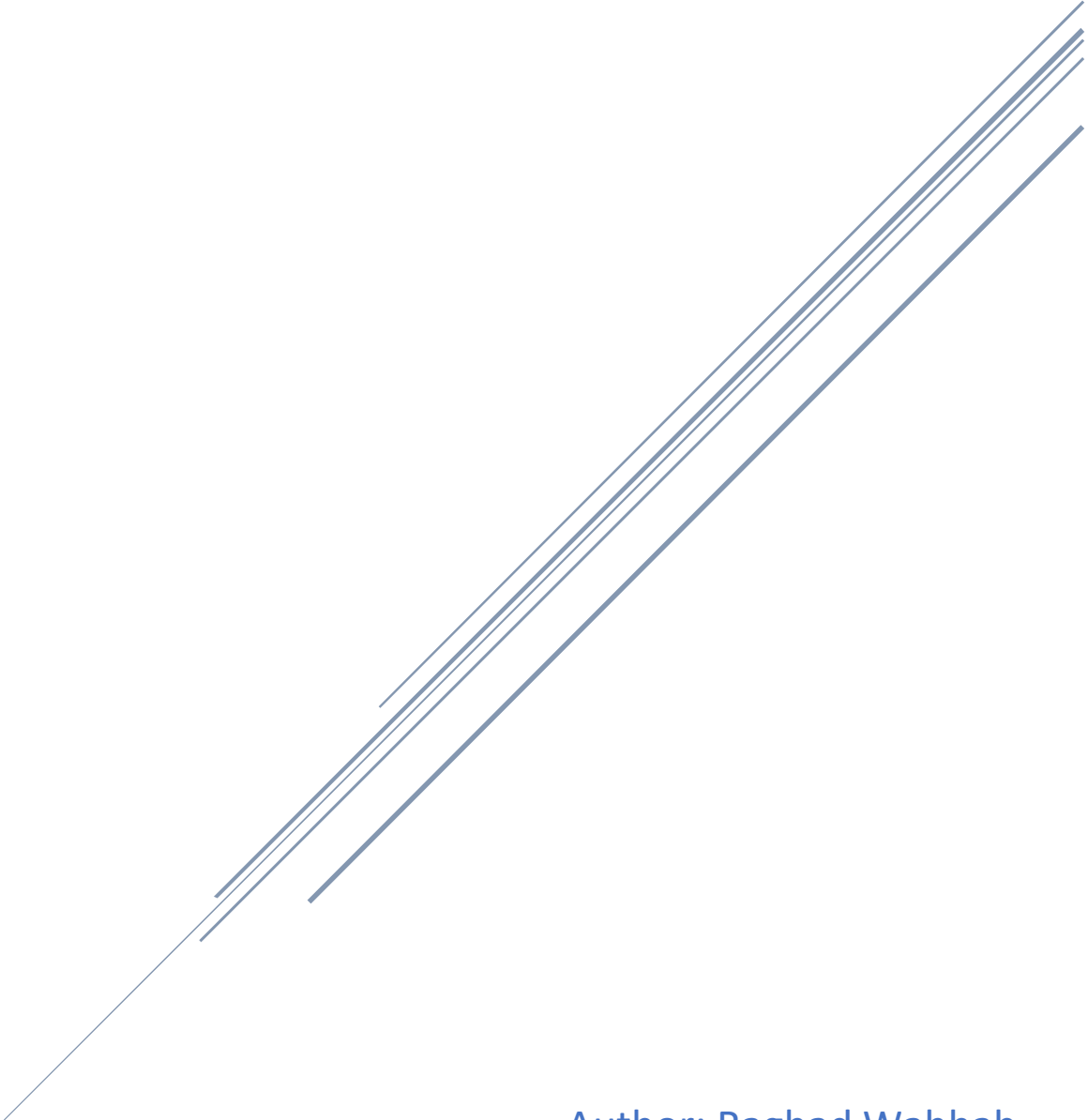


TDK THESIS

Developing routing algorithm to ensure QOS in IoT networks \ WSN.



Author: Raghad Wahhab
Széchenyi István University of Győr

Developing routing algorithm to ensure QOS in IoT networks \ WSN.

Eng. Wahhab Raghad

Supervised by: Richárd Németh - Assistant Lecturer

Faculty of Mechanical Engineering, Informatics, and Electrical Engineering

Department of Informatics

Széchenyi István University of Győr

29.11.2023

Abstract

As Internet of Things (IoT) applications have spread in a variety of industries in this era, including smart homes, healthcare, and environmental monitoring, it was necessary to design new reliable routing protocols that can transfer data efficiently in low-power and lossy networks LLNs. the most famous protocol designed for these networks is the Routing Protocol for Low-power and Lossy Networks (RPL) and it was considered as the standard protocol for LLNs. However, RPL still suffers from some issues such as node density and scalability problems which can reduce the quality of service (QoS) of RPL networks and increase energy consumption.

In this paper, we enhanced the current objective functions used in RPL protocol in order to increase the quality of service (QoS) in IoT networks by designing a new routing algorithm that integrates several routing metrics, including load metrics, residual energy, Expected Transmission Count (ETX), and Received Signal Strength Indicator (RSSI) in one Objective Function (OF). after applying the new algorithm and assessing it using Cooja simulator in different node configurations and network density, we found that the proposed algorithm performs better than default RPL functions, as it offers greater Packet Delivery Ratios (PDR), lower average ETX, and lower power usage. which means that it can improve the path selection process, increase the network reliability, and mitigate the bottleneck problem in busy nodes.

For further research, we will focus on optimizing this routing metric and extend its application to mobile IoT environments to enhance the protocol's operational efficiency. This work not only advances RPL but also improves IoT applications that work in challenging network conditions.

Contents

Introduction.....	1
RPL Protocol.....	2
Reference Study	4
Proposed Model	7
Routing Algorithm:	8
Algorithm Flow chart.....	9
Simulations and results	10
Applications and Advantages of the Proposed Protocol	12
Conclusion and Future prospects	12
References.....	14

Table Of Figures

Figure 1 - RPL DODAG	2
Figure 2 - Node Ranks	3
Figure 3 - Algorithm flow chart	9
Figure 4 - Packet Delivery Rate with 50 nodes.....	10
Figure 5 - Packet Delivery Rate with 70 nodes.....	11
Figure 6 - power consumption with 60 nodes	11
Figure 7 - average ETX with 60 nodes	12
Figure 8 - average ETX with 70 nodes	12

Introduction

Given the great trend in using Internet of Things applications and networks and their contribution to the development of fields that need remote monitoring, measurement, and control, such as smart home applications, smart cities, military applications, and health applications such as monitoring a patient's vital indicators remotely [13], it was necessary to work To develop Internet of Things networks, especially networks with limited resources and energy, such as wireless sensor networks.

