RPL Enhancement using a new Objective Function based on combined metrics

Hanane Lamaazi[1], Nabil Benamar[2]
1University Moulay Ismail, Faculty of Sciences, Meknes, Morocco
2University Moulay Ismail, High School of Technology, Meknes, Morocco
n.benamar@est.umi.ac.ma
Lamaazi.hanane@gmail.com

***Abstract*—The routing protocol for low-power and lossy networks (RPL) defines an objective function (OF) to choose the optimal route toward destination. OF can operate according to a set of metrics and constraints used in a single or combined way. The use of a single metric in the OF can improve routing performances while degrades others. To overcome these limitations, we present in this paper a new approach to enhance the RPL routing protocol. We propose OF-EC (objective function based combined metric using fuzzy logic method), a new objective function that considers both link and node metrics, namely ETX (expected transmission count), HC (hop count) and EC (energy consumption) based on fuzzy logic concepts. Our results show that the new OF-EC in comparison to the OF based ETX and OF based energy consumption only and OF_FUZZY allows improving RPL performances in terms of PDR and overhead. In addition, this new metric allows equalizing the energy consumption of nodes throughout the network.**

Keywords—RPL; Objective Function; ETX; Energy consumption; Fuzzy Logic

I. Introduction

RPL is an IPv6 routing protocol for low-power and lossy networks [1] that allow to these kinds of devices to be connected via Internet. This routing protocol is able to be adaptable over time with the change of metrics whatever node or link metrics. RPL is a distance vector protocol based on the concept of Directed Acyclic Graphs (DAGs). DAG uses a tree structure to designate the default routes between nodes. Nodes can have more than one parent. RPL uses an optimizing objective function (OF) that is responsible for best path choice according to a set of metrics. These metrics can be node metric such as energy, hop count or link metric such as ETX (expected transmission count) and LQL (link quality level). In this paper, we present a new objective function called OF-EC (objective function based combined metric using fuzzy logic method) that use fuzzy logic method. The main goal of this proposal is to apply best criteria to choose optimal way to reach the destination. The main idea of this work is to combine node and link routing metrics using a fuzzy logic method that use a membership function to provide best characterization of the quality of candidate nodes. OF-EC combines both the expected transmission count (ETX) and the Energy consumption using the fuzzy logical method. This combination allows resolving some limitations due to the use of single metrics. The proposed OF-EC is compared to the standard OF with ETX and OF with Energy consumption only, to show the improvement that it provides. In order to distinguish the efficiency of the proposed OF-EC, we compare it with OF_FUZZY (an objective function that combines ETX, Latency and remaining power using fuzzy logic) [2]. The rest of the paper is organized as follow. Section 2, presents an overview of RPL and objective function. The problem statement and contribution are explained in Section 3. Fuzzy logical functions and the different routing metrics are discussed in Section 4. Section 5, describes some research and studies related to RPL performances and Objective Functions. An assessment of different results obtained from simulation is described in section 6. Finally, we conclude the paper by discussing the results and proposing a future work.

II. RPL Overview

A. RPL

RPL is an IPv6 routing protocol designed for low power and lossy networks. The main goal of RPL is to allow constrained devices to be connected via the Internet. The specifics of RPL is that it can build connection between nodes based on a directed Acyclic graphs (DAG). The DAG defines a tree structure that allows designing the default route between nodes. RPL defines a set of ICMPv6 [3] control messages that allow exchanging information associated to DODAG. The four types of RPL control messages are:

- **DODAG Information Object (DIO):** initiated by the LBR (LowPAN *Border Router*) and retransmitted in multicast by its neighbors.
- **Destination Advertisement Object (DAO):** used to propagate destination information upwards along the DODAG.
- **DODAG Information Solicitation (DIS):** makes it possible for a node to solicit a DODAG information object (DIO) from a reachable neighbor.
- **Destination Advertisement Object Acknowledgement (DAO-ACK):** it sent by a DAO recipient in response to a DAO message.

B. Objective Function (OF):

RPL is based on the OF [4] to construct roots. The OF defines how a node translates one or more metrics into a Rank value. A node that provides the least Rank from a list of candidate nodes is selected as best parent. The Rank represents the location of nodes in DODAG. Moreover, the OF is separately implemented into the core of RPL specification which enables RPL to be adaptable to different optimization according to some criteria. These criteria allow choosing best parent based on a set of routing metrics. These metrics can be node metrics as hop count and energy or link metrics as throughput, latency, link quality level (LQL) and number of expected transmission count (ETX) or both if it is used in a combination. Until now, the ROLL working group has specified two objective functions. The first one is the objective function zero (OF0) [5] that uses the minimum hop count as a criterium for selecting best parent. The second one is the minimum rank with hysteresis objective function (MRHOF) with ETX metric to select the optimal route toward sink node.

