A New Objective Function Based on Additive Combination of Node and Link Metrics as a Mechanism Path Selection for RPL Protocol

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***Abstract*:** Since its development by IETF, the IPv6 routing protocol for low power and lossy networks (RPL) remains the subject of several researches. RPL is based on objective function as a mechanism selection of paths in the network. However, the default objective functions standardized selects the routes according to a single routing metric that leads to an unoptimized path selection and a lot of parent changes. Thus, we propose in this paper weighted combined metrics objective function (WCM-OF) and non-weighted combined metrics objective function (NWCM-OF) that are based both on additive link quality and energy metrics with equal weights or not to achieve a tradeoff between reliability and saved energy levels. The proposed objective functions were implemented in the core of Contiki operating system and evaluated with Cooja emulator. Results show that the proposed objective functions improved the network performances compared to default objective functions.

***Keywords*:** WSN, IoT, 6LowPAN, IEEE 802.15.4, RPL, Cooja, Contiki OS.

1. Introduction

The recent years were being known as an era of connected devices to internet (IoT) and have become the subject of several researches on the reliability and energy levels. Mostly, These devices on networks, classified as low power and lossy networks (LLN's), are constrained devices in term of memory resources, energy and processing, communicating over low power wireless technologies such as BLE (Bluetooth low energy) or IEEE 802.15.4 to cope with LLN networks [1].

The IETF group had adapted the protocol stack as shown in Tab.1 for IoT, and standardized a new routing protocol for low power and lossy networks (RPL) [2]. Among the main features of RPL, it is designed as being a protocol based on IPv6, using the IEEE802.15.4 at the PHY and MAC layer, an adaptation layer 6LowPAN and IPv6 that provides end to end two-way communication to each device. LLN networks are not based on infrastructure or predefined topology. So that, RPL constructs a Destination Oriented Directed Acyclic Graph (DODAG) according to an objective function (OF) that defines a set of metrics and constraints to selects the paths in the network to the root [3]. Several OF have been standardized based on link or node metrics in order to establish routes in the network. Until now, many OF have been developed to address problems such as energy consumption, reliability and bottlenecks or congestion…

The objective function in RPL defines how to use the link metrics and constraints to assign ranks to the nodes in the network, thus creating the topology and selecting/optimizing the paths [4]. The IETF-ROLL group defined two objective functions MRHOF and OF0 [3]. MRHOF was designed to minimize the cost of the paths according to link metric expected transmission count (ETX) or node metric energy. In the other hand, OF0 is based on the minimum hops to the root and do not consider the reliability of the path links [5]. Both of standardized objective functions takes into account a metric or constraint what lead to an unoptimized path selection.

Table 1. IETF protocol stack for IoT

Application	COAP, *DPWS,* *XMPP…*
Transport	UDP
Network	RPL ICMPv6
Adaptation Layer	6LowPAN
Data Link	CSMA (MAC) ContikiMAC (RDC) 802.15.4 (Framer)
Physical	IEEE 802.15.4

In this paper, we propose two objective functions that improve the routing protocol RPL by increasing the number of packets received to the sink and decreasing considerably the power consumption.

The rest of this paper is organized as follow. In Sect. II we give a brief overview of the routing protocol for low power and lossy networks RPL. In Sect.III we present the related works. In Sect. IV we present the WCMOF and NWCMOF objective functions. In section V, we explain the simulation design of network and results obtained, finally a conclusion and our perspectives are given in Section VI.

2. Routing protocol for low-power and lossy networks overview

RPL is a proactive routing protocol based on Ipv6 communication for low power wireless personal area networks (6LowPAN), standardized by the IETF ROLL working group [6]. Two types of nodes are defined in 6LowPAN; the root that collect all packets thought the network and sent by the sender sensors, it can be also bridge to cloud or internet.

With the unpredefined network topology on 6LowPAN, RPL builds a Directed Oriented Destination Acyclic Graph (DODAG) to root using four types of control messages called ICMPv6 [6]:

- DIO: DODAG Information Object.