Wireless sensor networks are considered one of the most popular types of low-power and low-resource networks that achieve communication between sensors using routing protocols designed specifically to suit the characteristics of these networks, such as limited battery, memory, and processing capabilities. These networks are considered the cornerstone of building Internet of Things applications, so it is necessary to develop a routing protocol capable of making ideal routing decisions because wrong routing decisions will waste network resources. That's why researchers began working on developing an optimal routing protocol capable of meeting the challenges facing low-power devices in wireless sensor networks [14]. and the most prominent and famous protocol developed for routing in these types of networks is RPL protocol (Routing Protocol for Low Power and Lossy Network).

RPL protocol was created mainly for routing in Low-power and Lossy Networks (LLNs). it is a low-power routing protocol intended to handle routing in limited resource networks, smart cities and smart homes, and many applications that consist of resource-limited devices[1]. Because poor-quality routes can exhaust the limited resources quickly, and because routing protocols such as “Open Shortest Path First” (OSPF), “Ad Hoc on Demand Vector” (AODV), “Enhanced Link State Routing” (OLSR), and “Dynamic Source Routing” (DSR) cannot overcome LLNS limitations such as low data loss, low data rates, and low power consumption, and network stability [2], It was necessary to design a new protocol capable of overcoming these limitations.

However, RPL still needs further modifications and improvements to improve the network quality of services Therefore, the main motivation behind this research is to develop the routing algorithm used in the RPL protocol with the aim of improving the performance of the protocol under the conditions of limited energy and resources.

The primary goal of this research is to study and improve the routing algorithm used in RPL protocol with the aim of improving the performance of networks with limited resources and energy and contributing to the dissemination of its applications. differently. This will be done by modifying the function used to make routing decisions in RPL, which is called Objective Function (OF), which currently routes packets according to one routing measure only, by making it consider several routing metrics in order to make the correct routing decisions and to choose paths that achieve optimization according to several metrics, thus improving the performance and reliability of limited resources networks.

The stages and contributions of this study are summarized in the following steps:

- Conduct an analytical study of the RPL routing protocol.
- Identify the weaknesses of the routing algorithm currently adopted in RPL by studying objective functions and evaluating their performance.
- Conduct a reference study of the proposed solutions to improve RPL performance.
- Proposing an algorithm that improves network performance and reliability and reduces energy consumption
- Evaluate the performance of the proposed algorithm by implementing it on Cooja / Contiki3 simulator and comparing it to the original routing algorithms used in the RPL protocol.

RPL Protocol

RPL protocol was designed by the Roll working group and is an abbreviation for Routing Protocol for Low Power and Lossy Networks. It was adopted by the IETF in 2012 as the standard and official protocol for routing in all types of Low-power and Lossy Networks (LLN) such as Wireless sensor networks, as it was designed primarily to meet the critical routing requirements of these networks [15]. RPL is considered a proactive routing protocol that works according to source routing. It also overcomes the previous routing protocols because it supports the IP protocol [16].

RPL protocol was designed based on the IEEE 802.15.4 MAC layer. RPL offers different types of nodes, the sink or root node collects the data and information from all the network's nodes. and the other type is source nodes that receive data from other different nodes and forward them to the sink node.

RPL designs the network topology by constructing a Directed Acyclic Graph (DAG), which consists of one or more Destination Oriented DAGS (DODAG). Each DODAG has its own root node that represents the default destination for all nodes within the DODAG [17]. The process of constructing the DODAG is the first and most important task of the RPL protocol, as it is considered the nucleus of its work and the basis of the routing process that will be carried out by the network nodes. the DODAG is characterized by being non-cyclic because the links that connect the nodes in it are directed in a way that prevents the occurrence of any loop within it, meaning if the path starts from a certain node, it is not possible to return to this node again via this path [18]. Each DODAG represents a tree that is created by the root node (the sink), which represents the final destination for all network nodes, as all nodes send their data periodically to the sink node.

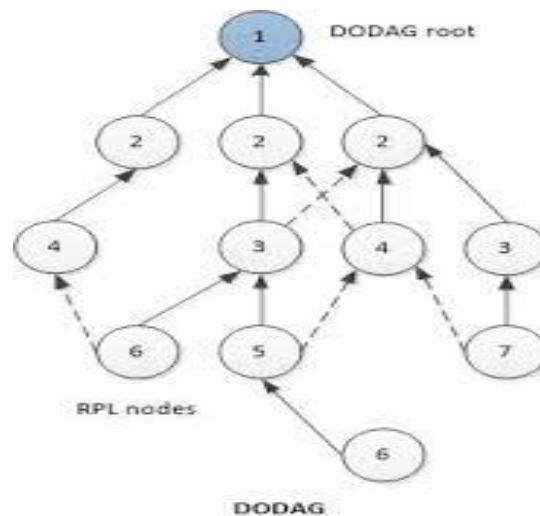


Figure 1 - RPL DODAG [37]

RPL protocol builds the DODAG by depending mainly on what is known as ranks, as each node within the DODAG must have a unique number that indicates the rank of this node, which in turn indicates the position of this node within the DODAG and its distance from the root, the ranks increase from the root towards the leaves, which means that the root node has the lowest rank within DODAG. Therefore, increasing the rank of the node indicates that it is farther from the root, which reduces the advantage of choosing it as a parent node by other nodes because nodes prefer to connect to nodes that are closer to the

destination. And since each node will be linked to a parent node that has a rank lower than its own, loops do not occur within the DODAG [18].

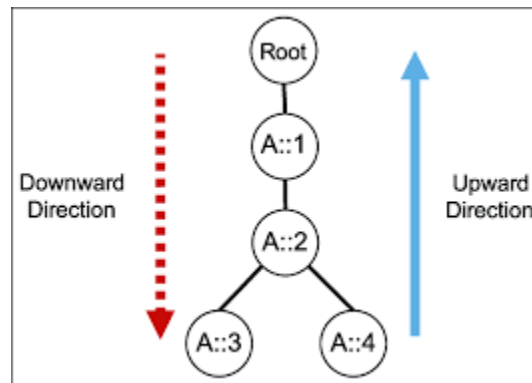


Figure 2 - Node Ranks [38]

Each node in the DODAG can calculate its rank and determine its position within the network using what is known as Objective Function (OFs) [16], which depend on a set of routing metrics such as link quality, remaining energy in the node, or other metrics as inputs [19] and then converted them into a value that indicates the node's rank. Therefore, the node with the best objective function value will be the node that has the lowest rank. Therefore, the objective functions are the direct responsible for building the DODAG [20].