III. PROBLEM STATEMENT AND CONTRIBUTION

RPL uses an objective function that specifies the optimal route toward destination based on a set of metrics. The use of a single metric as the standardized objective function MRHOF with ETX and OF0 with Hop Count provides some advantages and some limitations too [6] . The OFs based on link metrics such as MRHOF, may provide good quality of link while consuming more power. In this paper, we consider both link and node metrics to improve our objective function. We choose to combine both ETX and Energy consumption of nodes.

a) Problem statement:

With regards to there tiny size, the LLNs devices present the main issue of the energy consumption. To decrease the energy consumption and then increase device lifetime, the radio transceiver should sleep for a long duration. After the sleep time, it should wake-up in order to receive information from candidate neighbours.

During the listening step, where the transceiver listens if there are any ongoing transmissions in the network, it consumes more power. For this reason, it should be turned off to save its power. In this case, the devices cannot receive any information, which makes the use of a duty cycle mechanism a necessity to control the wake up process of the transceiver. ContikiMAC is an implementation of the duty cycle mechanism in Contiki Operating System, where nodes should periodically wake-up to listen if there is any information sent from the neighbours. In addition, Contiki makes the estimation of the energy consumption with the use of *Powertrace* tools based on an energetic model. These tools allow designing a new metric based on energy consumption called Total Energy Consumed routing metric (ENTOT). This metric was proposed by [7]. It sums the energy consumption of nodes and then select the preferred parent according to the less total energy that it provides. This proposal (ENTOT) attempts to balance the energy consumed by the network but it provides the worst link quality because it does not take into account the link quality.

b) Contribution:

With regards to the limitation of the use of this single metrics, we combine this metric (ENTOT) with the link metric. The latter is the number of expected transmission count (ETX). To make this combination possible, we apply the fuzzy logic method, which allows combining several routing metrics based on the fuzzy logic rules. This combination provides a new objective function called OF-EC (objective function based combined metric using fuzzy logic method). The process of selecting the best path considers both the link and node metrics. Low value of ETX and less energy consumption mean that the route is the optimal one.

IV. ROUTING METRIC DESIGN

2) FUZZY LOGIC METHOD [11]:

a) Fuzzy Logic method:

The use of the fuzzy logic method plays an important role in routing metrics combination. Indeed, this method allows converting a set of input variables (ETX and EC) into one output variable. To make this decision possible, there are however some steps to follow:

- *Fuzzification*: take a predetermined variable input and specify its membership degree (fuzziness) for fuzzy sets.
- *Fuzzy inference*: allows to combine fuzzified inputs and then calculate the output.
- *Aggregation*: unify the outputs if they depend on more than one rule.
- *Defuzzification*: transform the fuzzy output into determined value.

b) Linguistic variable:

In order to extrapolate the mechanism of fuzzy logic combination, we consider two routing metrics, which are ETX and EC. These metrics are represented as a linguistic variable:

ETX: is a link metric that predicts the number of retransmissions needed for a packet to be successfully received at the destination. It aims to find path that provides less ETX which means high throughput. The ETX of a route is the total ETX of each link in the route. It can be calculated as the product of the forward (df) and reverse (dr) delivery ratio. Df is the probability of a packet to reach the destination while (dr) is the probability of an ACK to be successfully received.

$$\mathrm{ETX} = \frac{1}{\mathrm{Df} * \mathrm{Dr}} \qquad (1)$$

Energy Consumption (EC): is the energy of nodes spent during the exchange of information in the network.

The energy consumption of a node is calculated based on the power consumed in the transmission and the reception. In transmission, the energy spent by the node is called ''all transmit'' while in the reception it is called ''all listen''. In addition, other parameters are considered for energy compute which are CPU that represents the power consumption during the full power mode and LPM representing the power consumption during the low power mode.

Energy (mJ)= (Transmit*19.5mA + Listen*21.5mA + CPU_time*1.8mA + LPM*0.0545mA)*3V/(32768) (2)

c) Fuzzification process:

To illustrate the fuzzy process, we choose to combine ETX and EC metrics. They are the input variables. The linguistic variables used to represent the ETX input are: *small, average* and *long*, and the EC input are: *low, average* and *high.* Figure 2, shows the relation between this linguistic variables. The unsuitable route is the path that provides very high value of both ETX and EC. The low value of these two variables provides a good route.