- DIS: DOGAG Information Solicitation
- DAO: Destination Advertisement Object
- DAO-ACK: Destination Advertisement Object Acknowledgement

In the first step of constructing DODAG by RPL, the root periodically sends DIO packets carrying many important parameters such as rank, metric, DODAGID, and routing cost until all nodes receive and send their ranks [7]. In the second step, the nodes choose their preferred parents according to objective function and have a lower rank in such a way that there is no loop in the routing. The nodes can also store the information of neighbor nodes apt to be preferred parents for a possible change after the update of the routing in the network triggered by the emission of new DIO messages according to the Trickle algorithm [7]. After that, the routes are closed between the root and senders by sending DAO messages [8]. Finally, a new node joins the network by sending a DIS message as a request to send DIO message by the root without having to wait for the next update of the network [9].
The rank of a node is represented by a number that defines its position in DODAG relative to the root. In other words, more closely the node is to root then it takes a lower rank. It is a part of the selecting process of multiple possible parents and the objective function is involved in choosing the best parent. The rank of a node k is given by R (k) following (1):

$$R (k) = R (parent) + RIncrease \quad (1)$$

Where:

R (k) is the updated rank of the node k.
R (parent) is the preferred parent rank.
RIncrease is a factor of variation between node and its preferred parent ranks can be calculated by (2):

$$RIncrease = (Sx+Sy)*MHIncrease \quad (2)$$

Where:

Sx is the step of the Rank.
Sy is the maximum value assigned to the ranking level to allow the sustainability of the success.
MHIncrease is a constant variable of minimum hop increase with value of 256.

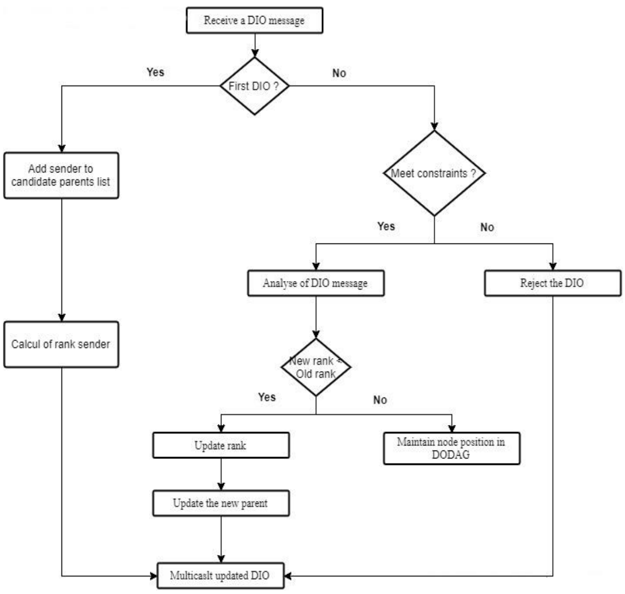

Figure 1. Process of rank calculation

The schema in Fig.1 explains the process of calculating rank and updating the candidate parent with lower rank after receiving a DIO message.
However, the objective function makes it possible to choose the best routing path based on several constraints and restrictions [10]. Its purpose is to minimize the cost of the routing path based on criteria relating to the node or the quality of links. In addition, two objective functions have been defined in the RPL specifications by IETF group MRHOF and OF0.
OF0 is based on the philosophy of the Dijsktra algorithm, minimizing the number of hops from sender to root while MRHOF is based on the expected transmission count (ETX) or energy consumption of nodes (ENERGY) [11].

