International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Energy Efficiency Minimum Rank with Hysteresis Objective Function (EE-MRHOF) for RPL routing in IoT Networks

[1*]Mr. A. Ramesh, [2]Ms. K. Kamali

Submitted: 02/12/2023 **Revised:** 10/01/2024 **Accepted:** 26/01/2024

Abstract : The challenges posed by Internet of Things (IoT) devices with limited resources can be overcome by developing cross-layer approaches that are adapted to their constraints. This paper aims to present a cross-layer technique in order to meet the QoS requirements of all IoT devices and maximise their energy efficiency. The IPv6 Routing Protocol for Low Power and Lossy Networks (RPL) is mainly intended for Internet of Things devices with limited resources. In this paper, Energy Efficiency Minimum Rank with Hysteresis Objective Function (EE-MRHOF) for RPL routing is proposed. The basic MRHOF consists of hop counts and Expected Transmission Count (ETX) metrics. In this work, MRHOF is extended by including a cost function which is derived from the cross-layer metrics Signal to Interference plus Noise Ratio (SINR), Strobe per Packet Ratio (SPR) and total power consumption. By simulation results, it has been shown that EE-MRHOF achieves maximum energy efficiency and packet delivery ratio with reduced packet loss rate and latency.

Keywords: *Internet of Things (IoT), Low power and Lossy networks (LLN), Minimum Rank with Hysteresis Objective Function (MRHOF), Energy efficiency, Cross-layer metrics.*

1. Introduction

By incorporating the idea of intelligence or smartness, the IoT is revolutionising and expanding fundamental study domains into new dimensions. A few instances of this transformation are the new domains, which include intelligent transportation systems, autonomous vehicles, smart homes, smart cities, smart industries, and smart healthcare [1]. The aim of inventions towards a smarter and greener society for sustainability reasons is what has led to the incorporation of IoT in nearly every area of human existence. The predicted high growth demonstrates both our reliance on IoT-enabled devices and the exponential rate at which the Internet of Things is expanding globally [2].

Two main obstacles stand in the way of smaller and smarter devices realising a smarter world through IoT enabled connected gadgets: communication and computational power limitations resulting from limited energy resources. The majority of sensor-enabled IoT devices primarily rely on batteries for power. When sensors are in operation, these devices use battery power to gather and transmit data among nearby devices [3]. In order to enable the automation of intelligent decision-making, sensor-enabled smart devices continuously sense, receive, compute, and distribute information. In order to prolong the running duration of network terminals, energy harvesting technology is regarded as a crucial way to lower system energy consumption and prolong device operation [4]. The incorporation of sustainability in recent greener and smarter world research has made the optimisation of energy usage in sensor-enabled IoT devices one of the basic challenges. Various energy-efficient ways have been established for sensor-enabled IoT devices [5].

In IoT, effective power control is essential for a number of reasons. Because IoT devices frequently run on tiny batteries or restricted energy sources, they require an effective power management system to increase their operational lifetime and reduce the frequency with which they need to be replaced or recharged. By optimising energy use and minimising waste and resource conservation, efficient power regulation in IoT is essential to lowering ecological impact [6].

Enhancing the efficiency, dependability, and performance of IoTs networks is made possible by integrating cross-layer techniques, which promote better coordination and communication among various protocol layers. Cross-layer approaches provide optimised resource utilisation, decreased latency, greater security, and better adaption to dynamic IoT environments by enabling information flow and coordination across many layers, including the physical, data connection, network, transport, and application layers [7][8].

1.1 Problem Identification

The challenges posed by IoT devices with limited resources will be overcome by developing cross-layer

---

[1] *Assistant Professor, Dept. of CSE, Annamalai university, Annamalainagar, Tamilnadu*
*Corresponding Author: *rameshmkdn@gmail.com*
[2] *Assistant Professor. , Dept. of CSE, Annamalai university, Annamalainagar, Tamilnadu Kamaliaucse2006@gmail.com*

approaches that are adapted to their constraints. Methods for reducing energy usage need to be examined while maintaining acceptable performance levels on devices with constrained memory, processing power, and battery life. The domain of standardisation efforts and interoperability protocols must be explored for cross-layer approaches in IoT. These optimisations should be made universally applicable to a broad range of IoT devices, platforms, and communication protocols for maximising energy efficiency and facilitating seamless integration and adoption. The possibility of combining artificial intelligence and machine learning techniques need to be examined to create cross-layer optimisations.