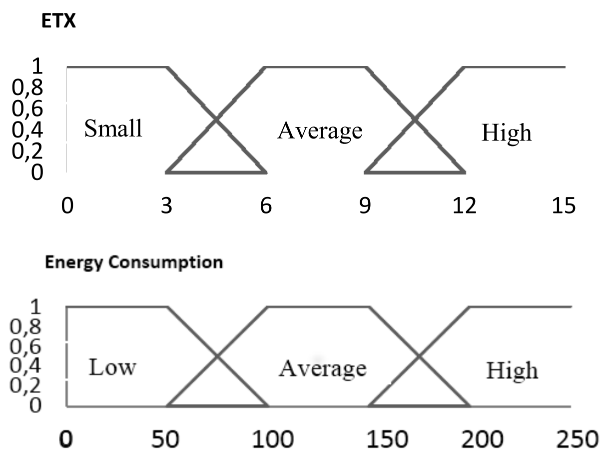

Figure 1: Membership functions

Table 1 illustrates the relation between these two linguistic variables for the computation of output variable. small value of ETX and low value of energy means that the Quality of the path is better.

Table 1: Fuzzy Output Metric

ETX/ Consumed Energy	**Low**	**Average**	**High**
Small	Very_good	Good	Average
Average	Good	Average	Bad
Long	Average	Bad	Vey-bad

The quality of a path can be detected from the ETX and EC membership function. Following the Mamdani model, the function of composition uses the minimum operator while it uses the maximum for aggregation operator. Formula 3 indicates how to calculate the quality of the link from the input [8].

$$avg(quality) = \max(\min(small(etx), high(eng)) \quad \min(avg(etx), avg(eng)) \quad \min(long(etx, low(eng))\ ) \qquad (3)$$

From these membership functions, three value of quality are provided: very good, good and average. These values are defuzzified in the next step to give a unique value in the output.

V. RELATED WORKS

There are many research studies dedicated to improving RPL routing protocol, using a set of methods such as fuzzy logic in order to optimize the objective function [9] [2] [10]. This optimization can use a single or multiple metrics to make the choice of the route based on the best decision. In [11], authors propose a new objective function (OF) based on a single metric, which is the remaining energy. In contrast to the traditional objective function that use link metrics as a single criterion (e.g. MRHOF based on Expected Transmission count) to select the next hop toward the destination, this new OF uses a node metric. The results show that the proposed implementation considers the distribution of energy equal between nodes with a transmission accuracy. Additionally, this OF allows increasing the lifetime of network. However, the use of this single metric is still not efficient because it does not consider the link quality. In [9], authors aim to find the best way to reduce the energy consumption based on mobile base station. They use fuzzy clustering method that consider three parameters: energy sensor, distance sensor from the sink and cluster-centric priorities. The results show an increase in terms of lifetime with the movement of the base station. In order to respond to the constrained application requirements that use RPL as routing protocol, authors in [2] try to optimize this protocol by improving the metrics used in its objective function. They use fuzzy logic based model that combine several metrics which are Expected Transmission Count, Delay and remaining energy in order to build the route toward the final destination. [12]. The new OF is compared to the standardized OF that use ETX as a metric. The results show that the new OF provides better performances in terms of packet reception rate and energy distribution which increases when the network experiences heavy data traffic. In [10], authors design a new Objective Function (OF-FL) that combines several metrics based on fuzzy logic methods. This method uses fuzzy parameters that allow configuring routing decision. In comparison to other objective functions, the OF-FL is based on a combination of four node and link metrics in order to select the best paths to the destination. These metrics are ETX, hop count, end-to-end delay and battery level. Simulation results reveal that RPL based OF-FL provide an enhancement of the protocol in terms of delay, lost packet and network lifetime compared to the standardized OF which are MRHOF and OF0. Furthermore, this proposal is only compared to the standard OF, which limits its efficiency compared to other proposals in this context.

VI. EXPERIMENTS RESULTS

a) simulation setup:

To implement our proposed OF-EC, we use the COOJA simulator running on Contiki Operating System (version 2.7). It is an open source emulator designed for IoT applications. We used the default values for all parameters which are summarized in Table 2.