3. Related works

Since it definition, a lot of researches were be conducted on studying the RPL objective functions performances based on recommended metrics defined for low-power and lossy networks.
In [11], Pradeska et *al.* present a performance analysis of MRHOF and OF0 observing parameters as packet delivery ratio, convergence time, routing link ETX, average hops, latency and power consumption in random and grid topology. The results shown that the reliability is assured with MRHOF as objective function while the fast convergence time of the DODAG and in term of less power consumption, the OF0 is suitable as objective function.
Also in [12], a comprehensive evaluation of objective functions is presented by Mardini and *al.* with static and mobile nodes in different topologies. The assessment showed that OF0 perform better than MRHOF in terms of Convergence time Energy Consumption, Convergence Time, Listen and transmit Duty Cycles with static nodes in grid topology. But in random topology with mobile nodes there is no major difference between performances of the two objective functions except the less power consumption by OF0.
However, many novel RPL objective functions were proposed based on single metric as RE defined in [13] that is the residual energy in node battery, so the best parent chosen is the node with the most available energy.
Other proposal in [14], which treats the problem of single long hop introduced when the number of density increased. Xiao et *al.* proposed an objective function based on new metric PER-HOP ETX that takes the average of ETX between nodes along the route. The new objective function improves the routing performances of RPL in term of PDR, latency and power consumption.
In this context, in [15], an extension of the mentioned metric above is proposed by Sanmartin et *al.* called SIGMA-ETX that combines minimum hop count and ETX metrics to avoid the problems of single long hops that generate bottlenecks while the network is dense.
In [16], in order to remediate to the problems of unbalanced energy, bad data reliability and short network life time in advanced metering infrastructure (AMI) for smart grids, Gao et *al.* proposed ETEN-RPL routing algorithm based on combination of ETX and remaining energy of nodes as a base selection for preferred parent. The new objective function reduces significantly the power consumption and improves the network stability.

In [17], Al-Kashoash et *al.* have been interested to the congestion in paths due to the buffer nodes occupancy. So that, Congestion-Aware Objective Function (CAOF) were be proposed that consider ETX metric in low data rate while the buffer occupancy is considered at high data rate what leads to select a less congested paths.

Despite of the implementing issue of fuzzy logic system (FLS) on constrained nodes, FL remains a method that improves the RPL objective function. In [18], Lamaazi et *al.* proposed a new objective function based on fuzzy logic system (EC-OF) that combines tree metrics: ETX, Hop Count and energy consumption. The results showed that the EC-OF keeps the routing protocol RPL efficient and improve its performances in term of PDR, network life time, convergence time, latency and power consumption in comparison with MRHOF.

Fig. 2 summarizes the structure of existing researches on the objective functions of routing protocol RPL.

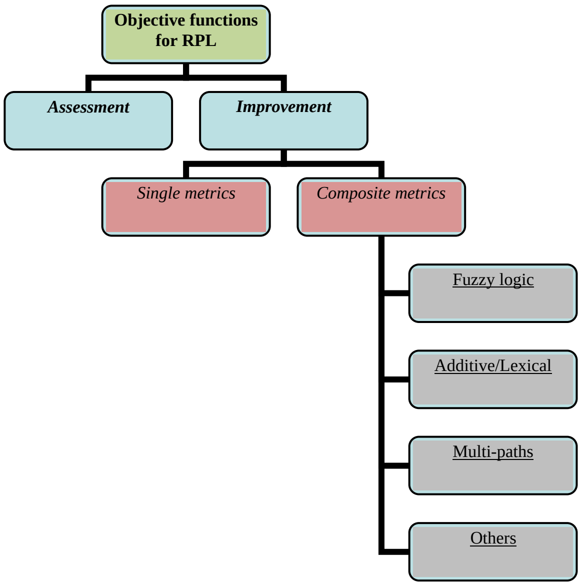

Figure 2. Structure of existing researches on RPL

4. Proposed objective functions

The ETX metric choose the best link between nodes with lesser expected transmission for successful packet delivery, while energy metric try to choose the node with low current energy consumption. So that, an objective function based on single metric consider a constraint ignoring others what leads to an unoptimized choosing paths.

The objective function Weighted Combined Metrics (WCM-OF) was designed to solve the mentioned problem above, based on additive combination of link metric ETX and current node energy consumption taking into account then the balance between reliability and energy efficiency. In this context, Non-weighted combined metrics (NWCM-OF) is an extension of WCMOF with non equal weights between the two metrics combined. The new combined metric injected into the objective functions is shown in Fig. 3.

