# FTC-OF: Forwarding Traffic Consciousness Objective Function for RPL Routing Protocol

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***Abstract*—The diversity of Internet of Things applications require a flexible routing protocol to cope with several constraints. In this context, the RPL protocol was designed to meet the needs of IoT. RPL relies on an objective function based on specific metrics to fulfill its routing strategy. The single routing metric problem leads generally to non-optimized routes selection. As a consequence, two major issues emerge, mainly the node's congestion due to the high number of forwarded packets, also the greedy energy consumption by those nodes that conduct to fast batteries draining. In that purpose, Forwarding Traffic Consciousness Objective Function has been proposed, which combines three routing metrics, namely hop count, RSSI and a newly designed Forwarded Traffic Metric (FTM). The proposed method, evaluated using COOJA against ETX and Energy based RPL, showed a packet delivery ratio increase respectively with 2% and 11% in low and high traffics, considerably reduces the power consumption with approximately 47% as well as it achieves a good balance of traffic managed by the relay nodes.**

***Index Terms*—WSN, RPL, IoT, combined metrics, load balancing, objective function, CONTIKI OS**

## I. Introduction

With the daily revolution that emerge the world using networked sensor technologies, connected objects to the Internet have become a necessity for better human-environment interaction [1]. This ingenuity and easy accessibility has boosted the focus on these network developments based essentially on wireless sensor networks. In this context, the vision of future sustainable smart cities is moving towards the installation of these networks for several types of urban applications [2].

In recent years, the routing protocols in wireless sensor networks have aroused great interest in research and development. The wireless network researches community has been interested in several new routing protocols aimed at different fields and applications [3]. One of them, known for its flexibility and versatility, the RPL protocol based on IPv6 and intended for networks with losses and low energy consumption. Most of the protocol exigencies consist on an optimal quality of service particularly the battery autonomy and link quality [4]. In other words, the routing is a big challenge in these networks for standardization groups and researchers. In this context, the routing protocol IPv6 for LLN standardized by IETF Task Force, called the "IPv6 Routing Protocol for Low-Power and Lossy Networks" (RPL) was designed [5]. 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 [6]. It is a protocol not based on infrastructure but it relies on the construction of a Destination-Oriented Directed Acyclic Graphs DODAG referring to its objective function in order to create closed paths upward and downward [7].

Two objective functions are defined in the core of RPL by IETF- ROLL group that are Minimum Rank Hysteresis Objective Function (MRHOF) based on Expected transmission Count [8] or energy consumption and Objective Function Zero (OF0) based on Hop count [9]. The common point between those two objective functions that they are based on a single metric which allows, on the one hand, minimizing it but on the other hand leads to non-optimized and unbalanced routes.

In heavy traffic cases, the sensor nodes cannot meet the increased input traffic, thus non-uniform workload distributions is inevitable what leads to congestion problems causing network reliability degradation and over energy consumption.

Considering those drawbacks, we propose a novel objective function called Forwarding Traffic Consciousness (FTC-OF). It is based on a combination of Radio Signal Strength Indicator (RSSI), hop count (HC) and a newly designed Forwarded Traffic metric (FTM) to cope with the single constraints problem and to select the optimal preferred parent node taking into account the load balancing with less frequent preferred parents change.

Indeed, the FTC-OF uses the FTM designed metric adjusted empirically with the input traffic, which penalizes the node with a lot of forwarding traffic by increasing its rank. Then nodes can change their preferred parents with high forwarding traffic according to certain stability introduced by FTM_Threshold. Thus alleviate the unbalanced workload between nodes in the network.

The main contributions of this paper are summarized as follows:

- Improve the RPL by a newly designed objective function FTC-OF for IoT networks. Our proposal combines with additive approach three different

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metrics chosen in such a way as to respect the objective function convergence and infinite loops avoid in the routing.

- Design of a new routing metric named FTM, whose main role is to balance the workload between the nodes.
- A simulation under COOJA emulator of our proposal that achieve our expectations in term of balancing network, avoiding congested paths and decreasing the power consumption.