By default, RPL provides a set of default routing functions (Objective Function), these default functions suffer from several weaknesses, and this can be attributed to the fact that they perform the routing operations based on one routing metric only,

- A. The first default Objective Function, OF0, depends only on the hop count metric to choose the shortest path to reach the destination, so the parent selection process in OF0 does not consider any metric related to link quality, instead, it tries to find the path with the least number of hops. This metric is not considered an efficient metric because it does not take into account the long hop issue which negatively affects energy consumption and quality of service.
- B. The second default Objective function, MRHOF, depends on the remaining energy metric which avoids selecting ineffective routes that contain nodes with small residual energy, but it does not consider the link quality metric which may affect the quality of service.
- C. On the other hand, MRHOF can depend on the ETX metric which selects the routes that contain the highest quality links without taking into account any other metrics such as Energy or reliability of the nodes, and this can negatively affect the network performance [3].

RPL also suffers from several problems, such as the problem of adding a lot of child nodes to one parent node, which may cause a bottleneck problem and result in network delays and a high percentage of packet loss because of the congestion in the parent node, this problem more likely to happen in the nodes located near the sink node.

Although RPL has several specifications that make it a standard routing protocol, including, rapid initialization, self-healing, and loop-less topologies, load imbalance is still a major weakness of RPL as it leads to uneven data transmission. As a result, overburdened nodes will lose their power before others. Moreover, If the overloaded nodes are located near the sink, the problem will be more serious because the energy of the nodes near the root node will deplete faster than other nodes which will cause network outages

and reduce network life, to solve the bottleneck problem in RPL networks, we suggest using a load metric to balance the load and extends network life.

In this paper, we tried to address all these mentioned problems by replacing the default objective functions that consider one routing metric with a new improved objective function that integrates four routing metrics, namely Load metric, Residual Energy, Received Signal Strength Indicator RSSI, and Expected Transmission Count ETX.

Reference Study

Authors in [4] tried to improve network lifetime by selecting the next hop node according to the remaining energy in the path. They calculated the route cost by summing the remaining power of all nodes in the route. After that, each node will select the parent that provides the path containing the highest energy nodes. The main downside of this approach is the perceived deterioration in wireless links' efficiency that was selected as parents over and over.

In [19], the authors used the remaining energy metric combined with the ETX metric in one formula, and Equal weights were used in both metrics.

The researchers in [5] suggested a novel function to increase network reliability by maintaining a balanced utilization of nodes' energy. The authors designed an “estimated lifetime” metric “ELT” to calculate how much time a node can run before it runs out of power. The new objective function guarantees that the nodes will consume power in a balanced manner regardless of their distance from the sink node, but it suffers from a large time delay.

In order to balance power consumption between nodes and extend the network life, researchers in [21] proposed two new OFs that both combine the ETX metric and the remaining energy metric, the first function is the “Parent Energy Objective Function” (PEOF) and the second function is (PEOF2). The first OF selects the parent node located one hop away based on ETX and remaining energy, while the second OF calculates the remaining energy in all nodes within the path and combines it with the ETX. Both objective functions were evaluated through simulation, and the simulation results showed that both OFs achieve a similar data delivery rate as in MRHOF, also both of them balance energy consumption between nodes, but PEOF2 outperforms PEOF in terms of extending the life of nodes in the network.

In [6], the authors suggest the (BD-RPL) protocol, which sets a limit on the number of child nodes that can be linked to one parent node. The strength of the suggested protocol is that it doesn't add any additional overhead in comparison to RPL.

In [7], the researchers propose a new RPL metric that depends on what is known as the Queue Backlog, which is a queue that exists within each node to store information about the neighboring nodes in order to increase the throughput efficiency and to ensure that there is no packets loss nor delay.

in [8], the researchers suggest a new Objective function called “LB-OF”, which tries to balance load distribution in all network's nodes, especially the bottlenecked nodes. The proposed technique enables the child nodes to calculate the number of overloaded nodes with the aim of balancing the load and avoiding choosing the bottlenecked nodes as parents, which will eventually improve the network lifetime. However, the authors did not consider other effects such as delay and packet delivery rate.

authors in [9] suggested a new OF relies on a composite routing metric using a fuzzy logic framework. They chose three metrics namely, Hop Count HC, ETX, and residual energy, but they calculated energy consumption differently, as both high and low energy consumption modes are used to evaluate power consumption. this metric may negatively influence energy consumption due to fuzzy logic complex processes.

the authors proposed in [10] a composite metric called (CMOF), which mixes the delay metric with the ETX along the path, and this is supposed to reduce the number of traffic paths and improve latency and packet delivery rate (PDR) as it selects the better links paths and ensures secure links by using ETX. The delay was calculated by summing the time packets spent in the sent queue and the time it took to be sent through the link, which reduced congestion and improved latency and packet delivery rate, but they did not simulate all the criteria needed to determine the protocol's efficiency accurately.

The researchers in [11] suggest a new OF called “OFER” based on a composite routing metric aiming to optimally choose the parent nodes. They use a set of weighted metrics, including packet loss metric, ETX metric, remaining energy metric, and response time metric. Compared with standard RPL, the proposed function reduces packet loss and reduces power consumption. However, they didn't study how the new metric affects the network traffic or if the function can support different network sizes.

-In [22] the authors proposed an improvement on the default objective functions used by RPL, where they developed a composed OF by combining the “hop count metric” (HC) with several metrics respectively (node “residual energy” metric, “ETX” metric, and “Packet Forward Indicator” (PFI) metric). The results showed that combining the hop count metric with the remaining energy metric reduces energy consumption without affecting packet loss and delay, and the combination with the PFI metric reduces the packet loss rate.

Also, authors in the research [23] proposed a modification to the standard OF MRHOF, and the modified function was named PER-HOP ETX. This function calculates the average value of the link's ETX between nodes along the path. This improved function outperformed OF0 and MRHOF as it reduce the energy consumption, delay, and packet delivery rate, but it consumes more energy in small networks with low node density.

In [24] the authors proposed a new objective function called EEQ. EEQ uses ETX, remaining energy, and Queue length metrics. The main idea of this function is to keep the bottlenecked nodes (nodes that receive a lot of requests) connected to the network. This OF was evaluated and the result shows that it reduces overhead in terms of traffic loads compared to MRHOF and OF0, but it has not been evaluated based on other significant metrics such as power consumption, network lifetime, and convergence.

A new protocol called EL-RPL was proposed with the aim of reducing energy consumption and balancing load [25], EL-RPL combines “load, battery depletion index (BDI), and ETX” metrics and uses them in the process of selecting the preferred parent. The path that achieves the lowest OF value after combining the three metrics is chosen as the optimal path.