With the use of new objective functions, at reception of a DIO message from parent, the receiver node update link quality metric between them and the current power consumption. After that, the new metric calculated is combined additively as in (3).

$$\text{Combined\_metric} = \text{Wetx}*\text{metric1} + \text{Wenr}*\text{metric2} \quad (3)$$

Where:

Metric1 is the ETX metric between parent and receiver.

Metric 2 is the current power consumption of node at received time of DIO message.

Wetx is the weight assigned to link quality metric. It's equal to 1 if the objective function is WCMOF or equal to Ω with $0.1 \leq \Omega \leq 0.9$ if the objective function is NWCMOF.

Wenr is the weight assigned to energy consumption metric. It's equal to 1 if the objective function is WCMOF or $\mu = 1 - \Omega$ if the objective function is NWCMOF.

After computing the new metric, the node adds the combined metric of sender to its own and forwards a DIO message that contains it to neighbors. Then, the paths are selected to the root with the lowest sum of combined metrics.

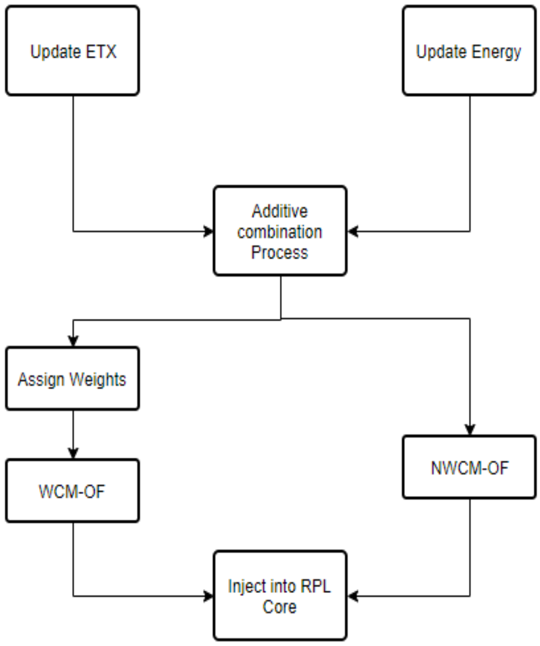

Figure 3. Proposed objective functions injected into RPL core

The implementation of the combined metric algorithm in the core of the new objective functions is illustrated in Tab.2.

Table 2. Pseudo code for combined metrics

Inputs: DIO from candidate parent p
Output: Combined metric

```
On reception of DIO packet from parent P
Begin
  if (P==NULL) then
      return maximum_path_cost;
  end if
  if (P!=NULL) then
    if (metric==combined_metric) then
      update ETX_metric value;
      update ENERGY_metric value;
        if (NWCMOF==TRUE) then
          update Wetx value;
          update Wenr value;
        else
          Wetx=1;
          Wenr=1;
        end if
 combined_metric=Wetx*ETX_metric + Wenr*ENERGY_metric;
  return combined_metric;
    end if
  end if
End
```

5. Performance evaluation

In order to evaluate the performance of proposed objective functions, the simulations are done with COOJA, a wireless network sensor simulator that provide a cross approach emulation of the hardware platforms and programming the software level through applications provided by the CONTIKI operating system API.
In our experiments, we use light and dense networks of 20 and 40 nodes with a single sink, distributed randomly in an area with side of 200m. The type of data traffic is multipoint to point (MPTP) where the nodes sent the captured data to the sink with a rate of 1 packet per minute. We set the transmitting range to 70 meters, the interference range to 100 meters and varied the Reception Success Ratio (RX) to 60% and 90%. Also, we inject the new objective function WCM-OF and NWCM-OF in the core of RPL and evaluate the performance compared to two objective functions based on ETX and energy metrics respectively, in term of packet delivery ratio, power consumption, throughput and churn. Tab.3 summarizes the simulation parameters.

