10].

The behavior of RPL protocol is investigated and evaluated using Cooja simulator in fixed and mobile sink environments in 2015 [11]. Twenty five nodes are deployed randomly in 100mx100m area. The work revealed that fixed sink LLNs performed better in terms of average power consumption, latency and packet delivery ratio. The results demonstrated also that RPL protocol is sensitive to mobility due to the increased number of isolated nodes. In another work, the RPL broadcast mechanism using Cooja in medium density network using two objective functions in grid and random topologies is also investigated [12]. The results showed that RPL performed better when the network density is between 50 to 65 nodes in grid and random topologies [12]. A comprehensive study covered the effects of the two objective functions used in RPL; the Minimum Rank with Hysteresis Objective Function (MRHOF) and Objective Function zero (OF0) using Cooja simulator in Contiki operating system on the performance. Different network topologies, number of nodes and transmission ranges were considered. The results showed that OF0 usually performed better than MRHOF in terms of energy consumption, listening duty cycle, and transmit duty cycle [13].

Expected Transmission Count (ETX), which is the number of retransmissions required over a given path, and Received Signal Strength Indicator (RSSI) are used to enhance the RPL protocol performance [14]. An algorithm is suggested to control the transmission power of a given node with respect to distance. The algorithm is also tested using Cooja simulator with two nodes. Different objective functions, such as hop count, ETX and RSSI-ETX in large scale network (from 200 to 600 nodes), are investigated. As a result, it is found that the mean end to end delay is decreased when using hop count objective function with a greater packet delivery ratio when using RSSI-ETX objective function. Such results are obtained when using OMNET++ simulator [15].

IoT rout selection based on fuzzy logic is proposed for objective functions in comparison to the existing one using Cooja simulator with 11 sensor nodes, 1 sink node, 2 tags (RFID) and 2 reader nodes (RFID) [16]. An improvement in lifetime of the network by about 30% is claimed. The energy consumption, delay, and packet delivery ratio of the existing OF (i.e OF0 and MRHOF) are measured. A new route metric is suggested to solve the bottleneck problem in dense network [17]. It is called SIGMA-ETX which is used to optimize both existing objective functions OF0 and MRHOF by calculating the standard deviation of ETX value rather than the average value. SIGMA-ETX performed better in terms of packet delivery ratio, power consumption, lifetime and network latency as compared to legacy RPL protocol [15].

In 2018, many searches used the energy as a metric parameter together with other metrics. Stability study for RPL is presented using two different objective functions; the link metric MRHOF-ETX and node metric MRHOF-Energy in Cooja simulator with 30 nodes [18]. The results show that the energy consumption is decreased by about 28% when using MRHOF-Energy objective function, but the stability of MRHOF-Energy is lower than that of the MRHOF-ETX by about 1.3% [18]. An objective function for Smart Grid applications is proposed and called Quality of Service differentiation (OFQS) [19]. Both the delay and energy metrics are used to select the optimal path. The use of OFQS increased packet delivery ratio, prolonged network life time, and decreased the delay.

In this paper, Energy Threshold RPL (ETRPL) protocol is proposed to improve the energy consumption and therefore prolonging the life time of the network. ETRPL protocol combines ETX as a link metric with energy as a node metric to define the proposed objective function.

Received 22 Sep 2018; Accepted 4 Dec 2018

ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

The rest of this paper is organized as follows. Section II presents RPL in details. In Section III, the proposed objective function is introduced. The performance evaluation of RPL and ETRPL is given in Section IV. Finally, the main concluding remarks are presented in Section V.

II. Routing protocol for low power and lossy network

The routing protocol for low power and lossy network (RPL) is a tree-like topology called Destination-Oriented Directed Acyclic Graphs (DODAG), which is Directed Acyclic Graphs (DAG) with one destination root as shown in FIG. 1 [20,21]. The main difference between DAG and tree is that the leaf in DAG can rout to multiple parents. This formation of network generates loops, so ranking is used to define position of node relative to other nodes with respect to a DODAG root [20].