To solve the problem of network congestion, which is considered one of the basic issues in RPL, the authors in [26] proposed a new protocol called COAR protocol which is a congestion-aware protocol that uses a new “congestion-aware objective function” (CoA-OF) to choose the preferred parent, this OF combines several routing metrics, namely “ETX, queue utilization (QU), and Residual Energy”, so it avoids congestion by choosing a less congested alternative path to the destination. This protocol achieves high reliability, reduces End-to-end delay, and increases packet delivery rate and energy consumption. However, CoAR is designed to support fixed networks only and is therefore not suitable for mobile environments.

In research [27], the authors tried to enhance RPL's performance and quality of service by suggesting a solution that combines several routing metrics using fuzzy logic, the combined metrics are hop count, end-to-end delay, link quality level (LQL), and ETX. The results showed that the solution enhanced RPL's performance in terms of packet delivery rate and delay, but it did not take into account the nodes' remaining energy and network lifetime.

In [28] authors proposed a composite routing metric that takes into account the link reliability using ETX metric in addition to the energy consumption metric. the new composite metric was named Lifetime and

Latency Aggregateable Metric (L2AM). L2AM guarantees the quality of the link and balances energy consumption between the nodes while creating DODAG and thus extending the network lifetime.

In [29], the authors proposed a new Objective Function to achieve energy efficiency and ensure link reliability, the new OF is called Energy Efficient and Path Reliability Aware Objective Function (ERAOF), this function combines two routing metrics, namely ETX and energy consumed by the node. The result showed that ERAOF increases in the packet delivery rate and reduces energy consumption, in addition, it reduces the hop count needed to reach the destination. However, ERAOF impact on delay, and parent switching process has not been evaluated.

A new OF, called AHP-OF, was proposed in [30] that combines several routing metrics, namely ETX, Hop Count, and Residual energy. The results showed that this combination reduces energy consumption and balances traffic in the network.

With the aim of improving the quality of service in RPL protocol, the authors in [31] developed an objective function called OFQS that combines several routing metrics, namely ETX, delay, and power state. This function maintains some of the characteristics of the default MRHOF function in order to reduce the process of switching parents. In comparison to the default OFs in RPL, OFQS increases network lifetime and packet delivery rate, reduces delay, and balances traffic between nodes.

In [32] the authors proposed two composite objective functions, the first is called the “weighted combined metrics objective function” (“WCM-OF”) and the second is called the “Non-weighted combined metrics objective function” (“NWCM-OF”), the two functions combine the ETX metric with the energy consumption metric. WCM-OF balances the preference between ETX and energy consumption metrics as it uses equal weights for both metrics, while NWCM-OF uses unequal weights in order to give preference to the link quality metric or the node energy metric. The results showed that the proposed functions improve the network performance in comparison with the Default OFs in RPL.

In response to the requirements of wireless sensor networks such as limited energy, the authors in [33] proposed the objective function TXPFI, which measures the expected number of frame re-transmissions needed for data to be sent successfully. This measure was designed primarily to be used in networks that contain a group of uncooperative nodes. The results show that TXPFI can perform more efficiently than other metrics, especially in avoiding unreliable links and nodes. TXPFI reduces the packet drop rate and significantly improves network performance.

In [34] the researchers analyze the performance of link quality and improve the equation that calculates routing reliability in RPL, the equation calculates the ratio of packets routed by a node to the total number of packets that were sent to it. This equation Improves the packet delivery rate, but it still has some drawbacks, Firstly, it is set to the value 0 at all nodes at the beginning of establishing the network, This means, theoretically, that no parent node will be chosen until after a long period of time, and this leads to a loss of bandwidth and delays. Secondly, the value of this equation should range between 0 and 1, but when applying the scale in simulations, it was found that the value may exceed 1 in some cases, therefore, this calculation method is theoretical and not suitable for practical application on networks.

In [35] packet forwarding indication (PFI) was defined as a new routing metric, moreover, a composite metric was defined to ensure the reliability of links and nodes by combining ETX and PFI metrics, thus guaranteeing quality of service and improving the level of reliability in the protocol. The combining process was performed in the additive method and the lexical method respectively. The results showed that using the additive method is more efficient than using the lexical method, as the additive method is more flexible in choosing the metric's weights and it can balance the reliability of the links and the trust value of the node.

- In [36] the authors proposed a new routing metric which is an energy-aware node metric (RERBDI), this new metric considers the remaining energy ratio (RER) and the battery discharge index (BDI) to make routing decisions. then they defined an objective function called (OFRBE) that combines RERBDI with the

ETX metric and used this OF to perform the routing process. After applying this OF, the simulation results showed that the network lifetime and packet delivery rate were improved.

Proposed Model

In RPL, default OFs used to select the next hop node have some weaknesses such as long hops, also there are some problems that appear when the number of nodes becomes large, and the network size increases [12]. This leads to flocking problems which have a great impact on network quality of service (QoS) and restricts IoT application services.

as we mentioned the objective function (OF0) chose parents without considering link quality as it only considers the hop count metric, which makes it inefficient enough because it does not take into account the long hop issue which has a negative impact on energy consumption and QoS. The second OF, MRHOF considers either the ETX metric without taking into account the Energy metric, or it considers the remaining energy metric without taking ETX into account, and this can negatively affect network performance.

The newly designed objective function integrates four metrics: Residual Energy, Load metrics, ETX, and RSSI. Residual Energy metric avoids connecting with low-power nodes which increases the network lifetime. meanwhile RSSI metric chooses the best node in terms of the strength of the received signal which will increase the Packet Delivery Rate (PDR). also, the Load metric prevents selecting bottlenecked nodes as parents, and the ETX metric guarantees the quality of the path's links.

eventually. the proposed protocol solves the bottleneck problem and decreases congestion.

According to the proposed algorithm, the node will be selected as a parent after evaluating it according to the previous metrics so that the node that has the minimum ETX, the minimum load scale, the maximum remaining energy, as well as the maximum received signal strength, is selected.

A. The remaining energy metric:

We used the residual energy metric to measure the lifetime of the network. Therefore, in the phase of creating the DODAG and selecting preferred parents, the node with low residual energy should not be selected as parents to prevent network outages. The power consumption of each node will be calculated based on different operating modes, usually these modes are listening mode which includes (listening + receiving + idle modes), transmit mode, processing mode (CPU mode), and low power mode (sleep mode). Thus, the current power consumption can be calculated as in the following relation:

$$EC(X) = P_{sleep}(X) \times T_{sleep}(X) + P_{tx}(X) \times T_{tx}(X) + P_{cpu}(X) \times T_{cpu}(X) + P_{les}(X) \times T_{les}(X)$$

Where P represents the energy consumed in each mode, while T represents the time period for each mode. Then the remaining energy can be calculated as follows:

$$ER_X = E_{initial} - EC_X$$

Where E-initial is the maximum initial energy of a node.