This research work aims to present a cross-layer technique to maximize the energy efficiency of all IoT devices while satisfying the QoS constraints of devices with maximum transmit power.

2. Related Works

ELITE, a cross-layer OF is proposed that uses less energy and introduces the Strobe per Packet Ratio (SPR) as a routing parameter [9]. The amount of transmitted strobes for each packet as a result of the MAC layer's Radio Duty Cycling (RDC) regulations is indicated by SPR. This newly defined metric can distinguish between nodes depending on the relative phase shift existing between them during communication. It is intended to be used in conjunction with asynchronous MAC protocols. ELITE attempts to choose a path that requires its nodes to receive fewer strobe transmissions.

As a smart agriculture application, we put forth an IoT-based WSN architecture with various design tiers [10]. Agricultural sensors employ a multi-criteria decision function to recognize a group of cluster heads after first collecting relevant data. SNR is utilized to evaluate the signal strength on the transmission connections in order to achieve dependable and efficient data transmissions. By employing the linear congruential generator's recurrence, data transfer from agricultural sensors to base stations is secured.

In order to maximise energy efficiency in wireless LoRa networks made up of LoRa end devices and a flying GW and prolong the network lifetime, deep reinforcement learning (DRL) is suggested [11]. Given the air-to-ground wireless link and the availability of spreading factors, the skilled DRL agent can assign TPs and spreading factors to end devices in an efficient manner. Furthermore, the flying GW is allowed to allocate resources online and modify its optimal policy while on-board. Retraining the DRL agent with a smaller action space allows for this.

Through performance monitoring of underlying communication technologies, an energy-efficient framework is built for an ideal balance between the energy consumed by linked devices in a time-critical and complex IoT system [13]. It also focuses on addressing the trade-off between network performance for communicating nodes and energy consumption. After the nodes for time-sensitive Internet of Things systems are modelled using Reinforcement Learning (RL), an Energy Harvesting MAC protocol is created.

3. Proposed Methodology

3.1 Overview

In this paper, we propose EE-MRHOF for RPL routing in IoT networks. The basic MRHOF consists of hop counts and ETX metrics. In this work, RPL protocol with MRHOF is extended by including a cost function which is derived from the cross-layer metrics SINR, total power consumption and SPR.

3.2 RPL Protocol for IoT

The main purpose of the IPv6 Routing Protocol for Low Power and Lossy Networks (RPL) is to accommodate IoT devices in Low Power and Lossy Networks (LLN) that have limited resources.

With its topology based on a Destination Oriented Directed Acyclic Graph (DODAG), RPL is a distance-vector routing system. The default routes to the Internet are gathered by the DODAG root and dispersed among several routing protocols.

Every node in the topology has a rank value assigned to it, which indicates where it is in relation to the DODAG root.

The collection of parent nodes in this case is chosen by the source nodes, and each node chooses its preferred parent node depending on which has a higher rank value.

Five control messages are used to maintain the topology of the RPL network:

i. DODAG Information Object (DIO)
ii. DODAG Information Solicitation (DIS)
iii. Destination Advertisement Object (DAO)
iv. DAO Acknowledgement (DAO-ACK)
v. Consistency Check (CC).

The flowchart which contains the basic steps involved in the RPL routing protocol, is illustrated in Figure 1.