Table 2: COOJA parameters

Network simulator	COOJA under Contiki OS (2.7)
Number of node	10,30,50
Emulated nodes	Tmote Sky
Deployment type	Random position, grid position
Radio environment	DGRM (Directed Graph Radio Medium)
Interference range	100m
Transmit and Received ratio	TX=100%, RX=100%
Total simulation time	2h30min

b) Chosen Metrics

To evaluate our new approach to improve RPL, we used the following metrics [13]:

- **Control Traffic Overhead:** is the total number of control messages transmitted by nodes in order to build DODAG and to select the best parent between candidate neighbours. The control messages contain the DAO, DIS and DIO messages.
- **PDR**: the packet delivered Ratio presents the ratio of the number of received packets and the number of sent packet of nodes.
- **Node Energy**: it indicates the average energy measured from nodes in the network over the network lifetime.

c) Evaluation results:

To evaluate the performance of OF-EC in dense network from (10 to 50 nodes) and with two different distributions (random and grip position), a set of metrics are considered. All our simulations figures illustrate RPL performances by considering the PDR, the Control Traffic Overhead and the energy consumption metrics. A comparison has been made between the standardized OF based ETX, ENTOT, OF_FUZZY and the new OF-EC using combined ETX and Energy consumption according to the fuzzy logic method. The results are analysed for both cases as follows:

1) Network density in random topology

a) Packet delivered ratio:

To extrapolate the network reliability of OF-EC, we have compared OF-EC with OF-ETX, ENTOT and OF-FUZZY in terms of packet delivered ratio. Figure 2 shows the PDR of nodes in the network. Simulations results show that for a scalable network, ENTOT provides the worst reliability than OF based ETX, OF-EC and OF_FUZZY. This result can be explained by the fact that node selects the best parent that offer low energy consumption even if they have bad radio links. In addition, both OF based ETX, OF-EC and OF_FUZZY provide high reliability due to the use of best links to transmit packets. However, our proposed objective functions still better in terms of PDR than OF that uses single metrics because it considers node energy and link quality. In contrast, it provides less PDR than OF_FUZZY that considers ETX, latency and remaining energy. This can be justified by the fact that OF_FUZZY makes a strict decision of link quality by considering two link metrics that are ETX and latency. Furthermore, The OF-EC outperform the OF based ETX and ENTOT in terms of PDR. We justify this effectiveness by providing low number of lost packets even if the network becomes denser.

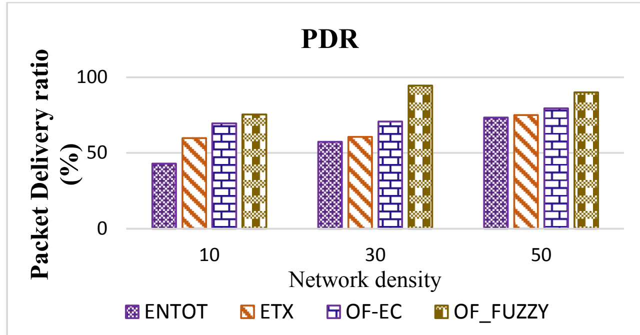

Fig. 2. Comparison between OF based ETX, ENTOT, OF_FUZZY and OF-EC in terms of PDR.

b) Routing stability

We evaluated the accuracy of the routing for traffic collection. For this, we measured the network stability by considering the number of control overhead. The comparison has been made between the four objective functions. In figure 3, we show that in a low density that not exceeds 10 nodes OF-EC provides low overhead than OF based ETX, ENTOT and OF_FUZZY. In contrast and in a high density from a range of 30 to 50 as showing in the figure 3, OF-EC has the highest control messages but less than OF_FUZZY. This can be justified by the fact that, in a high density, nodes transmit more messages to check the availability of candidate neighbor in order to choose the best parent from them. In addition, OF with ETX or ENTOT doesn't take into consideration the optimization of parent selection process which explains the low traffic overhead. In contrast, with OF_FUZZY the network is unstable due to the number of transmitted packets even if it has the benefit to ameliorate the routing performances by improving link quality. Moreover, our proposal still more stable than OF_FUZZY with low link quality.