B. Load metric:

Network traffic is the amount of data transmitted in a specified amount of time over a network. A load-balancing method has been suggested by the researchers in [11] based on the number of child nodes connected with each parent node throughout the network. Each node within DODAG broadcasts a DIO message containing the number of its children to all its child nodes, and then each node calculates the number of children for each of the potential parent nodes. so, by calculating the cumulative number of the child nodes, the rank value of these nodes is calculated, and the parent node with the lowest rank is determined based on the load scale. The load scale can be calculated as:

$$NT = \sum_{i=1}^n CN(i)$$

$$L(Px) = \sum_{N=1}^n NT(N)$$

Where n is the number of child nodes, NT is the traffic, and L is the load on the parent node.

C. received signal strength index:

Signal strength is used in order to effectively use resources and achieve reliable communication and reduce end-to-end delay through the transmission process.

To measure the signal strength, we use RSSI which stands for Received Signal Strength Index. RSSI is commonly used in 802.11 standards, and it refers to the calculated signal strength of a packet received between two nodes. It is defined by the following relations:

$$P_{rx} = P_{tx} - 20 \log \left(\frac{4\pi D}{\lambda} \right) + G_{tx} + G_{rx} \text{ (dbm)}$$

P_{rx} : received energy

P_{tx} : transmitted power

G_{rx} : transmission gain

G_{tx} : reception gain

D: the distance between the transmitter and the receiver

Routing Algorithm:

The Objective Function (OF) is mainly responsible for creating the DODAG and selecting parents in the RPL network. Our new OF uses four routing metrics to increase power efficiency and network life, use high-quality links, and solve data transmission issues in multipoint communications networks such as the bottleneck problem that usually occurs at the receiver node, thus, the proposed algorithm selects the node that contains Minimum ETX, minimum NT (load metric), maximum remaining energy of the node, and maximum signal strength (RSSI) so that this node represents the best node to be selected among the candidate nodes to form the path.

The final value is calculated based on the sum of the four metrics and choosing the optimal value among them: highest residual energy, lowest ETX (lowest expected transmission cost), lowest load, and highest received signal strength index (RSSI).

Considering all metrics, the objective function aims to select the best parent in terms of residual energy, received signal strength, and number of child nodes to improve power efficiency and network performance.

Rank of the node should consider max (ER), max (RSSI), min (ETX), min (load)

And because RPL usually chooses the lowest rank node as it is considered closer to the sink node, the proposed relation will be as follows:

$$Rank = \frac{1}{\max(ER)} + \frac{1}{\max(RSSI)} + \min(ETX) + \min(Load)$$

Algorithm Flow chart

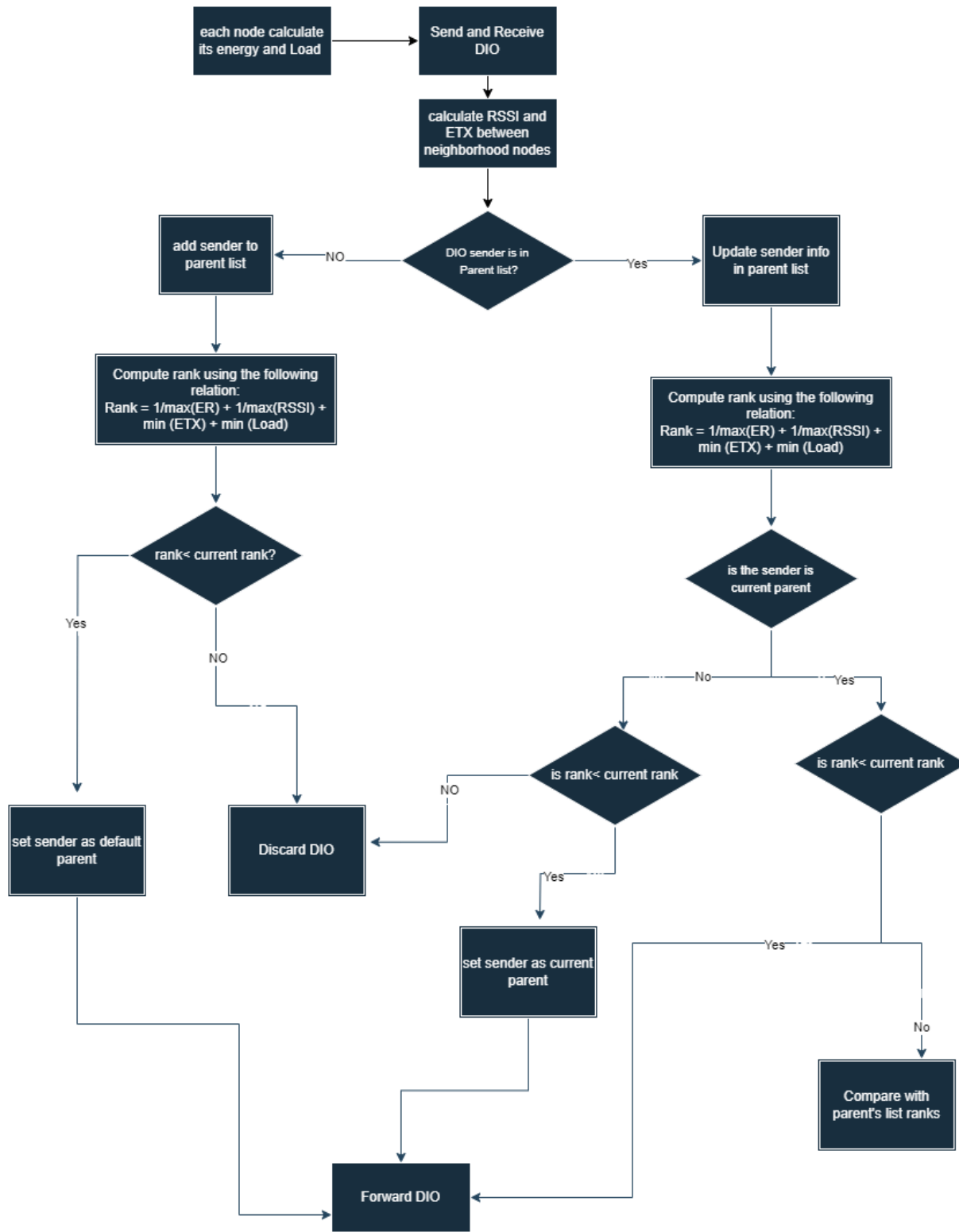


Figure 3 - Algorithm flow chart

Simulations and results

Cooja/Contiki3 simulator was used to perform the simulations in this research. The smart home was used as a case model. The used transmission ranges are 40, 50, and 60 m, and the interference distance is 100 m. About the MAC protocol, we used the CSMA protocol. The simulation area is 100 x 100 m, and the node type is skymote, with network topologies ranging between 50 and 70 nodes. We used three transmission bands 40, 50, and 60m, and nodes were randomly distributed.

