A New Objective Function for RPL Based on Combined Metrics in Mobile IoT

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***Abstract*—To satisfy the quality of service requirements for some applications in the Internet of Things (IoT) network with mobile nodes, routing protocols must be adaptable to make better routing decisions. Routing Protocol for Low-power and Lossy Networks (RPL) is one of the routing protocols that support metrics and constraints while building a Destination Oriented Directed Acyclic Graphs (DODAG) using a specific Objective Function (OF). However, RPL metrics that use standard OFs do not guarantee the performance criteria for a specific mobile IoT in terms of received and lost packets, overhead, throughput and power consumption. In this paper, we propose a new version of mrhof based on a combination of metrics such as total energy, the number of neighbors, and expected transmission count (ETX) to evaluate RPL performances in a mobile context. Then, we compare the assessment of this function to existing OFs based on various mobility models (Random Waypoint (RWP), Reference Point Group Mobility (RPGM), Nomadic) and node densities. The results show that this new function is more efficient than the standards OF in terms of packets received and packets lost with Random Way Point and RPGM models. Regardless of the number of nodes, it also reduces ETX and traffic overhead for all mobility models~~,~~ as well as convergence time in the Random Waypoint environment. Furthermore, this new function contributes to the improvement of Rtmetric, the enhancement of throughput at low density only in favor of RWP and RPGM models, and an effective power consumption reduction through all densities and mobility models.**

***Keywords*—internet of things (IoT), routing protocol for LLNs (RPL), objective function (OF), energy, neighbors, ETX, mobility, Contiki.**

I. INTRODUCTION

The Internet of things (IoT) describes the interconnection between physical "objects" from anywhere at any time to exchange data over a network without human interaction. This object can be any system capable of interacting with other objects or systems remotely. The IoT can rely on any network type as long as every device can be individually addressed [1]. For instance, this technology can be used to collect remote data from weather stations to monitor air quality, to accomplish tasks in home automation, to control systems such as door, lock, lights and heaters [2], to remotely monitor agriculture, and to manage energy. One of the promising IoT applications is flood monitoring, where developers have deployed a system based on solar power and fuzzy logic algorithms to extend the lifetime of batteries used in the LoRa network. The developed system enables the collection of reliable and real-time data on a river's water level and dissolved oxygen [3]. In general, the IoT is made up of a number of nodes (devices), including one or more sinks and gateways. It exploits the routing process for sending and receiving data packets from these devices. To enable these devices to communicate over a network, the Internet Engineering Task Force's (IETF) ROLL working group standardized the IPv6 routing protocol for low-power and lossy networks [4]. In low-power and lossy networks (LLN), RPL helps accelerate the creation of networks and the sending of information to a large number of nodes. It is a distance vector protocol that builds DODAG based on link and node metrics. The related DODAG is a tree topology that downstreams and upstreams routes based on an objective function (OFs). RPL usually uses these OFs to allow the selection of parents and the building of the DODAG topology. In this context, two major objective functions: Objective Function Zero (OFO) [5] and Minimum Rank with Hysteresis Objective Function (MRHOF) [6] have been designed by Routing Over Low-Power and Lossy (ROLL) in order to fulfil the optimization criteria and satisfy the application requirements. Indeed, OFO selects the ideal parent based on the fewest number of hops, whereas mrhof chooses the optimal route to the sink node using the minimum Expected Transmission Count (ETX). In this case, the routing path of the node is calculated by the number of neighbors available in the network. When a node is fairly closer to the root node or has many children with high-quality links that receive and transmit a large number of packets, their battery capacity is quickly depleted. In addition, the IoT network, especially the mobile IoT, will become congested due to an unbalanced load distribution between many nodes. As a result, the overloaded node's energy will really be depleted far more rapidly than that of

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other nodes. Also, if the congested node is the bottleneck node, the problem is even more detrimental [7, 8]. However, RPL is designed for static IoT and does not support device mobility. Moreover, it suffers from load imbalance, especially when there is a non-uniform distribution of in large-scale devices [9]. As a result, the network's quality of service is impacted in terms of overhead, throughput, convergence time and power consumption. As is can be seen, these issues pose major challenges to the IoT networks. Therefore, the innovation of this research is to solve the issues encountered in RPL during load balancing and mobility of the IoT devices by proposing a new objective function based on MRHOF that takes into account total energy consumption, the number of neighbors, and link ETX. To show the improvement that rpl-TotEg-Neighbors provides, we compare it to the standards MRHOF and OF0 that use the ETX link metric with the total Energy consumption and the hop count respectively.