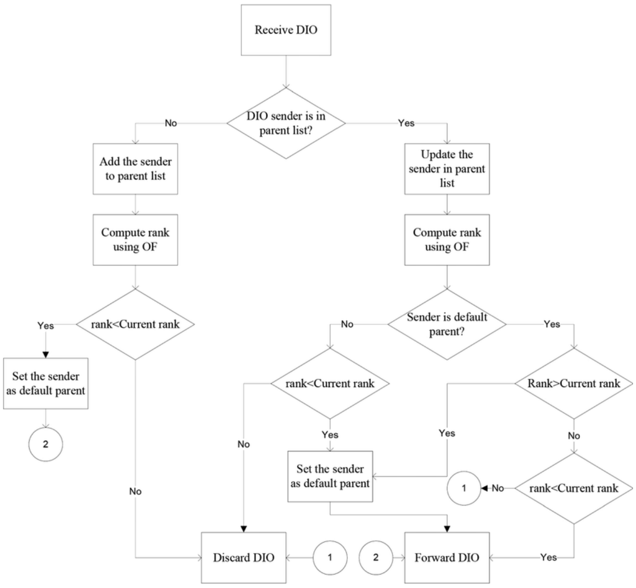

Figure 1 Flow chart of RPL routing protocol

3.3 Derivation of Cross Layer Metrics

The objective function in RPL serves as a selection path mechanism for the parent node that is selected to build a DODAG. The Minimum Rank with Hysteresis Objective Function (MRHOF) consists of hop counts and Expected Transmission Count (ETX) metrics [14].

In this work in addition to ETX, a cost function is derived from the cross-layer metrics SINR, total power consumption (P_T) and SPR. Then the MRHOF is extended by including the cost function.

3.3.1 Expected Transmission Count (ETX)

The term "ETAX" refers to the projected total number of transmissions needed for a message to reach its destination error-free. RPL may determine the stable minimum-ETX pathways from a node to a root in the DAG instance using the ETX metric.

It is given using the following equation:

$$ETX = \frac{1}{(R_{fw}.R_{rv})} \tag{1}$$

Where, R_{fw} indicates the probability calculation of received packet at neighbour node

R_{rv} indicates the probability estimation of acknowledgement (ACK) packet in receiver

Note: The ETX value may not be an integer or it may be a discrete number.

3.3.2 Signal to Interference plus Noise Ratio (SINR)

The SINR of the IoT device i at time t is given by the following equation [8]:

$$SINR_i(t) = \frac{p_i(t).h_{i,i}(t)..l_{i,i}(r)}{I_i(t) + N_0} \tag{2}$$

Where, I_i (t) is the interference caused by the IoT devices

$p_i(t)$ is the transmit power

$h_{i,i}$ (t) is the Rayleigh fading channel gain

$l_{i,i}$ (r) is the Rayleigh fading channel loss

N_0 is the noise power.

3.3.3 Strobe per Packet Ratio (SPR)

Radio Duty Cycling (RDC) protocol holds off the radio module until it is possible. It is a basic feature of IoT architectures which aims to turn off/on the transceiver based on a time intervals.

According to the RDC protocol, until the one-hop receiver wakes up and receives notice of the packet arrival, a series of Strobe packets are sent to it continually [9].

SPR shows how many strobes each packet needs to send to the one-hop receiver in order for it to wake up. The node counts the number of strobe packets it sends out until it gets an ACK from the receiving end in order to determine SPR.

SPR of a node is defined using the following equation:

$$SPR = \frac{N_{rss}}{N_{rsp}} \tag{3}$$

Where N_{rss} is the number of recently sent strobes

N_{rsp} is the number of recently sent packets

3.3.4 Power Consumption

The total power consumption of a node is computed as

$$P_T = P_c + P_{tx} + P_{rx} \tag{4}$$

where P_c, P_{tx} and P_{rx} correspond to power consumption during communication, transmission and reception, respectively.

3.3.5 Objective Function

The objective function is derived using the following equation:

$$\text{OF} = \frac{(w_1.ETX + w_2.SINR + w_3.SPR)}{w_{4.}.P_T} \tag{5}$$

Where w_j, j=1,2..4 are weight values in the range of 0 to 1.

3.4 MRHOF Algorithm

The steps involved in this algorithm are as follows:

Computing Path Cost

1. The variable X is set by the root nodes (either floating or grounded) to the metric value that computes to a rank of MinHopRankIncrease (MH).
2. A non-root node joins a candidate neighbour as an RPL Leaf if it lacks the metrics necessary to calculate the path cost through any of the candidate neighbours.
3. If not, nodes calculate the path cost for every potential neighbour that can be reached over an interface. The cost of the path, in terms of the chosen measure, from a node to the DODAG root via a neighbour is represented by the neighbor's path cost.
4. A non-root node calculates a neighbor’s path cost by adding two components:

- The route cost for the path through a neighbour SHOULD be set to MAX_PATH_COST if the chosen metric is a link metric and the metric of the link to that neighbour is not available.
- The path cost across each neighbour should be set to MAX_PATH_COST if the chosen metric is a node metric and the metric is unavailable.