We applied MRHOF OF and the newly edited OF to each network and compared the parameters such as packet delivery ratio (PDR), power consumption, and ETX to ensure the effectiveness of the proposed model.

-packet delivery rate (PDR)

PDR is defined as the ratio of data packets received by a node to the number of data packets sent. Figure 1 shows the packet delivery ratio (PDR) with network topology (50, 70 nodes). Each node is implemented with different transmission ranges (40, 50, and 60m). every node will send 20 packets using both MRHOF and the new OF. When we added 50 nodes and set the transmission range to 40m, the packet delivery rate in MRHOF is about 75.1%, while it is 95.9% in the proposed protocol. Meanwhile, the packet delivery rate in MRHOF is about 91%, and in the proposed protocol it is 97.3% at the transmission rate of 50m. The packet delivery rate in MRHOF becomes about 94% and 97.5% in the proposed protocol at the 60m transmission range.

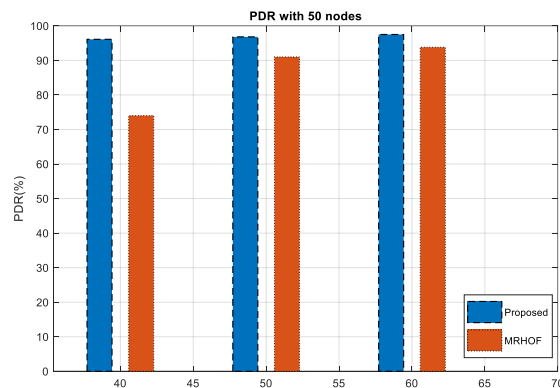


Figure 4 - Packet Delivery Rate with 50 nodes

When nodes are 70, and the transmission range is 40 meters, the findings show that the packet delivery rate in MRHOF is 31.2% while it is 85.5% in the proposed model. But, this percentage becomes about 34.7% in MRHOF, and 93.1% in the proposed protocol for 50m transmission range.

In the case of the 60-meter transmission range, we find that the packet delivery rate in MRHOF is 93.9%, while in the new protocol, it becomes 96.9%. Thus, we find that the efficiency of the enhanced RPL increased with increasing the number of nodes, in particular with 40 and 50 transmission ranges. The packet delivery rate increased with the transmission range because the number of network hops to the receiver node decreased. In the case of a 60-meter transmission range the proposed protocol effect is less.

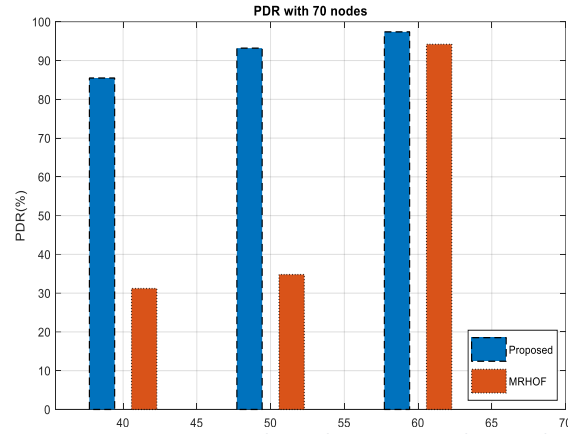


Figure 5 - Packet Delivery Rate with 70 nodes

-Energy consumption

Since IoT nodes are powered using batteries, the overall power consumption is an important criterion for the efficient operation of the network. Figure 2 shows that the new protocol consumes less power than the MRHOF protocol, for different transmission ranges. As the consumption decreased from 135 in MRHOF to 98 in the proposed protocol when the transmission range is 40 meters. As well as from 102 to 86 when the transmission range is 60 meters.

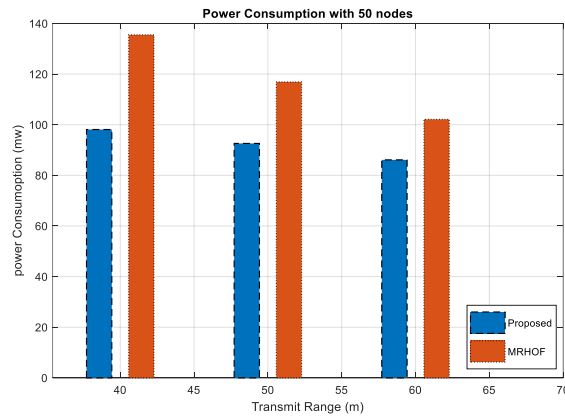


Figure 6 - power consumption with 60 nodes

When the number of nodes increased to 70 nodes, we noted that the performance of the proposed protocol was better in all transmission ranges. Where the MRHOF protocol still consumes a lot of power. In the new proposed RPL, the power consumption decreased with a high transmission range as the new protocol uses the load balancing metric and consumes less power.

- Expected Transmission Count

The following figure shows the average ETX for different transmission ranges and network topologies. And as we can see the average ETX was lower in the new protocol compared to the MRHOF. The smaller the ETX, the lower the power consumption, which mean that the new OF has a better ability to choose the best path to the receiver. This shows that the performance of the MRHOF function in large networks with transmission ranges less than 60 m is very poor, but the new protocol can achieve a high performance at any transmission range.