The remaining part of this paper is structured as follows: the second section provides an overview of the most recent research on RPL improvement, functions objectives, and problem statements. Section III describes the process of RPL in Contiki and presents our new OF approach for assessing QoS in a mobile context with various densities. Section IV presents the analysis and results of the new Objective Function and compares them to the other standard functions through simulations. Finally, Section V concludes the paper with some perspectives for future work.

II. RELATED WORKS

The challenge that the internet of things confronts is finding the best technique for communication between objects that guarantees better performance while consuming less energy. These objects have limited power resources and are frequently linked by radio links of varying quality. As a result, academia and industry collaborated to develop the 6LowPAN technique, which connects these low-power objects to the IP world (IPv6) over IEEE 802.15.4 links [10]. To that end, several communication protocols have been developed, including MQTT [11], CoAP (Constrained Application Protocol), and RPL [12, 13]. Many studies have been carried out to evaluate and improve the RPL protocol under various network conditions, including energy efficiency, quality of service, load balancing, congestion and mobility. Provided the inequity nature of RPL and the negative impacts of these imbalanced networks on IoT routing, the author of [14] presented a review study for increased energy efficiency and performance in a more load-balanced network. Specifically, the authors in [15] presented a comprehensive survey of RPL that focused on an existing objective function and a set of metrics, they also demonstrated the distinction between the use of single and composite metrics as well as the weight of each on parent choice and network performance. Lastly, this study discusses the advantages and the weaknesses of each method studied. The authors of [16] presentd an RPL protocol instantiation that employs residual energy as one of the routing metrics in the objective function. The deployment uses a well-known battery theoretical model for predicting the node lifetime for routing at runtime. The results show that this approach improves energy consumption distribution and network life time, but it does not account for the combined metrics energy and ETX. The authors of [17] presented ALABAMO, a model that uses a new objective function for RPL to balance packets forwarded by neighbor nodes. The results show that the proposal can reduce node energy consumption while increasing network lifetime. However, this approach does not consider its impact on other network metrics such as delay. On the other hand, the number of hops used in multi-hop routing increases the amount of information collected, which decreases power consumption and reliability. To address this congestion issue, various approaches such as control of resources, traffic control, and hybrid schemes have been proposed [18, 19]. Another enhancement of RPL called RPL-FZ [20] is designed based on an efficient objective function that uses three combined metrics: node residual energy, delay, and ETX to make routing decisions at the time using the fuzzy logic process. This technique selects the neighbor with the best quality value as the preferred parent to path data to the root node. The optimized objective function RPL-FZ achieves 7% higher PDR, 8% lower Latency and consumes 8% lower power than MRHOF and OF0. However, this protocol is designed for strained conditions with data rates of 10p/min, 100 node density, and a single sink node. It does not consider load balancing in a medium that supports mobility. Unlike these works, which focus on RPL, its improvements, and load balancing, the following research concentrated on mobility in RPL, its methods, and related issues.

Laamazi *et al.* [21] evaluated the performance of RPL in static and mobile environments using two mobility models: Random Waypoint Mobility Model (RWP) and Random Walk Mobility Model (RWK). Simulation results reveal that the type of mobility has a direct impact on packet loss to its destination. In [22, 23], Saad *et al.* introduce a strategic plan for mobile sinks in IPv6 of wireless sensor networks where each node evaluates its weight according to three metrics: number of hops, residual energy and number of neighboring nodes. The sinks move towards the node with the highest weight. The findings show that this strategy just takes into account the network's lifetime by balancing energy consumption; it is also restricted to specific applications. In [23, 24], Korbi *et al.* have proposed an enhanced version of RPL called ME-RPL (Mobility Enhanced RPL) that includes the mobility status of node in the control message. This approach allows the static node with the lowest rank to be selected as the preferred parent. MR-RPL provides high PDR and improves route stability, but it neglects the rule in control messages and does not incorporate any routing metrics in the parent selection process. In [23, 25], the authors proposed an extension of RPL called Co-RPL based on corona mechanism that allows the localization of mobile nodes. The evaluation is carried out in a mobile environment composed of fixed DODAG and mobile nodes with low speeds up to 4 m/s. Co-RPL achieves less packet loss ratio, shorter end-to-end delay, and consumes less energy than the standard RPL. Nevertheless, it does not discuss hybrid network with various mobility models. Another solution [26] for improving network routing quality has been proposed, which consists of using the K-Means approach while exploiting the free time slot of the dead node in favor of the cluster head during cluster formation [27, 28]. In order to address all these issues related to load balancing and quality of service for dense mobile nodes with non-uniform distribution, we focused on enhancing one of the RPL's components, specifically the objective function rpl-mrhof, which uses combined metrics, total energy consumption, the number of neighbors and ETX as a criterion for selecting the best path.