Table 3. Simulation setup

Operating system	Contiki 2.7
Hardware platform	Sky mote
Transmission/Interference ranges	70/100m
Propagation model	UDGM-Distance loss
Number of nodes	20,40
Reception success ratio (RX)	60%,90%
Network Protocol	RPL
PHY & MAC protocols	IEEE 802.15.4
Objective functions	MRHOF-ETX, MRHOF-ENERGY, WCMOF, NWCMOF
Squared area	200x200m
Inter-packets time	60s

5.1 Evaluation of Packet Delivery Ratio

The packet delivery ratio (PDR) is defined as the ratio of packets received by the sink and all packets sent by the nodes in network. It's a parameter that can give an idea on packet losses during the routing process and the reliability on the network.

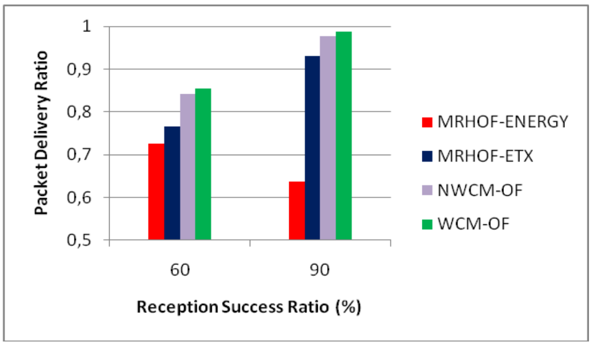

Figure 4. Performances in term of packet delivery ratio for 20 nodes.

Figure 4 present the performances of new objective functions compared to MRHOF-ETX and MRHOF-Energy with variation of RX ratio for 20 nodes while Fig.5 present the same performances for 40 nodes. The results show that for both scenarios, WCM-OF and NWCM-OF outperform other objective functions by increasing the packet delivery ratio since the new metrics provide more stability and reliability for selected paths. Detailing some results for 20 nodes, WCM-OF improved the PDR compared to MRHOF-ETX with 11.45% (at RX=60%) and to MRHOF-ENERGY with 55.04% (RX=90%), while NWCM-OF increased the PDR compared to MRHOF-ETX with approximately 10% (at RX=60%) and to MRHOF-ENERGY with 53% (RX=90%).

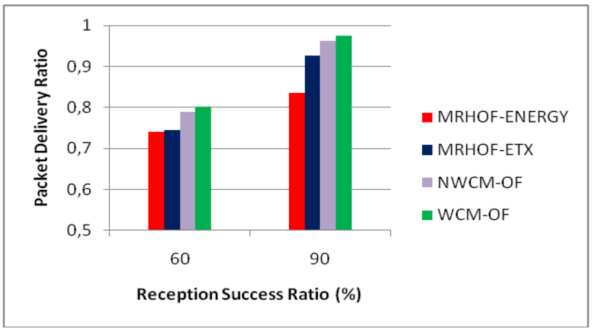

Figure 5. Performances in term of packet delivery ratio for 40 nodes.

5.2 Evaluation of Network Power Consumption

The network power consumption is defined as the average of energy consumption of each node in the deployed network. It's a critical parameter that gives an idea of the life time of the network since the nodes are powered with batteries.
As shown in Fig.6 and Fig.7, the proposed objective functions can reduce the average power consumption compared to MRHOF-ETX and MRHOF-ENERGY since the preferred paths are more optimized by considering the quality of link and energy consumption too. Regarding some results for 20 nodes, WCM-OF consume 11% less than MRHOF-ETX and 86.43% than MRHOF-ENERGY at RX=60%. Also for 40 nodes, NWCM-OF reduce the consumption energy with 19.95% compared to MRHOF-ETX and 68.88% compared to MRHOF-ENERGY at RX=90%.

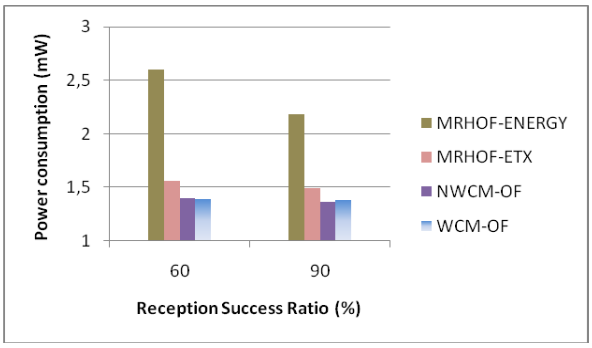

Figure 6. Performances in term of power consumption for 20 nodes.