5. If the Metric Container is empty, the neighbour advertises the Rank as the second component using ETX, S, and V as the metrics.

Recalculating the path cost associated with a neighbour is necessary whenever any of the following scenarios is true:

- An update is made to the link's chosen measure to the potential neighbour.
- A node metric was chosen, and it is currently updated.
- The candidate neighbour sends a fresh metric advertisement to a node.

Periodically, this computation should also be done.

Parent Selection

1. The node should not take into account a link during parent selection if the chosen metric for that connection exceeds MAX_LINK_METRIC.
2. A node, with the following exceptions, must designate as its preferred parent the candidate neighbour with the lowest path cost:

- Depending on how the system is set up, a node may identify as a floating root and not have a preferred parent.
- The node may identify itself as a Floating root if cur_min_path_cost exceeds MAX_PATH_COST.
- The node may keep using the current preferred parent if the least path cost for paths across the candidate neighbours is less than PARENT_SWITCH_THRESHOLD by cur_min_path_cost.
- The node lacks a preferred parent if ALLOW_FLOATING_ROOT is 0 and no neighbours are found; in this case, cur_min_path_cost must be set to MAX_PATH_COST.

3. A node may employ various selection criteria to determine which of its neighbours should be regarded as having the lowest cost if there are several that share the smallest path cost.
4. The path's cost through any node in the parent set is either the same as or less than the path's cost through any node that is not in the parent set.
5. A node may maintain a smaller parent set than PARENT_SET_SIZE if the cost of the path via the worst and preferred parents is excessively high.
6. The node sets its cur_min_path_cost variable to the path cost associated with the chosen parent after the preferred parent has been chosen.
7. When DIO messages are issued, the value of the cur_min_path_cost is carried in the Metric Container corresponding to the chosen metric.

Computing the Rank

A non-root node computes the rank value using the objective function OF given in Eqn. (5) after choosing its parent set:

The node needs to become an RPL Leaf node by joining one of its neighbours if the Rank is unknown.

This Rank value is used by MRHOF to calculate the Rank that each path through a member of the parent set is associated with.

The maximum of two values determines the Rank linked to a path that passes through a member of the parent set.

1. Equivalent Rank value determined using the equation above
2. Nodes' advertised Rank plus MinHopRankIncrease;

4. Experimental Results

4.1 Simulation Settings

The proposed Energy efficient MRHOF (EE-MRHOF) protocol has been implemented in the LoRaWAN cross-layer simulation framework [12]. The performance is compared with the existing MRHOF protocol and traditional RPL routing protocol. The performances of these protocols are evaluated in terms of packet delivery ratio, average packets dropped, average residual energy, average latency and throughput, by varying the nodes. The simulation settings are presented in Table 1.

Number of Nodes	10 to 50
Size of the topology	150m X 150m
Propagation Model	Two Ray Ground
Antenna Model	OmniAntenna
MAC protocol	IEEE 802.15.4
Traffic Source	CBR
Packet size	512 bytes
Traffic Rate	50Kb
Initial Energy	12 Joules
Transmit power	0.3 watts
Receiving power	0.3 watts
Simulation time	100 seconds
Transmission range	30m

Table 1 Simulation Settings

4.2 Results & Analysis

A. Performance on Network Size

In order to analyze the performance of the protocols on network size, the number of nodes has been varied from 10 to 50.