III. RPL PROCESS IN CONTIKI AND METHODOLOGY OF PROPOSED OBJECTIVE FUNCTION

A. RPL process in Contiki

The Contiki operating system supports both standard protocols and new IoT enabling protocols such as uIPv6, 6LoWPAN, CoAP, RPL, and others. This system is also controlled and analyzed by Cooja simulator. RPL routing modules and their files are provided inside a separate directory "contiki/core/net/rpl" in this system. The related directory contains logically separated files according to the functions they provide, such as rpl-dag.c for DAG formation, rpl-icmp6.c for ICMP message packaging, and so on [29]. Regarding routing, Contiki-OS applies RPL, which organizes a topology as a Directed Acyclic Graph (DAG) that is subdivided into one or more DODAG. DODAG information is conveyed via control (packets) ICMPv6 messages called DODAG Information Object (DIO), DODAG Information Solicitation (DIS) and DODAG Destination Advertisement Object (DAO) [30]. In order to identify and maintain a RPL topology, the following parameters are used:

- RPLInstanceID is a unique identifier within a network. It identifies the sender's relationship to an RPL instance.
- DODAG Version Number is the numeric value that the root continuously increments to identify the current DODAG Version.
- DODAG ID is the identification of a DODAG.
- Rank specifies the node's individual position with respect to the DODAG root.

To start the DODAG system, at first the root node broadcasts to its neighboring nodes the DIO message containing information: RPL instanceID, versionNumber, rank, G, MOP, Prf, DTSN, Flags, Reserved, energytotal, number of neighbors, dio_input() and dio_ouput(). Second, the neighbor node that receives the DIO message calculates its rank and advertises the graph with supplementary DIOs. If another neighbor node does not want to wait for the DIO message, it can send a DIS message that contains Flags, Reserved, dis_input() and dis_output(), which initiates the DIO transfer and resets the Trickle timer. Third, the node that wants to participate in the DODAG's construction sends DAO message (RPLinstanceID, K, D, Flags, Reserved, DAO Sequence, dao_input() and dao_output()) to announce its address in order to establish a downward/upward route according to the operation's mode. Finally, in reply to the DAO unicast message, a DAO parent sends a DAO acknowledgement [31, 32]. In this context, RPL builds a logical topology using these three control messages, as well as a set of metrics and constraints provided by a specific Objective Function. This help in the translation of metrics such as ETX, energy and the number of neighbors into ranks, which are then employed by the ICMPv6 class (code, type, update_energytotal(), update_numberNeighbors()) to select and optimize routes in the RPL instance. The corresponding DODAG construction process for our proposed RPL is depicted in Fig. 1 below.

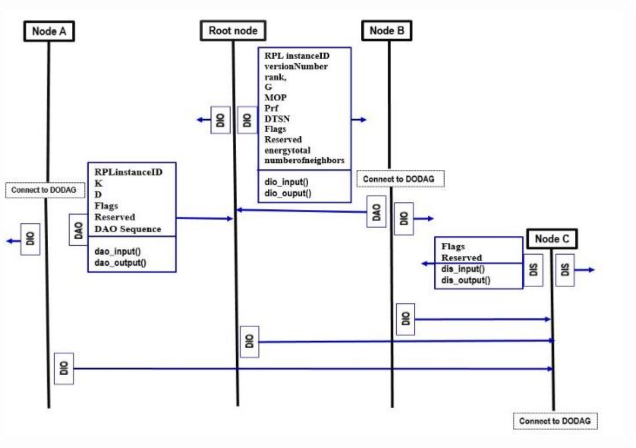

Figure 1. DODAG construction with rpl-TotEg-Neighbors [1, 33].

B. Methodology of a proposed Objective Function

In most RPL implementations, the MRHOF objective function uses the ETX metric to measure the path with minimal cost. When DODAGs are formed, nodes tend to choose parents with the best link quality and the minimum root hops. It is found that this objective function leads to the construction of topologies with unbalanced load traffic in the bottleneck nodes, especially the nodes of the first hop, i.e. from the root. Additionally, nodes closer to the root or having many children with high quality links will receive and forward a large number of packets, causing congestion and quickly draining their battery life [34]. However, this objective function is designed using RPL metrics and constraints, which do not guarantee performance criteria in a dense mobile IoT network. To resolve these imbalance issues, notably in a mobile environment, we propose a new MRHOF objective function that takes into account energy consumption, the number of neighbors of the nodes, and ETX links.

The proposed objective function process is illustrated as follows:

1) First, a logical topology of the mobile IoT network is built, with a sink (root) node fixed in the center of the simulation surface.
2) Root node initiates and broadcasts the DIO message to its neighboring nodes.