RPL nodes can be root, router or leaf node. Root node is a special node programmed to be a destination of all others nodes and it is considered as a border router. Router node forwards data packets from its child to root. Leaf node on the other hand just sends its data to preferred parents [7,10]. RPL network can have more than one DODAG. Instance ID is used to identify each DODAG. Each instance can use different OFs [7]. Further, RPL supports three types of traffic, which are point-to-multipoint (P2MP), multipoint to point (MP2P) and point to point (P2P) [24].

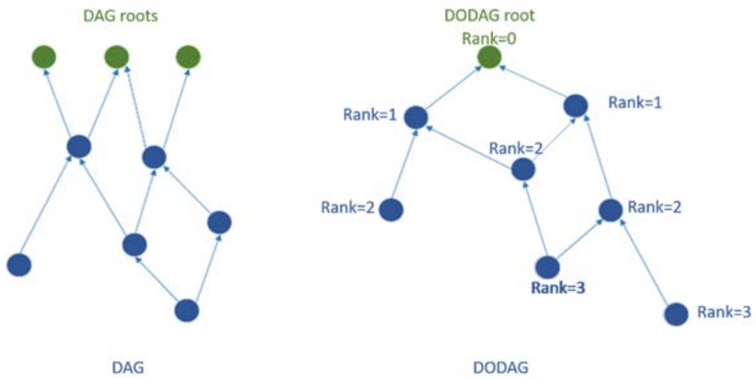

FIG. 1. RPL DAG AND DODAG.

A. RPL Control Messages

RPL used four types of control messages which are [20,22,23]:

- DODAG Information Object (DIO) that contains routing metric and OF to be advertised to all nodes to allow nodes to discover RPL instance, learn its configuration parameters, and select a DODAG parent set.
- DODAG Information Solicitation (DIS) which is used by any node that wants to join DODAG when no announcement is heard.
- Destination Advertisement Object (DAO) that requests child to join a DODAG. In storing mode, DAO is unicast to selected parents. In non-storing mode, it is unicast to the DODAG root.
- Destination Advertisement Object (DAO-ACK) is an acknowledgment message sent by a DAO recipient.

RPL used upward routing and downward routing to build its topology. The node used DIO message to construct its path upward to root and DAO message in downward routing. RPL supports two modes of operation in downward traffic, which are storing and non-storing modes. In storing mode, the node saves the whole routing table unlike the non-storing mode. Root is always storing, and all other nodes are either storing or non-storing for an instance [25].

Received 22 Sep 2018; Accepted 4 Dec 2018
 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

B. Trickle Timer

RPL used a mechanism to detect and respond to network inconsistency and instability. The instability includes detection of routing loops, first time joining a DODAG, and rank change of a node. This mechanism is known as trickle timer mechanism used by DIO message [26]. A trickle timer also determines the frequency of sending messages in the network [15].

C. RPL Topology Construction

The topology construction of RPL network starts when root multicasts DIO message. Each node receives DIO message from root will set root as a preferred parent, calculate rank, calculate path cost, and send DAO message to root. Each node then multicasts a DIO message with a new parameter. Each node used an objective function (OF) to calculate its rank and path cost to root to select its preferred parent.

D. RPL Objective Function

RPL selects optimal route, constructs DODAG topology and calculates rank of each node based on OF [12,27,28]. OF used link metric and/or node metric to determine the optimal parent to the node and to calculate rank. Two objective functions are used; OF0 [27] and MRHOF [28]. OF0 uses hop count as a metric to determine the best path which is the nearest path to root. MRHOF uses ETX to compute the best path to root [29]. RPL can use other metrics such as energy, and received signal strength indicator (RSSI) [30].

In the case where OF0 is used, the selected path is according to the hop count to root. Fig. 2 is used to demonstrate the protocol operation for given network nodes scenario as an example. Node 5 in Fig. 2 chooses node 3 as the preferred parent because there is 2 hops from node 5 to node 1 through node 3 rather than other paths. Two problems can be noted here. The ETX value for the path is high 5.5 which means that the quality of the link is low. In this case, nodes 3 and 5 will resend packets and consume node energy while the quality of paths through node 4 is 3 for both paths 5-4-3-1 and 5-4-2-1 and may consume less energy even the number of hops is 3. The other problem is that node 4 can choose node 2 or node 3 as the preferred parent randomly. In this case node 3 is the preferred parent for node 4, thus the energy of node 3 will be consumed faster while node 2 still has a lot of energy.