Nodes	EE-MRHOF	MRHOF	RPL
10	0.9328	0.9122	0.9017
20	0.9186	0.9045	0.8911
30	0.9076	0.8872	0.8677
40	0.8932	0.863	0.8467
50	0.8844	0.8502	0.8419

Table 2 Results for packet delivery ratio

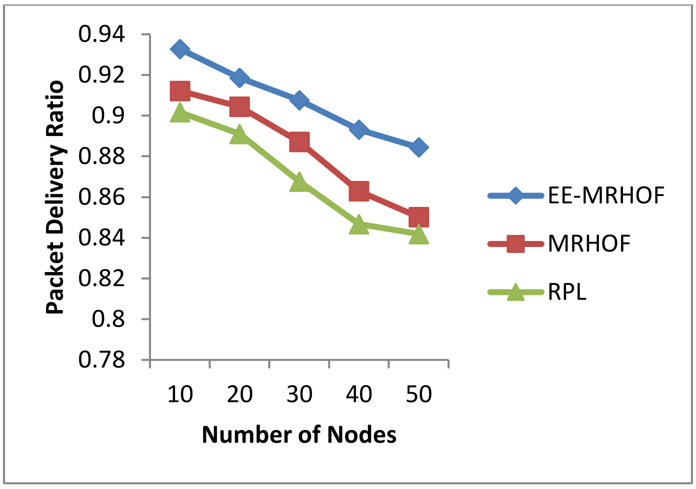

Figure 2 Nodes Vs Packet delivery ratio

The packet delivery ratios of all the protocols are shown in Table 2 and Figure 2. From the figure, it can be seen that EE-MRHOF has 2.6% higher delivery ratio than MRHOF and 4% higher delivery ratio than RPL.

Nodes	EE-MRHOF	MRHOF	RPL
10	0.1034	0.1213	0.188
20	0.1763	0.2018	0.2237
30	0.2228	0.2395	0.2534
40	0.2521	0.2672	0.2914
50	0.2663	0.2815	0.3184

Table 3 Results for packet loss rate

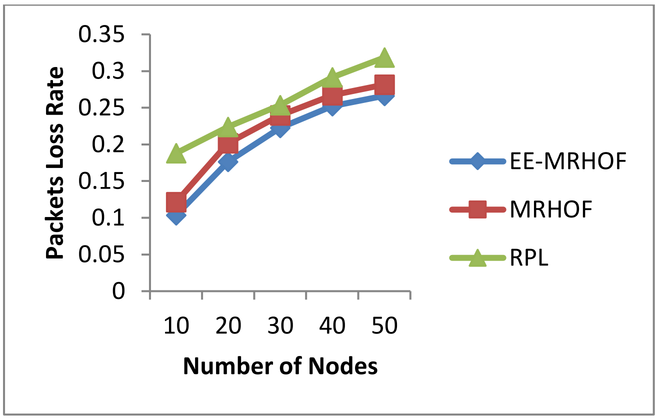

Figure 3 Nodes Vs Packet loss rate

The average packet loss rates of all the protocols are shown in Tabel3 and Figure 3. From the figure, it can be seen that packet loss rate of EE-MRHOF is 9% lesser than MRHOF and 21% lesser than RPL, for varying the nodes.

Nodes	EE-MRHOF (Joules)	MRHOF (Joules)	RPL (Joules)
10	10.89	10.74	10.52
20	10.69	10.57	10.48
30	10.43	10.39	10.18
40	10.27	10.21	10.07
50	10.22	10.11	9.73

Table 4 Results for residual energy

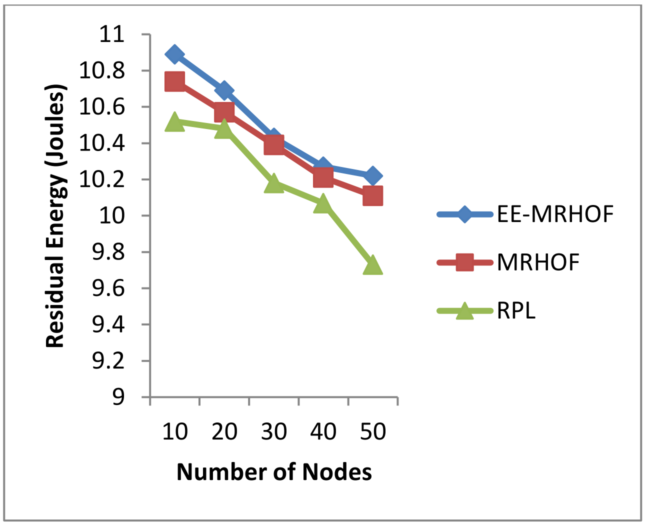

Figure 4 Nodes Vs Residual Energy

The average residual energies of all the protocols are shown in Table 4 and Figure 4. From the figure, it can be seen that residual energy of EE-MRHOF is 1% higher than MRFOF and 3% higher than RPL, for varying the nodes.