The rest of this paper is organized as follow. In Section II we present the related works. In Section III we present the proposed objective function FTC-OF. In Section IV, we report the experimental results and discussion, finally a conclusion is given in Section V.

## II. Related Works

The RPL protocol has been the subject of several research projects that have been carried out in order to improve or adapt it to many applications since any objective function is specified to be used. The researches have all focused on the RPL core protocol. Several authors were interested first on the performance evaluation of objective functions implemented by default for RPL [10]-[13], to know their advantages and limits. Based on the wide performance evaluations, attention has turned to the vision of designed new or combined metrics.

San Martin *et al*. in [14] proposed Sigma-ETX metric which is the ETX standard deviation value for each routing path to sink. The best path is that with minimum number of deviations. However, the energy consumption is not considered which may conduct to fast nodes depletion. Also, a Expected Lifetime metric (ELT) was proposed in [15], where the remaining time of node it denoted until draining its battery as well as the energy-bottleneck of nodes is identified in the work. Kamgueu *et al*. defined in [16] remaining energy of candidate parent as a metric in preferred parents selection. This new metric has proven its extending network lifetime effectiveness, but the proposal lead to choose lossy links owing to neglecting a link metric. Also in the new proposal of single metrics case, the average delay to sink was also defined in [17] by Gonizzi *et al*. The proposal showed a significant decrease in terms of end to end delay despite a low reliability.

Single metrics have shown that, in any application, lead to non-optimized routes because they tend to focus on one constraint. In this context, to respect the smart grid applications, OFQS was introduced by Nassar *et al*. combining three metrics namely ETX, delay and power state. Also, ETEN-RPL in [17] by Gao *et al*. based on additive combination of ETX and remaining energy. Both of them are based on MRHOF to conserve the stability in paths selection. The proposed methods showed an improvement in term of reliability, power consumption and latency but they did not treat different densities to show the issues induced. A novel designed objective function presented by Mishra *et al*. in [18], based on ETX, hop count and available energy using lexicographic and additive approaches, to fulfill the IoT QoS requirements. EHA-RPL showed better performances in term of latency, PDR and power consumption against MRHOF and OF0 in a density of 75 nodes.

Fuzzy logic is also adopted as a combined approach, Bhandari *et al*. in [19] proposed a new RPL objective function context-oriented objective function (COOF) considering the queue fluctuation (QFI) and remaining energy index (REI) in order to cope with network dynamics and IoT-based smart city application requirements. In [20], 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 improve the RPL performances in term of PDR, network life time, convergence time, latency and power consumption in comparison with MRHOF but don’t cope with the load balancing problem. In [21], Araujo *et al*. proposed a new objective function called DQCA-OF that combine tree metrics, i.e. ETX, hop count and energy consumed. DQCA-OF provides a packet delivery ratio over 95%, reduce end to end delay and the number of excepted transmission count. However, the proposal is simulated with a topology of 20 nodes which need other tests for high densities.

The balancing problem attracts the attention of researchers in the RPL routing protocol. Indeed, In [22], a Multi-gateway Load Balancing Scheme for Equilibrium (MLEq) approach is adopted by Ha *et al*. to solve the load-balancing problem using multiple gateways. However, the traffic congestion issue is solved but they did not address the load-balancing problem with a single gateway. Similarly, Oliveira *et al*. in [23] proposed ALABAMO based on ETX metric and traffic load value, that can provide a load balancing of the network, but lead to more packet loss against MRHOF. Another study in [24] proposed a Lightweight Load Balancing and Route Minimizing solution for RPL. A function was induced, which prevents the Herd Decampment Phenomenon (HDP) problem. The solution proposed enables delayed parent joining for the nodes in order to achieve a lower rank instead of a greedy thundering, leading to multiple instabilities in the network topology. This method revealed that it could improve the average Packet Loss Ratio, End-to-End Delay and energy consumption.