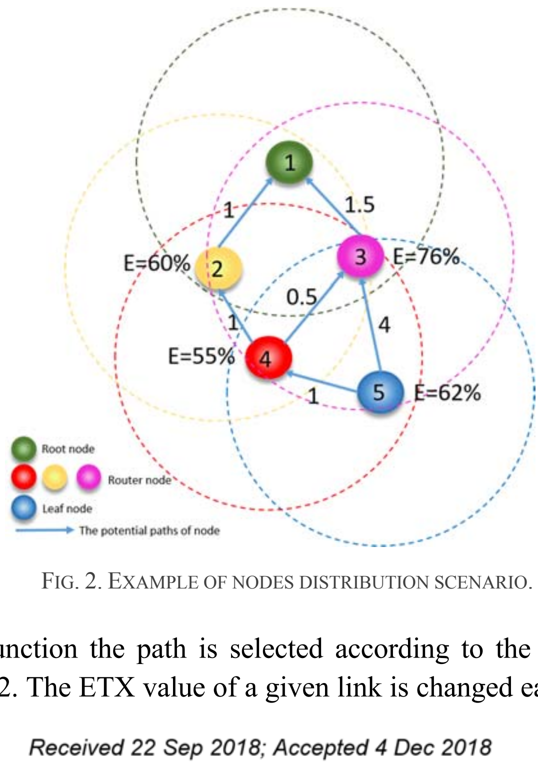

FIG. 2. EXAMPLE OF NODES DISTRIBUTION SCENARIO.

In MRHOF objective function the path is selected according to the minimum ETX value. The initial value of ETX is set to 2. The ETX value of a given link is changed each time the node receives a

Received 22 Sep 2018; Accepted 4 Dec 2018
 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

callback from the MAC layer. Since the MAC layer sends the expected number required to send a given message until ACK received, then the ETX reflects the link quality. The path quality is calculated from the link quality by summing all link qualities through the path. The minimum ETX path will be selected by the node as an optimal path to root. In FIG. 2, for example, node 5 has two neighbors that can be considered as preferred parent. These are nodes 3 and 4 with paths 5-3-1 (with path cost of 5.5) and 5-4-3-1 (with path cost of 3), respectively. Here node 5 will choose the second path. Two problems can be noted here, node 4 can select node 2 or 3 as a preferred parents because these two paths have the same ETX value of 2. In this case node 4 will select node 3 as a preferred parent. This will consume the energy of node 3 faster and there is no mechanism to make node 4 change its preferred parent. The other problem is that, if the link metric between nodes 5 and 3 is 2 then metric path for node 5 will be 3.5 with 2 hops or 3 with 3 hops. Node 5 will select the path with ETX of 3 with 3 hops rather than the other path but this selection may consume extra energy when compared to other paths.

III. Energy Threshold RPL ProtocoL

Energy Threshold RPL (ETRPL) protocol starts by building its topology as in RPL by multicasting DIO messages from root to its neighbors. The neighbor nodes receive the DIO messages from root, set root as preferred parent (the first DIO received from root), calculate path metric to root then calculate the rank of node based on OF. The node schedules DAO message to be sent to its parent which is root, as a request to join DODAG instance. The root sends DAO-ACK when receives DAO to accept node request. Each neighbor of root will repeat this procedure until all nodes join to the DODAG instance.

ETRPL is proposed here to improve the energy consumption of RPL network by implementing a new objective function. The objective function tries to enhance energy consumption of RPL protocol by overcoming the drawbacks of the previous objective function. ETRPL selects a path based on link quality (ETX) and at the same time it excludes the parent with energy less or equal than the preset threshold. In addition to link metric, each node in ETRPL adds a node metric. The node metric is added to each neighbor to increase the path metric to this neighbor. Adding node metric to just the preferred parent will cause a problem because the node may switch later to a parent already having energy below the threshold.