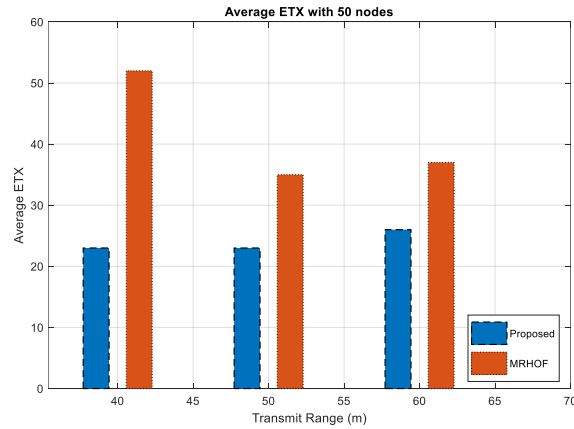


Figure 7 - average ETX with 60 nodes

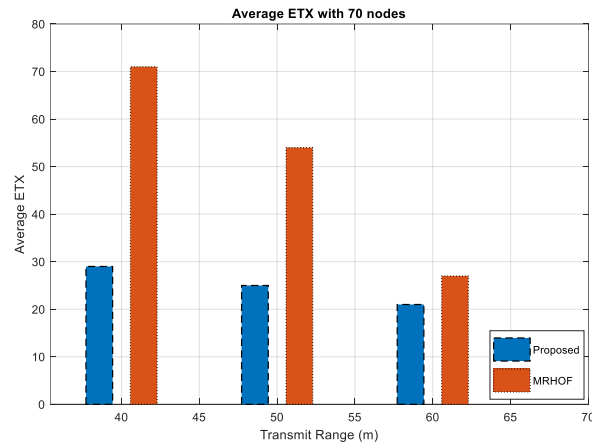


Figure 8 - average ETX with 70 nodes

Applications and Advantages of the Proposed Protocol

the new algorithm offers a significant contribution in the field of wireless sensor networks (WSNs) and IOT networks particularly because it achieved higher PDR, lower average Expected Transmission Count, and reduced energy consumption across various network scenarios. One of the most important advantages of our algorithm is its ability to effectively select optimal routing paths, regardless of the transmission range which will enhance the network performance. These achievements are crucial in applications where reliable and timely data delivery is paramount, such as environmental monitoring, industrial automation, and healthcare systems. In environmental monitoring, for instance, the proficiency of the new protocol in path selection ensures that critical data from sensors are reliably transmitted to the receiver which will ensure the accurate analysis of environmental parameters.

Moreover, the protocol's scalability makes it a robust solution for large-scale WSN deployments, as it offers scalability for applications in smart cities and infrastructure monitoring. Also, the protocol reduces the power consumption which is an important factor for remote applications or energy-constrained environments, contributing to extended network lifetime and reduced maintenance efforts.

The algorithm also offers sustainability benefits as reducing power consumption align with modern environmental concerns, which make our protocol an eco-friendly choice for applications that focus on sustainable and energy-efficient wireless sensor networks.

Conclusion and Future Prospects

in this paper, we introduced the RPL routing protocol and its default objective functions, and we enhanced the default OF “MRHOF” by using four routing metrics which are: Load, Residual energy, RSSI, and Expected Transmission Count. after implementing the new proposed OF we perform a simulation and the findings show that the newly composed metric can choose a better routing path than the original MRHOF, moreover, it achieves lower average ETX, and lower power consumption than the RPL protocol in all network situations with varying transmission ranges (40, 50, and 60 meters).

The findings showed that the efficiency of the newly edited RPL protocol has increased with the number of nodes, particularly at low transmission ranges (40, 50), and that the PDR has increased with an increase in transmission range. In the case of a transmission range of 60 meters, power consumption and packet loss percentage decreased because of the single hop in the network to the receiver.

For future work, other approaches can be considered in order to obtain high efficiency of the protocol and to save more power by suggesting an efficient algorithm that saves DIO downtime to increase the efficiency, and also studying the mobile models of the network nodes for greater efficiency.

References

- [1] Tim Winter, Pascal Thubert, Anders Brandt, Jonathan W Hui, Richard Kelsey, Philip Levis, Kris Pister, Rene Struik, Jean-Philippe Vasseur, Roger K Alexander, et al., "RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks," RFC 6550, pp. 1-157, 2012.
- [2] Kris Pister, Pascal Thubert, Sicco Dwar, and Tom Phinney, "Industrial Routing Requirements in Low-Power and Lossy Networks", 2009.
- [3] Omprakash Gnawali and Philip Levis, "The Minimum Rank with Hysteresis Objective Function," RFC 6719, 2012.
- [4] Patrick Olivier Kamgueu, Emmanuel Nataf, Thomas Ndie Djotio, and Olivier Festor, "Energy-Based Metric for the Routing Protocol in Low-Power and Lossy Network", *Sensornets*, pp. 145-148, 2013. <https://doi.org/10.5220/0004313401450148>
- [5] Oana Iova, Fabrice Theoleyre, and Thomas Noel, "Using Multiparent Routing in RPL to Increase the Stability and the Lifetime of the Network," *Ad Hoc Networks*, vol. 29, pp. 45-62, 2015. <https://doi.org/10.1016/j.adhoc.2015.01.020>
- [6] Fadwa Boubekur, Lelia Blin, Remy Leone, and Paolo Medagliani, "Bounding Degrees on RPL," *Proceedings of the 11th ACM Symposium on QoS and Security for Wireless and Mobile Networks*, pp. 123-130, 2015. <https://doi.org/10.1145/2815317.2815339>
- [7] Abdullah MA Awad, Rosminazuin Ab Rahim, and Aisha Hassan Abdalla Hashim, "Queue Backlog as A Node Metric for RPL Protocol," *International IEEE Conference on Computer and Communication Engineering (ICCCE)*, pp. 246-250, 2016. <https://doi.org/10.1109/ICCCE.2016.61>
- [8] Mamoun Qasem, Ahmed Al-Dubai, Imed Romdhani, Baraq Ghaleb, and Wajeb Gharibi, "A New Efficient Objective Function for Routing in Internet of Things Paradigm," *IEEE conference on standards for communications and networking (CSCN)*, pp. 1-6, 2016. <https://doi.org/10.1109/CSCN.2016.7785168>
- [9] Hanane Lamaazi and Nabil Benamar, "RPL Enhancement Using A New Objective Function Based on Combined Metrics," *13th IEEE international wireless communications and mobile computing conference (IWCMC)*, pp. 1459-1464, 2017. <https://doi.org/10.1109/IWCMC.2017.7986499>
- [10] TG Harshavardhana, BS Vineeth, SVR Anand, and Malati Hegde, "Power Control and Cross-Layer Design of RPL Objective Function for Low Power and Lossy Networks," *10th IEEE international conference on communication systems and networks (COMSNETS)*, pp. 214-219, 2018. <https://doi.org/10.1109/COMSNETS.2018.8328200>
- [11] Parmod Singh and Yaw-Chung Chen, "RPL Enhancement for A Parent Selection Mechanism and an Efficient Objective Function," *IEEE Sensors Journal*, vol. 19, no. 21, pp. 10054-10066, 2019. <https://doi.org/10.1109/JSEN.2019.2927498>
- [12] P. Sanmartin, A. Rojas, L. Fernandez, K. Avila, D. Jabba, and S. Valle, "Sigma Routing Metric for RPL Protocol," *Sensors*, vol. 18, no. 4, pp. 1-18, 2018. <https://doi.org/10.3390/s18041277>
- [13] Vasseur, Jean-Philippe, and Adam Dunkels. *Interconnecting smart objects with ip: The next internet*. Morgan Kaufmann, 2010.
- [14] Palattella, Maria Rita, et al. "Standardized protocol stack for the internet of (important) things." *IEEE communications surveys & tutorials* 15.3 (2012): 1389-1406.
- [15] S. Umamaheswari and A. Negi, "Internet of Things and RPL routing protocol: A study and evaluation," *International Conference on Computer Communication and Informatics, India*, 2017.