## III. FTC-OF: Forwarded Traffic Consciousness Objective Function

### A. Problem Statement

In its selection of routing paths to sink, the RPL protocol uses a single metric which leads to choose routes that minimize their cost according to the objective function, some advantage performances are provided by this approach, but it shows some limits as choosing static or non-optimized routes. For example, using OF0, it tends to minimize the number of hops which leads to choose pure static routes, while MRHOF based on ETX and Energy tend respectively to choose routes minimizing the ETX and energy consumption along the routing path, which leads to setting up dynamic routes where frequency of parent changes respect only one constraint.

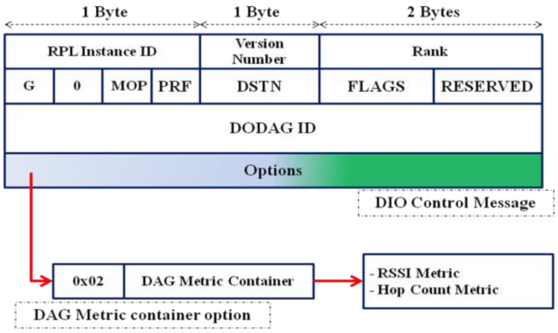


Fig. 1. Amended DIO control message.

In these two cases, the problem turns out the same by choosing the nodes that offer the best conditions according to one metric which results in paths congestion, that impose a non-uniform distribution of the workload for the different nodes in the network, more frequent packet losses and greedy energy consumption against others not loaded.

For all those reasons, we propose a combination of three different metrics namely hop count and forwarded packets as node metrics while RSSI as link quality metric. So, for that purpose the DIO message options is amended in order to lead the metric container section to support the RSSI and HC as shown in Fig. 1. Our proposal allows first choosing routes based on good link quality over the shortest path and secondly to balance the network through forwarded metric.

## *B. Metrics of Interest*

In the process of designing an objective function, several metrics can be considered and combined by different approaches as seen previously in related works section. In our paper, we have chosen metrics aiming to increase the network reliability, decrease the energy consumption and the most important thing is to ensure a well-balanced node workload throughout their life cycle of the network.

However, combined metrics must be chosen in such a way that all must be minimized to don't lose the objective function convergence.

**RSSI:** it's a metric based on the signal strength of CC2420 radio and provided through an RSSI_register. In order to adjust the antenna variation, an offset is added to the RSSI_register empirically modeled during the system development. Thus, the value of RSSI is computed as

$$\text{RSSI} = \text{RSSI\_register} + \text{RSSI\_offset} \tag{1}$$

where RSSI_offset is equal to –45dBm. The RSSI value is measured with logarithmic scale in dBm, typically ranges between 0dBm for a very strong signal level and-110dBm. It is a metric to maximize, so in our method, we work with the invert of RSSI. The RSSI of a node $n$ is calculated as

$$\text{RSSI}(n)=\begin{cases}\text{RSSI}(n,s), & \text{cp=sink}\\ \text{RSSI}(n,\text{cp})+\text{RSSI}(\text{cp}, s), & \text{cp} \neq \text{sink}\end{cases} \tag{2}$$

where $s$ is the sink node, cp is the candidate parent of a node $n$, RSSI ($n$) is the RSSI of $n$ along the path, RSSI ($n$, $s$) represents the RSSI between node and sink, RSSI(cp, $s$) represents the RSSI between candidate parent and sink.

**Hop Count (HC):** It is a metric that shows the number of nodes in a routing path. It must minimized metric in the objective function in order to find the shortest path to sink node. The hop count for a node n is calculated as

$$\text{HC}(n)=\begin{cases}1, & \text{cp=sink}\\ \text{HC}(\text{cp}, s), & \text{cp} \neq \text{sink}\end{cases} \tag{3}$$

where HC($n$) is the number of hops towards sink, HC (cp, $s$) represents the number of hops between the candidate parent cp and sink node s.