3) When the nearest node (N) receives this DIO message, it can decide whether or not to join the DODAG. The DIO packet contains information such as node rank, Mode of Operation (MOP): storing mode and non-storing mode, Objective Function and other metrics.
4) Each node recognizes these neighbors based on the DIO messages regularly received from them, which include ranking information, ETX, energy consumed and the number of neighbors, where:

- Node's rank is determined by the hop distance between the node and the sink node
- ETX is a dynamic metric focused on a node's lowest number of successful transmissions [35, 36]. It's calculated using the formula shown in Eq. (1) below:

$$\mathrm{ETX} = \frac{1}{d_f * d_r} \tag{1}$$

where:

d_f : is forward delivery ratio, it’s deduced from the probability computation of the received packet at the neighboring node.

d_r: is reverse delivery ratio, it’s calculated from the probability of an acknowledgement (ACK) packet at the receiver.

5) If it is a DIO message for the first time, it is added to the list of candidate parents. In this case, the OF is used to calculate the rank and the DIO message multicasted to the other nodes.
6) Otherwise, the current parent (PN) node will be changed to the lower rank based on the combined metrics using the following formula [34]:

$$\mathrm{Rank(N)} = \mathrm{Rank(PN)} + \mathrm{ETX\ (N, PN)} + \alpha \times \mathrm{NEIGHBORS\ (PN)} + \beta \times 1 / \mathrm{AverageEnergy} \times \mathrm{ENERGY\ (PN)} \tag{2}$$

where:

Rank (N) is Rank of node

Rank (PN) is Rank of parent node

ETX (N, PN) is value from node N to parent node PN

NEIGHBORS(PN) is number of neighbors of the parent node PN

α is coefficient that controls the weight given to the number of neighbors. It's fixed to 2.

β is corresponds to the weight attributed to ENERGY (PN), it's fixed to 3.

α and β should be higher than 1 to have a discernible effect on the parent node selection. Otherwise, Neighbors and ENERGY would have a smaller effect than ETX.

AverageEnergy: Average energy of nodes.

ENERGY(PN): Total Energy consumed by the parent node PN, it's measured by the following equation:

$$\mathrm{ENERGY(mJ)} = \mathrm{Transmit}{\times}19.5\ \mathrm{mA} + \mathrm{Listen}{\times}21.5\ \mathrm{mA} + \mathrm{CPU_{time}}{\times}1.8\ \mathrm{mA} + \mathrm{LPM}{\times}\ 0.0545 \times \left(\frac{3\mathrm{V}}{32768}\right) \tag{3}$$

where:

LPM is a power consumption parameter that measures the amount of power used while sleeping.

CPU is a power parameter that specifies the node processing level.

Radio listen and transmit are node communication parameters (transmit and receive)

7) The parent node will be replaced by the best alternative node if the following condition is met:

Rank (PBest) < Rank(PN)

This node will be selected to be the preferred parent.

8) The node enhances its position and computes its own rank.
9) Following the parent node selection process, data will be multicast to neighboring nodes.

IV. SIMULATION AND CONFIGURATION

In order to access our approach, we use the Cooja simulator running for small devices [37]. It supports some implementations such as: MSPSim that is the most used software package emulator of the MSP430 series microprocessor and sensors, multiple platforms equipped with low ROM and RAM like (SkyMote/TelosB, Wismote, ESB, …), multiple radio API, both IPv4 and IPv6 stack shared by all processes and others [37-39]. Furthermore, it includes all the tools and compilers required for Contiki development and debugging. For these reasons, we chose 2.7 as the version to implement our rpl-TotEg-Neighbors approach under the OS Ubuntu. The main objective of our approach is to improve one of the RPL's components, specifically the objective function mrhof, in terms of received and lost packets, throughput, overhead, ETX, Rtmetric, convergence time and power consumption for the IoT networks. However, in order to do this, we have selected a random distribution with varying density in the range [10 to 45] under different mobility models. In addition, the Bonnmotion simulator is applied to create the mobility pattern traces [40]. However, the Bonnmotion output must be converted using a built-in application called WiseML [40]. The additional setup parameters for this simulation are shown in Table I and Table II. The tools collectview, awk scripts, and the pcap file are used to generate the performance measures. Finally, the obtained results are plotted in figures using the Gnuplot software.