In each time when the node receives DIO message from a new neighbor, it adds this neighbor to the neighbor list, checks the remaining energy of DIO sender then calculates path cost to root through this neighbor. If the DIO sender is from a neighbor already in the neighbor list then the node checks the remaining energy of DIO sender. It then calculates the path metric to the root. Finally, the node selects the neighbor with minimum path metric as a preferred parent. In case when the node dose not receive any DIO messages or a new node is added, the node will multicast DIS message to its neighbor. When the neighbor node receives this DIS message, it resets trickle timer and multicasts DIO messages.

Each node sends its remaining energy in DIO message to its neighbors. When the node receives DIO message from any neighbor, it will check if this neighbor remaining energy is equal or below the threshold. If the neighbor energy is less or equal than the threshold, the node will add node metric. The node metric is the minimum value that makes the node switch its parent without affecting the rank calculation. The node selects the path with better quality, excludes parent with energy less or equal to the energy threshold. Also, the node will not choose neighbors as parents with energy equal or less than the energy threshold. Fig. 3 shows the flow chart that summarizes the procedure of ETRPL just described.

Received 22 Sep 2018; Accepted 4 Dec 2018
 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

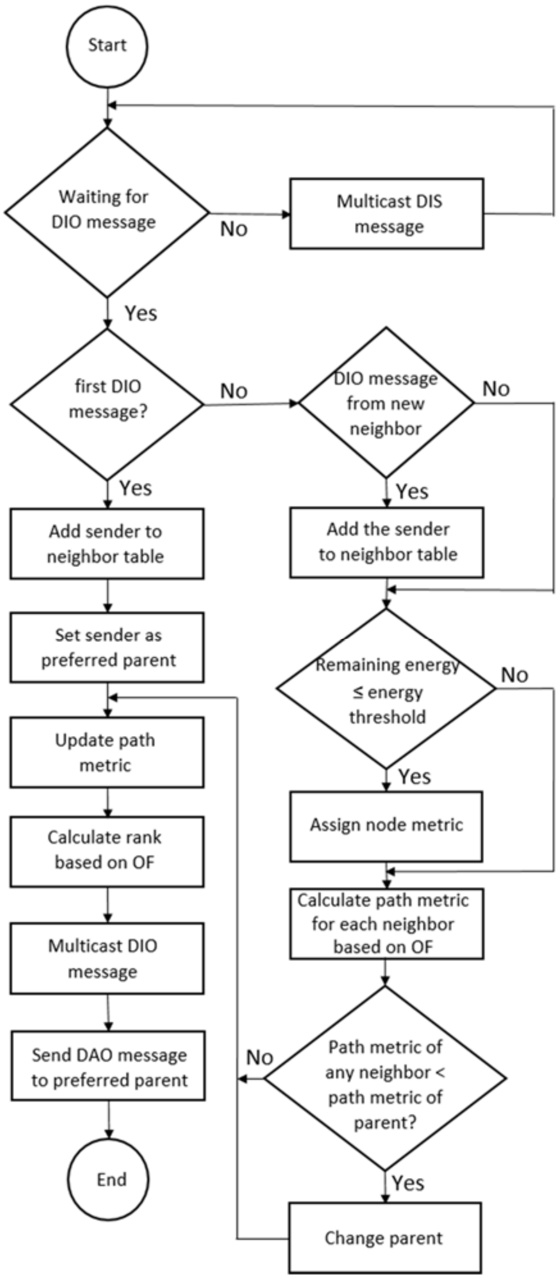

FIG. 3 FLOWCHART OF ETRPL

Considering the example shown previously in FIG. 2, node 4 has two paths to root. The mentioned percentage of consumed energy (E) presented for each node is just for demonstration. The first is 4-2-1 with ETX of 2. The second path is 4-3-1 with ETX of 2 as well. Node 4 will choose node 3 as a preferred parent randomly. Suppose that the energy threshold in ETRPL is 25%. When the remaining energy of node 3 becomes less or equal to the threshold (remaining energy of node 3= 100%-76% = 24%), node 4 switches its parent. Node 4 will choose node 2 as the preferred parent because its remaining energy is still above the threshold. If the remaining energy of node 2 is less or equal to 25% before the remaining energy of node 3 reaches the threshold then node 4 will never switch its preferred parent.