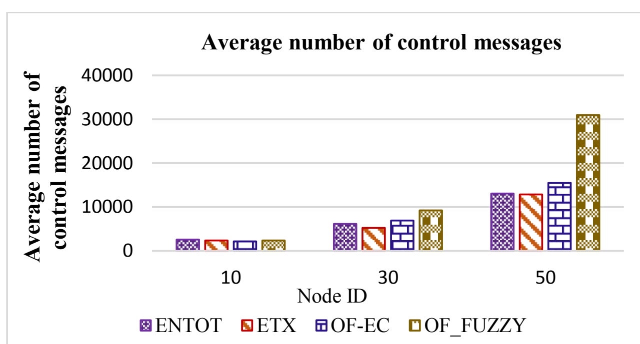

Fig. 3. Comparison between OF with ETX, ENTOT, OF_FUZZY and OF-EC in term of the average number of control messages

c) Network lifetime:

It is clear that the objective function has a direct impact on the energy consumption of the whole network [7] [6] [10]. The main goal of our study is not to demonstrate how the OF-EC acts in the whole network but to study how the energy consumption is distributed within the network. We can notice that OF-EC and OF_FUZZY consumes more energy than OF based ETX and ENTOT. This is due to the Fuzzy calculation that takes more time to compute the optimal route toward the destination. This result has an impact on the network survivability but not on the node failure. For this reason, we studied the energy consumption of each node in the network with a number of 10 nodes. Figure 4 illustrate the distribution of the energy consumption of nodes along the network. We can clearly notice that in the case of OF based ETX, ENTOT and OF_FUZZY provide low power consumption than combined metrics used in OF-EC. In contrast, the simulation demonstrates that our proposed OF-EC has an important impact on the distribution of energy consumption for each node in the network. As shown in figure 4, the distribution of the energy consumption in OF based ETX, ENTOT and OF_FUZZY is not well balanced between all nodes. This result is relevant from the fact that OF based ETX chooses a route with low ETX without considering the energy consumption of node, while with ENTOT it chooses node with low energy consumption even if it provides bad link quality. These reasons extrapolate the benefit of the use of combined metrics with OF-EC where nodes are selecting according to their good link quality and low energy consumption. This allows making the network more survivable and nodes can keep their energy for a long time. In addition, OF-EC in comparison with OF_FUZZY consume more energy but keep the energy consumption of nodes balanced throughout of the network.

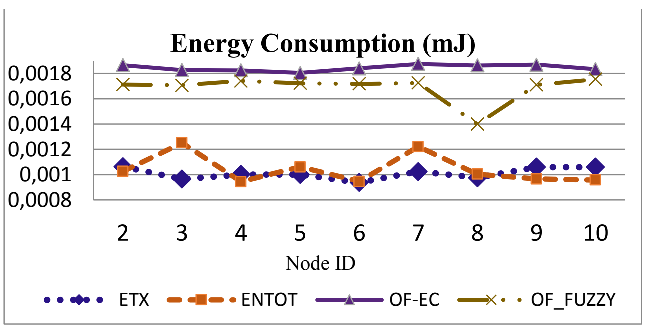

Fig. 4. Comparison between OF with ETX, ENTOT, OF_FUZZY and OF-EC in term of consumed energy per node

2) Network density in grid topology

a) Packet Delivery Ratio (PDR):

In order to demonstrate the efficiency of our proposed OF-EC, we have changed the topology of the network from random to grid position. As shown in figure 5, OF-EC still provides best PDR than OF based ETX and ENTOT for both distributions. Moreover, with grid position the performances of the routing protocol are improved than random topology. Moreover, OF-EC provides high PDR than OF_FUZZY in grid position unlike to the random position. OF base ETX has 73% of packet delivered ratio in random distribution while in grid one it provides 63%. Therefore, ENTOT has as PDR approximately 74% with Random topology, while it was approximately 63% with grid topology. For our proposed OF-EC, in grid topology, the PDR was approximately 73% while it was 79% in random topology. It is clear that the distribution of node according to a specific topology could change the routing performances but in both condition our proposal still efficiency in terms of PDR whatever the topology adopted in such condition.