TABLE I. COOJA PARAMETERS SETUP

Parameter	Value
Operating System/Simulator	Contiki OS 2.7/Cooja
Radio Medium model	Unit Disk Graph Medium (UDGM): Distance Loss
Random Seed	123,456
Aera	100 × 100 meters
Sink Position	(50,50)
Number of nodes (motes)	15, 25, 35, 45
Topology	Point-to-multipoint, Multipoint-to-multipoint
Simulation time	600000 ms
Transport protocol	UDP
Objectives functions	rpl-mrhof, rpl-of0,rpl-TotEg-Neighbors
Application program	Examples/ipv6/rplcollect
MAC Layer	IEEE 802.14.5
Duty Cycle	ContikiMAC
Transmit and received ratio	TX=100%, RX=100%
Transmission range	50 m
Speed	No limit speed

Mobility Model	RWP, RPGM, Nomadic

TABLE II. BONNMOTION PARAMETERS SETUP

Parameter	Value
X; Y area	100 m
Minimum speed	0
Maximum speed	100 m/s
Simulation Duration	1200 sec
Minimum pause time	0
Maximum pause time	20 s

We estimated an average of several runs for each test to validate our simulations. In this simulation, the proposed objective function rpl-TotEg-Neighbors is compared to the current functions rpl-mrhof and rpl-of0 in terms of average received and lost packets, throughput, average control traffic overhead, average ETX, average Rtmetric, average convergence time, and average power consumption. The simulation metrics used serve as proof of network performance requirements that require upgrading for excellent efficiency.

V. RESULTS AND ANALYSIS

To investigate the impact of the chosen metrics on both protocol and network behavior, we consider various scenarios for optimizing packet delivery and selecting the best routes while consuming the lowest amount of power. For the evaluation of our rpl-TotEg-Neighbors in this paper, we focus on the performance metrics described below.

A. *Average Received and Lost Packets*

In this scenario, we have increased the number of nodes and moved all nodes except the sink, using three mobility models: RWP, RPGM, and Nomadic. As shown in Fig.2.1, as the network size increases, our proposed objective function rpl-TotEg-Neighbors records a high number of received packets and a low number of lost packets when compared to the mrhof and of0 functions in a Random Waypoint environment. In Fig.2.2, we see the same behavior of our approach as before in terms of receiving packets and very low packet loss when compared to rpl-mrhof and rpl-of0 in the mobile RPGM. In Fig.2.3 and in a nomadic environment, we show that our approach provides significant improvements over other objective functions only for lost packets. When compared to rpl-mrhof and rpl-of0, our approach records more packets received and fewer packets lost in Random WayPoint and RPGM environments than Nomadic, implying that these mobility models may be better for RPL than others. We conclude that the rpl-TotEg-Neighbors function, when applied to a variable density network during RWP and RPGM mobility, is more reliable than the standard mrhof and of0 functions.

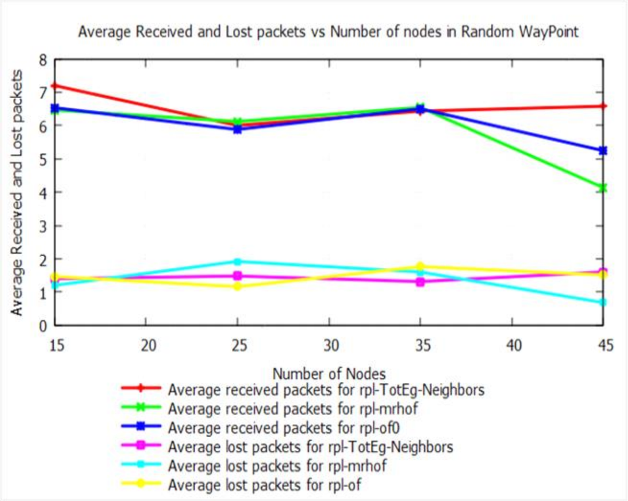

Figure 2.1. Average received and lost packets vs number of nodes for Random WayPoint Model (RWP)