IV. Simulation Tests and Results

There are several real time operating systems used to provide functionality of IoT applications such as Contiki OS, Tiny OS, and others [22,31-33]. Contiki OS is one of the most widely used

Received 22 Sep 2018; Accepted 4 Dec 2018
 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

operating systems for WSN supporting IoT. Cooja simulator is the tool in Contiki OS used to simulate and emulate WSN over IoT. It is mentioned that about 63% of all simulation studies used Cooja simulator [34]. Contiki OS 3.0 is used to simulate the network for implementing and testing the given protocols. The performance evaluation covered both the legacy RPL and the proposed ETRPL protocols. In the evaluation, the following parameters are measured; the average remaining energy, Packet Reception Ratio (PRR), time delay, and the number of dead nodes. Table I shows the emulation parameters.

The assumed topology deployed 20, 40 and 80 IoT nodes randomly in the given area. Two different areas are considered 100m**X**100m and 200m**X**200m. Also, three different energy thresholds are used 25%, 50% and 75% in relation to the initial energy set for each node. Thus regardless of the exact value used as for the initial energy, the protocol assumed that all nodes have 100% initial energy before starting any transmission. The transmission scenario here also assumes that all nodes transmit one data packet within one minute with the transmitting node being selected randomly at each time.

TABLE I. PARAMETERS OF EMULATION

Parameter	Specification or Value
Topology	Random
Number of nodes	20, 40 and 80
Simulation time	60 Mins.
Node type	Tmote sky [35]
Transmission range	50m

A. The Average Remaining Energy

Tables II, III, and IV show the average remaining energy of the network for the two different areas with 20, 40 and 80 nodes, respectively. It is clear that the average remaining energy in ETRPL is better when compared to RPL for both areas, all number of nodes and energy thresholds used in the tests. It is clear that, for ETRPL, as the area is reduced and the number of nodes increased more remaining energy is achieved. This is due to the mechanism of ETRPL in selecting the parent depending on the remaining energy. For a large area of 200mx200m with small number of nodes more energy is consumed by all nodes due to the low number of candidate parents unlike the case of 100mx100m area, where each node has many neighbors that can serve as parents. The improvement in increasing the value of the remaining energy for ETRPL is at least 36% for all thresholds considered for 20 nodes, 64.7% for 40 nodes and 87.4% for 80 nodes. For the case where the area is small and the number of nodes is relatively high, any given node will always find an alternative parent with more residual energy. When the number of nodes is small, the nodes have small number of neighbors and may not find any parent with residual energy greater than the energy threshold. Also the chance of isolated node is high due to a big chance that the preferred parent died with no other candidate parent exists.

B. Packet Reception Ratio

As shown in Tables V, VI, and VIII, the Packet Reception Ratio (PRR) is improved for a small area of 100mx100m as expected for both RPL and ETRPL and for all energy thresholds with slightly better performance shown by ETRPL. For 200mx200m area PRR is reduced with better performance for the case of low energy thresholds of 25% and 50%. This is due to the fact that in a large area there is less number of nodes ready to forward data. In ETRPL, when the router node died in the large area with a small number of nodes no parent exists, so the child messages will not arrive to the root. Thus PRR is reduced when the number of dead nodes is high and so leaf nodes are isolated.

Received 22 Sep 2018; Accepted 4 Dec 2018
 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

C. Average Delay

Tables VIII, IX, and X show the average delay time in packet reception for both RPL and ETRPL using small, medium and large number of nodes. It is clear that for a small number of nodes the average delay time for RPL is almost the same for the two different areas tested while it is increased according to the area for a large number of nodes. In the case of ETRPL, the average delay time depends on the area considered in the test. For all energy thresholds, ETRPL produced small delay for small area, and vice versa.

D. Number of Dead Nodes

Tables XI, XII, and XIII show the number of dead nodes and the area considered for different energy thresholds and different numbers of nodes for ETRPL and RPL protocols. For 100mx100m area, there are no dead nodes in ETRPL for all energy thresholds with 20 nodes, while the number of dead nodes increased for the case of 40 and 80 nodes due to more consumed energy by the network. For a large area, there is a slight increase in the number of dead nodes.