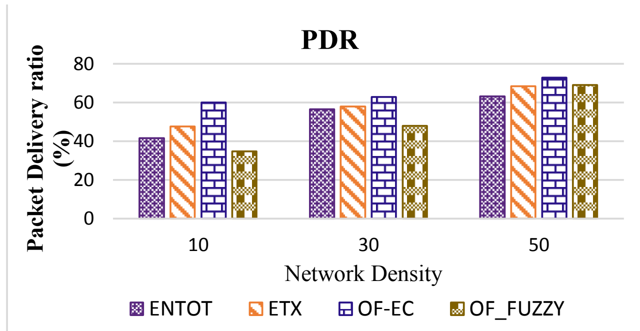

Fig. 5. Comparison between OF based ETX, ENTOT, OF_FUZZY and OF-EC in term of PDR under grid topology

b) Routing stability

In contrast to the figure 5 on which the PDR is decreased, figure 6 shows that nodes in grid topology have more overhead for all OFs than random topology. This increase in the number of control messages is due to the position of sink node. In random topology sink node is positioned in the middle of sender nodes while in grid topology it is situated in the extremity of the topology. In grid topology, nodes use more hop count to attain sink node which imposes it to send more packets to select the optimal way to reach the destination. In both distributions, OF-EC still provides the worst overhead than OF based ETX and ENTOT but the better than OF_FUZZY.

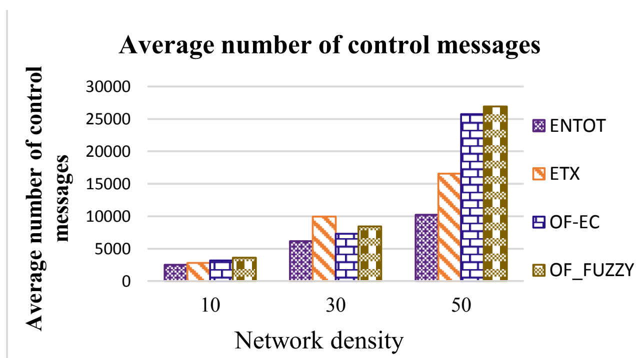

Fig. 6. Comparison between OF based ETX, ENTOT, OF_FUZZY and OF-EC in term of number of control messages under grid topology

c) Energy consumption

In figure 7, the energy consumption is measured for the four OFs. The results show that nodes in a grid distribution spend more energy than nodes in random topology. This is relevant to the fact that node sends more packets to reach sink node situated in the extremity of the topology. This high value of overhead in grid topology gets nodes to spend more power and consume more resources from the network. In contrast, our proposed OF-EC still better in what concern the distribution of the energy for almost of nodes. As showing in the figure, there are some nodes that spend their energy more than others in OF based ETX, ENTOT and OF_FUZZY which, can provides network failures if these nodes consume all their energy. In contrast, in OF-EC the energy consumption is well balanced along the network. This allows us to conclude that our OF-EC keeps its effectiveness even if the network topology is changed.

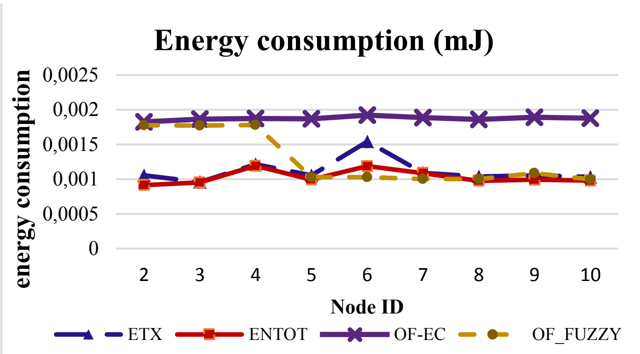

Fig. 7. Comparison between OF based ETX, ENTOT, OF_FUZZY and OF-EC in term of consumed energy under grid topology

VII. CONCLUSION

In this paper, we proposed an enhancement of the RPL routing protocol based on its objective function. The OF standardized by the IETF uses a single metric as Hop Count for OF0 and Expected Transmission Count for MRHOF. We propose a new objective function based on a combination of ETX and energy consumption called OF-EC. To apply this combination, we have adopted the fuzzy logic method, which is based on fuzzy membership that determines a set of rules for combination. The comparison has been made for four objective functions: OF based ETX, ENTOT, OF_FUZZY and our proposed OF-EC. The simulation results showed that the proposed new OF-EC has better performances than OF based ETX and ENTOT in terms of PDR but low than OF_FUZZY. Furthermore, it provides high traffic overhead in comparison of objective function that uses single metrics while it still better than OF_FUZZY that combine ETX, Latency and Remaining Energy. Additionally, the proposed combination allows equalizing the distribution of energy consumption of all nodes, which allow avoiding network failure and increase nodes lifetime. Moreover, OF-EC proves its effectiveness in comparison with OF based ETX, ENTOT and OF_FUZZY even if the network topology is changed. In future works, we suggest adding more routing metrics to this combination such as LQL, RSSI, and PFI in order to give the best routing decision to choose the optimal path.

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