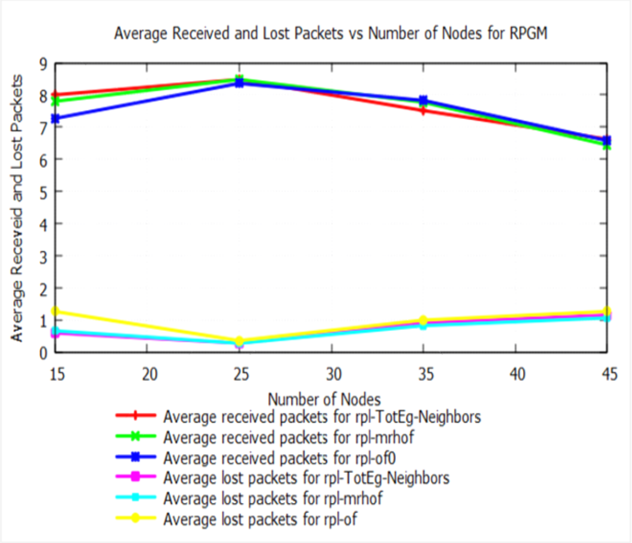

Figure 2.2. Average received and lost packets vs Number of nodes for RPGM Model

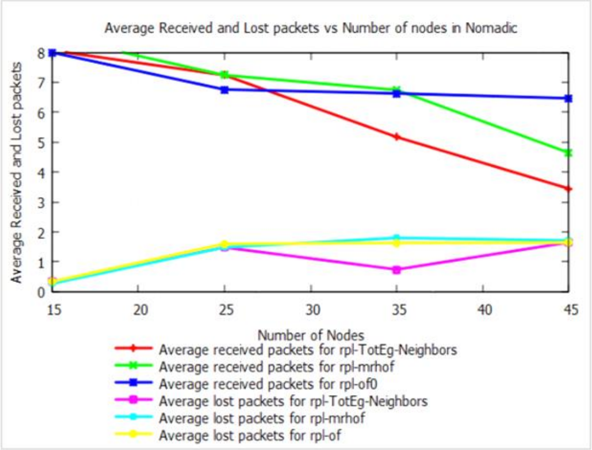

Figure 2.3. Average received and lost packets vs number of nodes for Nomadic Model

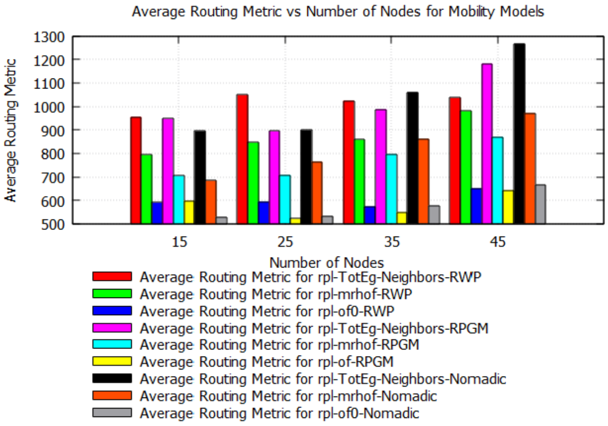

Figure 3. Average rtmetric vs number of nodes for mobility models

B. *Average ETX and Rtmetric*

This section presents the average Expected Transmission Count (ETX) and Routing Metrics (Rtmetric) evaluation results for the three objective functions (rpl-TotEg-Neighbors, rpl-mrhof and rpl-of0) based on node density and the three mobility models (RWP, RPGM, and Nomadic). Except for the sink node, the following figures show the ETX and Rtmetric values of all nodes. These values are assigned by the application using the rpl collect protocol. In Fig.3, our proposed function provides better average routing metric than other standard functions for all densities in all mobile scenarios. The Rtmetric value can be calculated by using the best neighbor's previous Rtmetric value, which is also determined by the ETX value. A lower ETX value denotes a better neighbor. As a result, Rtmetric is better, and the protocol seemed to to be more reliable.

Furthermore, as shown in Fig.4, our rpl-TotEg-Neighbors function outperforms others functions in terms of average ETX in RPGM and Nomadic mobile scenarios for all densities. To conclude, these results show that the new improvement of the standard mrhof has a direct influence that can reduce ETX and improve Rtmetric according to the number of nodes and mobility models.

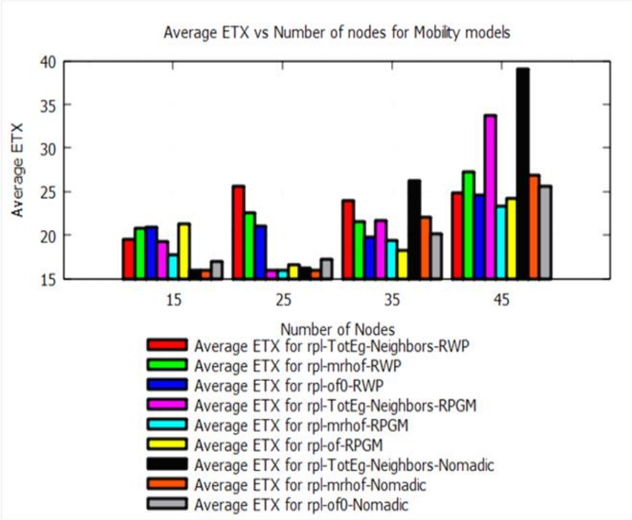

Figure 4. Average ETX vs number of nodes for mobility models

C. *Average Convergence Time*

Multiple control messages are exchanged across the network during the DODAG's construction and until the topology is accomplished in the RPL protocol. For this, the convergence time measures the time taken between the first DIO sent and the last DIO that joined the DAG. To ensure better network stability, this metric need to be as minimal as possible [41]. Fig.5 depicts the average convergence time of the standards RPL (mrhof, of0) and rpl-TotEg-Neighbors based on the number of nodes and three mobility models: RWP, RPGM, and Nomadic. In this context, we notice that the new improvement provides a slower convergence time than the standard RPL ones (mrhof and of0) in Random Waypoint for all densities.