Nodes	EE-MRHOF (ms)	MRHOF (ms)	RPL (ms)
10	10.34	10.77	11.52
20	11.17	11.72	12.47
30	12.51	13.45	15.11
40	12.92	13.90	15.55
50	14.15	15.29	17.64

Table 5 Results for average latency

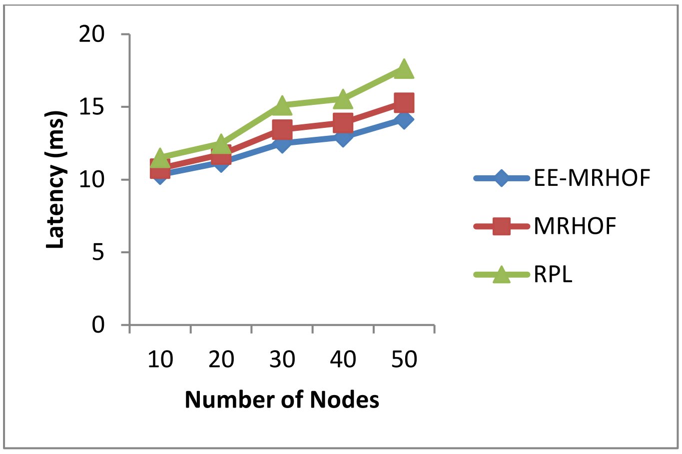

Figure 5 Nodes Vs Latency

The average latencies of all the protocols are shown in Table 5 and Figure 5. From the figure, it can be seen that latency of EE-MRHOF is 6% lesser than MRHOF and 14% lesser than RPL, for varying the nodes.

Nodes	EE-MRHOF (Mb/s)	MRHOF (Mb/s)	RPL (Mb/s)
10	1.85	1.53	1.48
20	1.75	1.46	1.35
30	1.68	1.35	1.23
40	1.59	1.24	1.17
50	1.53	1.18	1.03

Table 6 Results for Throughput

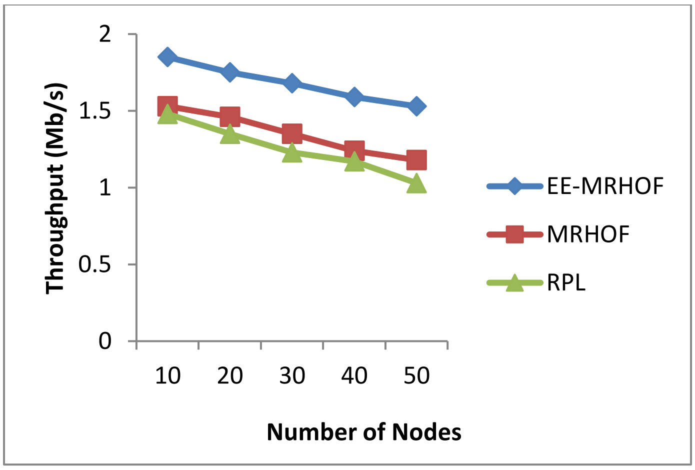

Figure 6 Nodes Vs Throughput

The throughput measured for all the protocols are shown in Table 6 and Figure 6. From the figure, it can be seen that throughput of EE-MRHOF is 19% higher than MRHOF and 25% higher than RPL, for varying the nodes

5. Conclusion

In this paper, we propose EE-MRHOF for RPL routing in IoT networks. The basic MRHOF consists of hop counts and ETX metrics. In this work, RPL protocol with

MRHOF is extended by including a cost function which is derived from the cross-layer metrics SINR, total power consumption and SPR. The performance of EE-MRHOF is compared with the existing MRHOF and traditional RPL routing protocol in terms of packet delivery ratio, average packets dropped, average residual energy, average latency and throughput. By simulation results, it has been shown that EE-MRHOF achieves maximum energy efficiency and packet delivery ratio with reduced packet loss rate and latency.

Funding: The authors didn't get any funding support for this research.