- [16] T. Winter, P. Thubert, A. Brandt, J. Hui, R. Kelsey, P. Levis, K. Pister, R. Struik, J. Vasseur, and R. Alexander, "Rpl: Ipv6 routing protocol for low-power and lossy networks," Internet Requests for Comments, IETF, RFC 6550, 2011.
- [17] Zaatouri, I., Alyaoui, N., Guiloufi, A. B., Sailhan, F., & Kachouri, A. (2022). Design and Performance Analysis of Objective Functions for RPL Routing Protocol. *Wireless Personal Communications*, 124(3), 2677-2697.
- [18] S. A. A. Hakeem, A. A. Hady, and H. W. Kim, "RPL routing protocol performance in smart grid applications based wireless sensors: Experimental and simulated analysis," *Electronics (Switzerland)*, vol. 8, no. 2, pp. 1–23, 2019.
- [19] J. Abied Hatem, H. Safa, and W. El-Hajj, "Enhancing Routing Protocol for Low Power and Lossy Networks," 13th International Wireless Communications and Mobile Computing Conference, pp. 753–758, 2017.
- [20] N. Pradeska, Widyawan, W. Najib, and S. S. Kusumawardani, "Performance analysis of objective function MRHOF and OF0 in routing protocol RPL IPV6 over low power wireless personal area networks (6LoWPAN)," 8th International Conference on Information Technology and Electrical Engineering: Empowering Technology for Better Future, pp. 0–5, 2017.
- [21] J. Nurmio, E. Nigussie, C. Poellabauer, Equalizing energy distribution in sensor nodes through optimization of RPL, in: Proc. - 15th IEEE Int. Conf. Comput. Inf. Technol. CIT 2015, 14th IEEE Int. Conf. Ubiquitous Comput. Commun. IUCC 2015, 13th IEEE Int. Conf. Dependable, Auton. Se, 2015, pp. 83–91
- [22] J.P. Yunis, D. Dujovne, Energy efficient routing performance evaluation for LLNs using combined metrics, in: 2014 IEEE Bienn. Congr. Argentina, 2014, pp. 741–746.
- [23] W. Xiao, J. Liu, N. Jiang, H. Shi, An optimization of the object function for routing protocol of low-power and lossy networks, in: The 2014 2nd International Conference on Systems and Informatics (ICSAI 2014), 2014, pp. 515–519.
- [24] S. Sarwar, S. Rauf, R. Rasheed, L. Aslam, Energy-aware routing in internet of things (IoT), in: 2nd Int. Conf. Commun. Comput. Digit. Syst. (C-CODE), Islam. Pakistan, Pakistan, 2019, pp. 81–86.
- [25] S. Sennan, P. Srinivasan, Energy and load aware routing protocol for internet of things, *Int. J. Adv. Appl. Sci.* 7 (3) (2018) Septno. October, p. 255~264, 2018, doi:10.11591/ijaas.v7.i3.pp255-264.
- [26] K.S. Bhandari, A.S.M.S. Hosen, G.H. Cho, CoAR : congestion-Aware routing pro- tocol for low power and lossy networks for IoT applications, *Sensors* 18 (2018) 3838
www.mdpi.com/journal/sensors , doi: 10.3390/s18113838
- [27] Gaddour, O., Koubaa, A., & Abid, M. (2015). Quality-of-service aware routing for static and mobile IPv6-based low-power and lossy sensor networks using RPL. *Ad Hoc Networks*, 33, 233-256.
- [28] S. Capone , R. Brama , N. Accettura , D. Striccoli , G. Boggia , An energy efficient and reliable composite metric for RPL organized networks, *Int. Conf. Embed. Ubiquitous Comput.*, 2014 .
- [29] N. Sousa , J.V.V. Sobral , J.J.P.C. Rodrigues , R.A.L. Rabêlo , P. Solic , ERAOF: a new RPL protocol objective function for internet of things applications, in: Com- puter and Energy Science (SpliTech), 2017 2nd International Multidisciplinary Conference on, 2017, pp. 1–5 .
- [30] W. Alayed, L. Mackenzie, D. Pezaros, Analytical hierarchy process multi-metric objective function for RPL, in: 2018 IEEE 17th Int. Symp. Netw. Comput. Appl. (NCA), 2018, pp. 1–5, doi: 10.1109/NCA.2018.8548054 .
- [31] J. Nassar , N. Gouvy , N. Mitton , Towards multi-instances QOS efficient RPL for smart grids, 14th ACM Int. Symp. Perform. Eval. Wirel. Ad Hoc, Sensor, Ubiquitous Networkst, 2017 .

- [32] AE Hassani, A Sahel, A Badri, A new objective function based on additive combination of node and link metrics as a mechanism path selection for RPL protocol International Journal of Communication Networks and Information Security (IJCNIS), 2020
- [33] P. Karkazis , I. Papaefstathiou , L. Sarakis , T. Zahariadis , T. Velivassaki , D. Bargio- tas , Evaluation of RPL with a transmission Count- Efficient and trust-aware routing metric, in: IEEE ICC - Ad-hoc and Sensor Networking Symposium Evaluation, 2014, pp. 550–556 .
- [34] Pranesh V. Kallapur, N. Ranjan, Rohan Vidyarthi, Anshuman, Vishwamitra Singh, Enhanced Variant of RPL for Improved Security, 2017 International Conference on Advances in Computing, Communications and Informatics (ICACCI)
- [35] Terpsichori-Helen N. Velivasaki, Panagiotis Karkazis, Theodore V. Zahariadis, Panagiotis T. Trakadas4 and Christos N. Capsalis, Trust-aware and link-reliable routing metric composition for wireless sensor networks, October 2012 Transactions on Emerging Telecommunications Technologies 25(5)
- [36] Ali Hassan, Saleh Alshomrani, Abdulrahman Altalhi and Syed Ahsan, “Improved Routing Metrics for Energy Constrained Interconnected Devices in Low-Power and Lossy Networks”, KICS Journal of Communications and Networks, Vol. 18, No. 3, pp.327- 332, June 2016
- [37] IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL). (2001, January 12). <http://pervasivecomputinginfo.blogspot.com/2017/01/ipv6-routing-protocol-for-low-power-and.html>
- [38] Oh, S., Hwang, D., Kim, K., & Kim, K.-H. (2018). A hybrid mode to enhance the downward route performance in routing protocol for low power and lossy networks. International Journal of Distributed Sensor Networks, 14(4), 155014771877253-155014771877253.