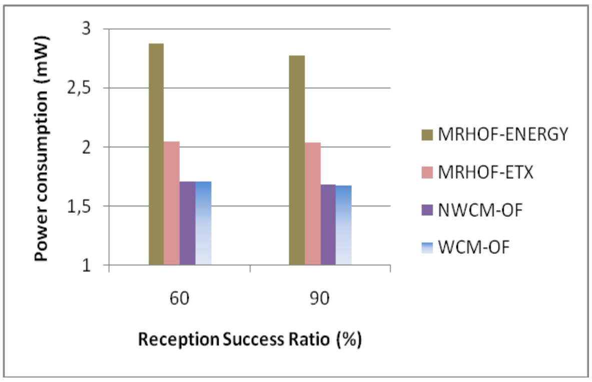

Figure 7. Performances in term of power consumption for 40 nodes.

5.3 Evaluation of Churn

Churn is defined as the node parent switch; it's a parameter that refers to the stability of routing path when the churn value is low.
As shown in Fig.8 and Fig.9, WCM-OF and NWCM-OF cancels parent changes for both densities also when varying RX, which means that they give more stability in the routing path, which can also explain increasing PDR compared to other objective functions as we have seen before.

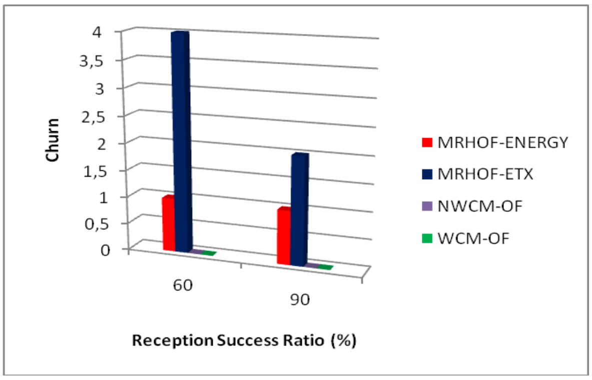

Figure 8. Performances in term of churn for 20 nodes.

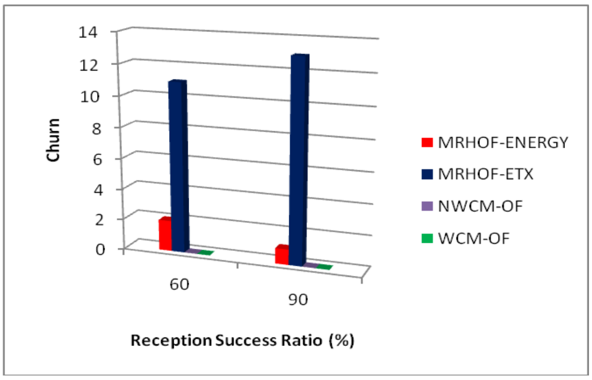

Figure 9. Performances in term of churn for 40 nodes.

5.4 Evaluation of Throughput

The throughput is defined as number of bytes received by the sink amount of simulation time. It's a parameter that gives an idea on the reliability in the network and transmission speed hop by hop to the sink in the network.
As shown in Fig.10, WCMOF can increase the throughput with approximately 14% compared to MRHOF-ETX and 52.79% to MRHOF-Energy at RX=90% for 20 nodes. Also in fig.11 for 40 nodes, the NWCM-OF gives good performance compared to MRHOF-ETX and MRHOF-Energy with an improvement of 12.5% and 51% respectively at RX=90%.