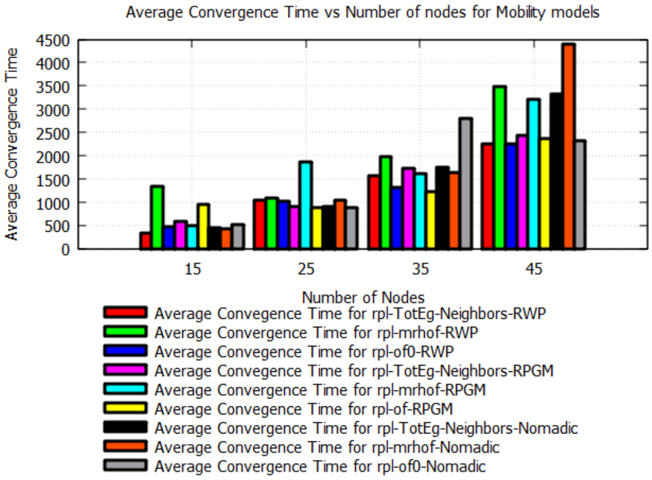

Figure 5. Average convergence time vs number of nodes for mobility models

D. *Average Control Traffic Overhead*

Control traffic overhead is the total sum of control messages (Internet Control Message Protocol version 6) such as DIO, DIS and DAO generated in RPL in order to setup and maintain the network. This traffic occurs when nodes report discovering routes and sending error messages, which leads to network congestion. In this scenario, the flow of control messages should be reduced because any accumulated traffic would exhaust the network resources in LLN [42]. Fig.6 presents the average RPL control traffic messages (DIO, DIS, DAO) for all mobility models (RWP, RPGM, and Nomadic) with a random network topology and different densities using rpl-mrhof, rpl-of0, and rpl-TotEg-Neighbors. As a result, under all mobility models and densities, our improved function outperforms the standard OF mrhof in route calculation, whereas of0 requires more control messages due to collisions and retransmissions.

E. *Throughput*

This metric is measured by counting the number of data packets successfully delivered in a given period of time. This metric's traffic can be injected into the network with the same quantity from any of the source nodes. To be considered better, the value of this metric should be significantly high for an IoT network. Throughput is affected by the network's traffic workload [43]. It is also calculated using the following formula:

$$\mathit{Throughput} = \frac{\text{Number of delivered packets}\times\text{size}\times 8\ (\text{bit})}{\text{Total duration of simulation } (s)}$$

Fig. 7 depicts the throughput analysis of the proposed objective function rpl-TotEg-Neighbors versus rpl-mrhof and rpl-of0 under various mobility models. It's also worth mentioning that rpl-TotEg-Neighbors has slightly better throughput than rpl-mrhof in this test for low node densities and in Random Wapoint and Nomadic mobile environments. In these mobile conditions (RWP and RPGM), rpl-TotEg-Neighbors solves the congestion problem by using the new metric that combines the total energy and the number of neighbors of the nodes. The results show that the proposed function successfully provides more delivered packets than the current functions for any low density and any type of mobility. In this case, we can confirm that our proposed method avoids the collision problem.

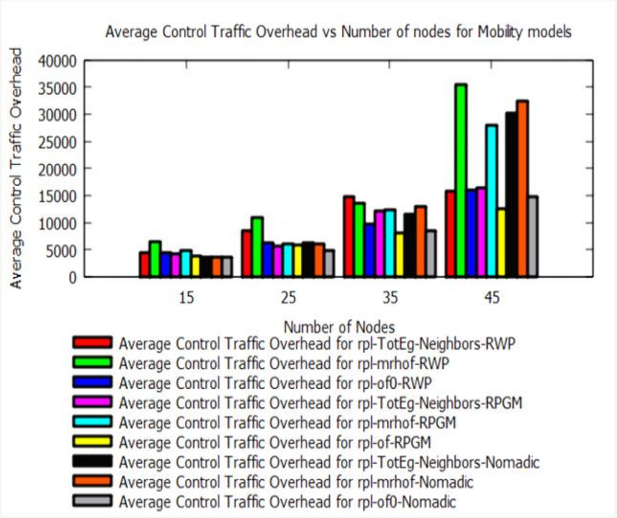

Figure 6. Average Control Traffic Overhead vs number of nodes for mobility models