Conflict of Interest: The authors don't have any conflict of Interest

Data Availability: The authors didn't use any third party data materials in their research.

Authors Contribution: In this manuscript preparation author 1 prepared the concept and author 2 prepared the implementation part and author 3 prepared the english grammatical errors.

References

[1] Rekha and Ritu Garg, "Improved energy efficiency using meta-heuristic approach for energy harvesting enabled IoT network", Kuwait J.Sci., Vol.50, No.(2A),April.2023,pp(1-18).

[2] L. Sathish Kumar, Sultan Ahmad, Sidheswar Routray, A. V. Prabu, Abdullah Alharbi, Bader Alouffi, and S. Rajasoundaran, "Modern Energy Optimization Approach for Efficient Data Communication in IoT-Based Wireless Sensor Networks", Hindawi, Wireless Communications and Mobile Computing, Volume 2022.

[3] Iwendi, C and Maddikunta, PKR and Gadekallu, TR and Lakshmanna, K and Bashir, AK and Piran, MJ (2020) A metaheuristic optimization approach for energy efficiency in the IoT networks. Software - Practice and Experience.

[4] Zhijie Su, Wanmei Feng, Jie Tang, Zhen Chen, Yuli Fu, Nan Zhao, Kai-Kit Wong, "Energy Efficiency Optimization for D2D Communications Underlaying UAV-assisted Industrial IoT Networks with SWIPT", IEEE.

[5] Ghanshyam Singh, Pallavi Joshi, and Ajay Singh Raghuvanshi, "A Novel Duty Cycle Based Cross Layer Model for Energy Efficient Routing in IWSN Based IoT Application", KSII Transactions On Internet And Information Systems, 16(6), 2022.

[6] Kirshna Kumar, Sushil Kumar, Omprakash Kaiwartya, Yue Cao, Jaime Lloret and Nauman Aslam, "Cross-Layer Energy Optimization for IoTEnvironments: Technical Advances and Opportunities", Energies 2017, 10, 2073.

[7] Cao, Y.; Zhong, Y.; Peng, C.; Peng, X.; Pan, S. Energy Efficiency Optimization for SWIPT-Enabled IoT Network with Energy Cooperation. Sensors 2022, 22, 5035.

[8] Sami Nadif, Essaid Sabir, and Abdelkrim Haqiq, "A Mean-Field Framework for Energy-Efficient Power Control in Massive IoT Environments", 2019 IEEE 30th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC): Track 3: Mobile and Wireless Networks.

[9] Bardia Safaei, Amir Mahdi Hosseini Monazzah, and Alireza Ejlali, "ELITE: An Elaborated Cross-Layer RPL Objective Function to Achieve Energy Efficiency in Internet of Things Devices", IEEE, 2020.

[10] Khalid Haseeb, Ikram Ud Din, Ahmad Almogren and Naveed Islam, "An Energy Efficient and Secure IoT-Based WSN Framework: An Application to Smart Agriculture", Sensors 2020, 20, 2081.

[11] Mohammed Jouhari, Khalil Ibrahimi, Jalel Ben Othman and El Mehdi Amhoud, "Deep Reinforcement Learning-based Energy Efficiency Optimization For Flying LoRa Gateways", 2023 IEEE International Conference on Communications (ICC), Rome, Italy.

[12] Gilles Callebaut, Geoffrey Ottoy, Liesbet Van der Perre, "Cross-Layer Framework and Optimization for Efficient Use of the Energy Budget of IoT Nodes", 2019 IEEE Wireless Communications and Networking Conference (WCNC).

[13] Shaik Shabana Anjum, Rafidah Md Noor, Ismail Ahmedy and Mohammad Hossein Anisi, "Energy optimization of sustainable Internet of Things (IoT) systems using an energy harvesting medium access protocol", IOP Conf. Series: Earth and Environmental Science 268 (2019).

[14] Nurrahmat Pradeska, Widyawan, Warsun Najib, Sri Suning Kusumawardani," Performance Analysis of Objective Function MRHOF and OF0 in Routing Protocol RPL IPV6 Over Low Power Wireless Personal Area Networks (6LoWPAN)", 2016 8th International Conference on Information Technology and Electrical Engineering (ICITEE), Yogyakarta, Indonesia