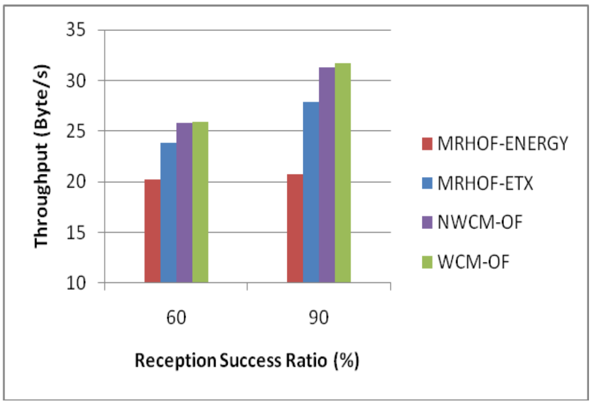

Figure 10. Performances in term of throughput for 20 nodes.

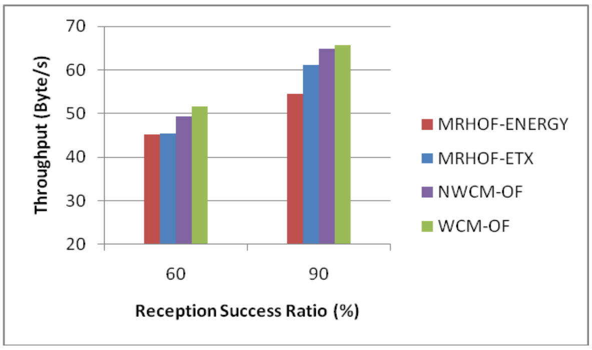

Figure 11. Performances in term of throughput for 40 nodes.

Tables 4, 5, and 6 summarize the improvement of WCM-OF and NWCM-OF compared to others objective functions measuring packet delivery ratio, average power consumption, and the churn and throughput respectively while varying the values of RX (60% and 90%) using random topologies of 20 and 40 nodes.

Table 4. Improvement of Packet Delivery Ratio

Density	RX	Proposed objective function	MRHOF-ETX	MRHOF-Energy
20 nodes	60%	WCM-OF	**11.45%**	**17.74%**
		NWCM-OF	**9.92%**	**16.12%**
	90%	WCM-OF	**6.28%**	**55.04%**
		NWCM-OF	**5.03%**	**53.21%**
40 nodes	60%	WCM-OF	**7.66%**	**8.07%**
		NWCM-OF	**6.13%**	**6.53%**
	90%	WCM-OF	**5.23%**	**16.72%**
		NWCM-OF	**4%**	**15.35%**

Table 5. Improvement of Power Consumption

Density	RX	Proposed objective function	MRHOF-ETX	MRHOF-Energy
20 nodes	60%	WCM-OF	**10.76%**	**46.36%**
		NWCM-OF	**10.50%**	**46.20%**
	90%	WCM-OF	**6.91%**	**36.40%**
		NWCM-OF	**8.25%**	**37.32%**
40 nodes	60%	WCM-OF	**16.63%**	**40.70%**
		NWCM-OF	**16.63%**	**40.70%**
	90%	WCM-OF	**18.03%**	**39.64%**
		NWCM-OF	**17.78%**	**39.46%**

Table 6. Improvement of Throughput

Density	RX	Proposed objective function	MRHOF-ETX	MRHOF-Energy
20 nodes	60%	WCM-OF	**8.68%**	**27.92%**
		NWCM-OF	**8.35%**	**27.54%**
	90%	WCM-OF	**13.83%**	**52.79%**
		NWCM-OF	**12.50%**	**51.01%**
40 nodes	60%	WCM-OF	**13.90%**	**14.33%**
		NWCM-OF	**8.78%**	**9.18%**
	90%	WCM-OF	**7.61%**	**20.79%**
		NWCM-OF	**6.19%**	**19.19%**

6. Conclusion and future works

In this paper, two new objective functions for RPL routing protocol WCM-OF and NWCM-OF are proposed based on link quality ETX and energy consumption of node additive combination with equal and non equals weights respectively, aiming to increase the reliability, maximizing the network life time and reducing the parent changes that provide more stability on routing paths.

As a future work, we will be investigated on improving more the RPL based on combination of other metrics and the fuzzy logic system.

7. Acknowledgement

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