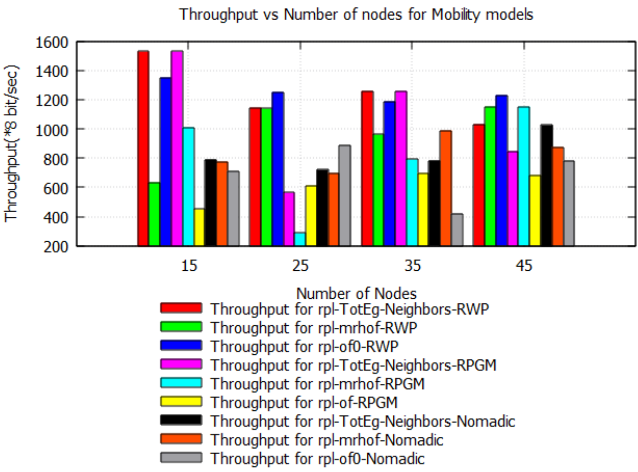

Figure 7. Throughput vs number of nodes for mobility models

F. *Average Power Consumption*

Energy consumption is one of the most significant challenges of any IoT, and it is crucial to evaluate it over a mobile and dense IoT network running RPL. This metric's performance is determined by the power consumed by nodes to collect and transfer packets of data between any source and its preferred parent. The average power consumption is the average sum of the node states in terms of CPU, LPM, Tx, and Rx consumed power. To illustrate this point, Fig. 8 compares the proposed function objective to the standards OF (mrhof and of0) with various mobility models and densities for average power consumption. As shown in this figure, rpl-TotEg-Neighbors provides better performances with all mobility models (RWP, RPGM, nomadic) in terms of power consumption than with the standard mrhof for all densities. However, the of0 consumes more power than the other cases because it does not use any routing metrics to choose a data path, whereas the new function rpl-TotEg-Neighbors selects a path based on the minimum total power consumption and the number of nearest neighbors. So average power consumption for rpl-TotEg-Neighbors is smaller. Therefore, the objective of our new improvement is achieved.

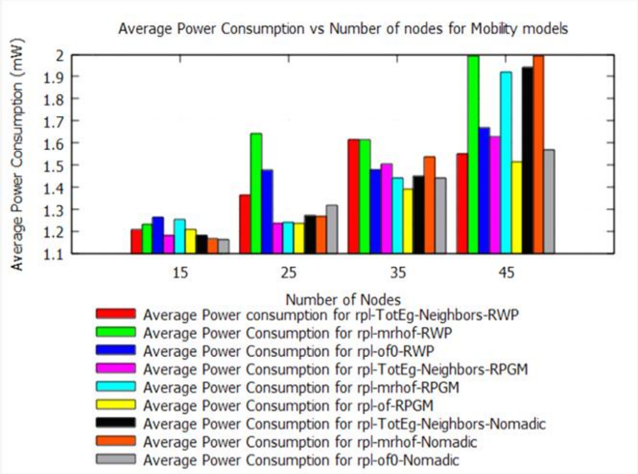

Figure 8. Average Power Consumption vs number of nodes for mobility models

G . *Discussion*

RPL's design is based on the objective function. This means that any change to the RPL specification's core can maintain the primary basis of its parameters while improving its performance. For this reason, we have proposed a new objective function (rpl-TotEg-Neighbors) which uses combined metrics (ETX, total energy and number of neighbors) according to different mobility models and various densities. Our solution is compared with the standards mrhof and of0. The new function outperforms the current mrhof function under certain conditions. It reduces traffic overhead and expected transmission for all mobility models, which helps avoid collisions. It also improves routing metrics and the packet's delivery, minimizes convergence time and reduces power consumption for any type of mobility and for a low density.

VI. CONCLUSION

In this paper, we presented an overview of related works of RPL protocols and their problem statements related to load balancing in the Internet of Things. Second, we proposed a new objective function based on combined metrics that are total energy, the number of neighbors and ETX to evaluate RPL performance under different mobility models and node densities. The comparison has been made between rpl-TotEg-Neighbors, rpl-mrhof and rpl-of0 using seven metrics: the number of received and lost packets, Rtmetric, ETX, Convergence time, Control Traffic Overhead, Throughput and Power Consumption through the simulation ContikiRPL platform. As demonstrated by the results obtained, the proposed approach records more packets received and fewer packets lost during Random WayPoint and RPGM mobility's. Furthermore, for all mobility models, this approach reduces ETX and control messages, enhances Rtmetric, provides minimal convergence time only for RWP, successfully delivers more packets at low node densities only for RWP and RPGM, and minimizes power consumption when compared to mrhof at various densities. However, in Nomadic, this approach is unreliable in terms of packets received and consumes more energy at high densities, it also suffers from a long convergence time for RGPM and Nomadic models. The future work will concentrate on overcoming the limitations of this approach and attempting to use artificial intelligence approaches for automatic generation of metrics to mitigate mobility problems in RPL.

CONFLICT OF INTEREST

The authors declare no conflict of interest

AUTHOR CONTRIBUTIONS

The first author designed, performed the simulation results and wrote the paper. All authors approved and analyzed the final results.

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