TABLE II. THE AVERAGE REMAINING ENERGY IN MJ FOR 20 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	567.8	945.7	889.4	934.0
200mX200m	559.4	660.8	671.1	619.2

TABLE III. THE AVERAGE REMAINING ENERGY IN MJ FOR 40 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	133.84	461.64	446.43	379.35
200mX200m	148.82	246.41	233.30	238.87

TABLE IV. THE AVERAGE REMAINING ENERGY IN MJ FOR 80 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	10.10	83.41	89.55	80.93
200mX200m	73.83	89.50	76.84	73.83

TABLE V. THE PACKET RECEPTION RATIO FOR 20 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	0.9972	1	1	1
200mX200m	0.9898	0.9936	0.9954	0.9826

TABLE VI. THE PACKET RECEPTION RATIO FOR 40 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	0.9874	0.996	0.9969	0.9928
200mX200m	0.9642	0.9802	0.9783	0.9762

TABLE VII. THE PACKET RECEPTION RATIO FOR 80 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	0.9666	0.9922	0.9927	0.9895
200mX200m	0.9711	0.9724	0.9728	0.9711

Received 22 Sep 2018; Accepted 4 Dec 2018

ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

TABLE VIII. THE AVERAGE DELAY IN MSEC FOR 20 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	0.2909	0.1511	0.1360	0.1762
200mX200m	0.2503	0.4011	0.3891	0.2652

TABLE IX. THE AVERAGE DELAY IN MSEC. FOR 40 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	0.3184	0.3219	0.3415	0.397
200mX200m	0.5187	0.4732	0.6982	0.4148

TABLE X. THE AVERAGE DELAY IN MSEC. FOR 80 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	0.7045	1.0164	0.7297	0.7336
200mX200m	1.1799	1.5274	1.5915	1.1799

TABLE XI. THE NUMBER OF DEAD NODES FOR 20 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	4	0	0	0
200mX200m	5	3	3	6

TABLE XII. THE NUMBER OF DEAD NODES FOR 40 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	32	12	10	13
200mX200m	28	23	20	23

TABLE XIII. THE NUMBER OF DEAD NODES FOR 80 NODES.

Area	RPL	ETRPL 25%	ETRPL 50%	ETRPL 75%
100mX100m	79	65	62	61
200mX200m	70	67	67	70

V. CONCLUTION

A modification of the original routing protocol for low power and lossy network (RPL) is considered in this work. RPL selects its optimal path based on a standard objective function depending on either ETX or hop count to nominate preferred parent. The proposed Energy Threshold RPL (ETRPL) protocol is suggested to improve energy consumption of the whole network. An objective function based on remaining energy of preferred parent is proposed. The simulation tests of ETRPL, using Cooja simulator, show that the energy consumption of ETRPL is better than that of the RPL protocol. For a small area of 100mx100m considered in the work, an increase in the remaining energy of at least 36%, 64.7% and 87% is achieved using 20, 40 and 80 nodes, respectively. ETRPL also performed better than RPL with regards to Time Delay, Packet Reception Ratio, and the number of dead nodes in a small area. For a large area of 200mx200m, the performance is degraded for some test conditions. Thus, the proposed ETRPL protocol is useful for IoT networks with relatively small areas.

REFERENCES

[1] D. Evans, “The Internet of Things - How the Next Evolution of the Internet is Changing Everything,” CISCO, San Jose, CA, USA, White Paper, 2011.

Received 22 Sep 2018; Accepted 4 Dec 2018

 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

[2] P. Sarwesh, N. Shekarm, V. Shet, and K. Chandrasekaran, “Energy Efficient and Reliable Network Design to Improve Lifetime of Low Power IoT Networks,” IEEE WiSPNET 2017 Conference, pp. 117–122, Chennai, India, 2017.

[3] V. Sachan, S. Imam, and M. Beg, “Energy-Efficient Communication Methods in Wireless Sensor Networks: A Critical Review,” Int. J. Comput. Appl., Vol. 39, No. 17, pp. 35–48, 2012.

[4] A. A. Kadhim, M. W. Abdulrazzaq, "Efficient Routing Techniques for Wireless Sensor Networks", Journal of Applied Sciences, vol. 14, no. 24, pp. 3479-3485, 2014.

[5] R. Ramya and S. Ravi, “Recent Advances in Energy-Efficient Routing Protocols for Wireless Sensor Networks,” Middle-East Journal of Scientific Research, Vol. 24, No. 1, pp. 113-119, 2016.

[6] E. Aljarrah, M. Yassein, and S. Aljawarneh, “Routing Protocol of Low-Power and Lossy Network: Survey and open issues,” Engineering & MIS (ICEMIS) International Conference, pp.1-6, 2016.

[7] T. Winter, P. Thubert, A. Brandt, and J. Hui, R. Kelsey , P. Levis , K. Pister , R. Struik , JP. Vasseur and R. Alexander “RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks,”DOI 10.17487/ RFC6550, pp. 1–157, March 2012.

[8] G. Gardašević, M. Veletic, N. Maletic, D. Vasiljevic, I. Radusinovic, S. Tomovic, M. Radonjic, “The IoT Architectural Framework, Design Issues and Application Domains,” Wirel. Pers. Commun., Vol. 92, No. 1, pp. 127–148, 2017.

[9] Z. Sheng, D. Tian, and V. Leung, “Towards Energy and Resource Efficient Internet-of-Things : A Design Principle Combining Computation, Communications and protocols", IEEE Communications Magazine, Vol. 56, Issue 7, pp.89-95, July 2018)

[10] A. Sebastian and S. Sivagurunathan, “A Survey on Load Balancing Schemes in RPL Based Internet of Things,” International Journal of Scientific Research in Network Security and Communication, Vol.6, No. 3, pp. 43–49, 2018.

[11] I. Wadhaj, I. Kristof, I. Romdhani, and A. Al-dubai, “Performance Evaluation of the RPL Protocol with Fixed and Mobile Sinks,” IEEE International Conference on Computer and Information Technology; Ubiquitous Computing and Communications; Dependable Autonomic and Secure Computing; Pervasive Intelligence and Computing, October, 2015.

[12] Q. Abuein, M. Yassein, M. Shatnawi, L. Bani-Yaseen, O. Al-Omari, M. Mehdawi, and H. Altawssi, “Performance Evaluation of Routing Protocol (RPL) for Internet of Things,” Int. J. Adv. Comput. Sci. Appl., Vol. 7, No. 7, pp. 17–20, 2016.

[13] W. Mardini, M. Ebrahim, and M. Al-Rudaini, “Comprehensive Performance Analysis of RPL objective Functions in IoT Networks”, Int. J. Commun. Networks Inf. Secur., Vol. 9, No. 3, pp. 323–332, 2017.

[14] M. Mahmud, A. Abdelgawad, and K. Yelamarthi, “Energy Efficient Routing for Internet of Things (IoT) Applications”, 2017 IEEE Int. Conf. Electro Inf. Technol., pp. 442–446, Lincoln, NE, USA, 2017.

[15] X. Liu, Z. Sheng, C. Yin, F. Ali, and D. Roggen, “Performance Analysis of Routing Protocol for Low Power and Lossy Networks (RPL) in Large Scale Networks,” IEEE Internet of Things J., Vol. 4, No. 6, pp. 2172–2185, 2017

[16] S. Ara, R. Filho, J. Rodrigues, R. Rabelo, N. Sousa, and J. Filho, “A Proposal for IoT Dynamic Routes Selection Based on Contextual Information,” Sensors, Vol. 18, No. 2, pp. 1–16, 2018.

[17] P. Sanmartin, A. Rojas, L. Fernandez, K. Avila, D. Jabba, and S. Valle, “Sigma Routing Metric for RPL Protocol”, Sensors (Switzerland), Vol. 18, No. 4, 2018.

[18] S. Kharche and S. Pawar, “Stability Model for RPL with Minimum Rank Hysterisis Objective Function in 6LoWPAN,” Int. J. Pure Appl. Math., Vol. 118, No. 5 Special Issue, pp. 731–737, 2018.

[19] J. Nassar, M. Berthomé, J. Dubrulle, N. Gouvy, N. Mitton, B. Quoitin, “Multiple Instances QoS Routing In RPL : Application to Smart Grids,” Sensors, Vol. 18 No. 8, 2018.

[20] A. Parasuram, D. Culler, and R. Katz, “An Analysis of the RPL Routing Standard for Low Power and Lossy Networks,” Technical Report, Electrical Engineering and Computer Sciences, University of California at Berkeley, 2016

[21] O. Iova, F. Theoleyre, T. Noel., “Improving Network Lifetime with RPL Through Energy Efficient Load Balancing", IEEE. 7th IFIP Wireless and Mobile Networking (WMNC), Villamoura, Portugal, May 2014.

[22] A. Al-Fuqaha, M. Guizani, M. Guizani, M. Mohammadi, M. Aledhari, “Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications,” IEEE Communications Surveys & Tutorials, IEEE Org., Vol. 17, No. 4, pp. 2347–2376, 2015.

[23] O. Iova, G. Picco, T. Istomin, and C. Kiraly, “RPL : The Routing Standard for the Internet of Things…Or Is It ?,” IEEE Commun. Mag., Vol. 54, no. 12, pp. 16–22, December 2016.

[24] A. Dhumane, R. Prasad, and J. Prasad, “Routing Issues in Internet of Things : A Survey,” Lect. Notes Eng. Comput. Sci. Proc. Int. MultiConference Eng. Comput. Sci., Vol. 1, pp. 404–412, 2016.

[25] S. Maamar, “Evaluation of QoS Parameters with RPL Protocol in the Internet of Things,” Proc. Int. Conf. Comput. Eng. Sci. - ICCES ’17, pp. 86–91, 2017.

[26] P. Levis, T. Clausen, J. Hui, O. Gnawali and J. Ko, “The Trickle Algorithm,” DOI 10.17487/RFC6206, March 2011.

[27] P. Thubert, “Objective Function Zero for the Routing Protocol for Low-Power and Lossy Networks (RPL),” DOI 10.17487 / RFC6552, March 2012.

Received 22 Sep 2018; Accepted 4 Dec 2018

[28] O. Gnawali and P. Levis, “The Minimum Rank with Hysteresis Objective Function,” DOI 10.17487/RFC6719, September 2012.

[29] A. Al-dubai, H. Altwassi, M. Qasem, M. Yassein, and A. Al-Dubai, “Performance Evaluation of RPL Objective Functions,” Int. Work. Internet Things Smart Spaces Appl. Challenges Futur. Trends in conjunction with 14th IEEE Int. Conf. Ubiquitous Comput. Commun. IUCC 2015), Liverpool, UK, September 2015.

[30] JP. Vasseur, M. Kim, K. Pister, N. Dejean and D. Barthel, “Routing Metrics Used for Path Calculation in Low Power and Lossy Networks,” RFC 6551, DOI 10.17487/RFC6551, March 2012.

[31] A. Velinov and A. Mileva, “Running and Testing Applications for Contiki OS Using Cooja Simulator,” In Information Technology and Education Development, Zrenjanin, Serbia, 2016.

[32] Z. Wang, W. Li, and H. Dong, “Review on Open Source Operating Systems for Internet of Things,” Journal of Physics: Conference Series, Vol. 887, No. 1, 2017.

[33] A. Hicham, A. Sabri, A. Jeghal, and H. Tairi, “A Comparative Study between Operating Systems for the Internet of Things (IoT),” Trans. Mach. Learn. Artif. Intell., Vol. 5, No. 4, 2017.

[34] H. Kim, J. Ko, D. Culler, and J. Paek, “Challenging the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL): A Survey,” IEEE Commun. Surv. Tutor, Vol. 19, No. 4, 2017.

[35] Tmote Sky : Datasheet, " Low Power Wireless Sensor Module", https://insense.cs.st-andrews.ac.uk/files/2013/04/tmote-sky-datasheet.pdf.

Received 22 Sep 2018; Accepted 4 Dec 2018

 ISSN (Print) 1811-9212 ISSN (Online) 2617-3352