**Forwarded Traffic Metric (FTM):** It is a metric created in order to lead each node to count the number of packets created locally or to be forwarded. It is a minimizable metric that reduces the workload of a node. Fig. 2 describes the processing of this metric. Indeed, when a node creates a packet from its application layer, then the metric is FTM is incremented, the same thing when it receives a packet to forward by its child node.

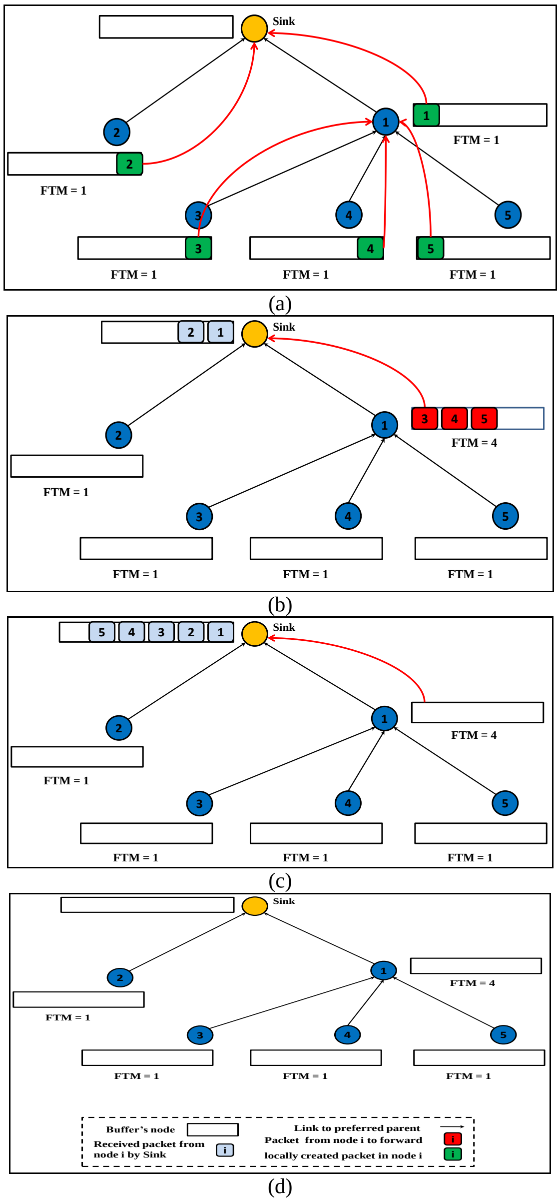


Fig. 2. Processing of the metric: (a) Creation of locally packets by each node, (b) forwarding packets to preferred parents, (c) reception of all packets by the sink node, and (d) waiting for new packets.

### C. *Designed Objective Function FTC-OF*

The proposed objective function is based on additive three combined metrics in order to calculate the rank of node. Indeed, at the reception of DIO message from a neighbor which is at the same times a candidate parent, the rank is processed in 4 steps:

**Step 1:** The node measure the RSSI at the MAC layer and add it following (2) to the advertised RSSI in the received DIO message. IHC($n$) is obtained by multiplying the HC($n$) by −1. Similarly, the HC metric is calculated following (3), where HC(cp, $s$) is advertised too on the container metric section of the DIO message. Whereas the FM metric is a specific metric of the node calculated in the buffer.

**Step 2:** After processing all the metrics, the node $n$ calculates its rank as

$$\text{Rank}\ (n) = \text{Rank}\ (\text{cp}) + \text{Rank\_Increase} \qquad (4)$$

where the Rank_Increase is processed with (5).

$$\text{Rank\_Increase} = \alpha \times \text{FTM}\ (\text{n}) + \text{IHC}(n) + \text{RSSI}\ (n) \qquad (5)$$

where $\alpha$ is an empirical parameter for adjusting the influence of the FTM metric.

**Step 3:** When the node processed its rank after step2, the node compares the new rank with the preferred parent rank, if it's higher, then the candidate parent is discarded. Otherwise, if it's lower than the rank with a threshold then the candidate parent is retained and the node switches to the new preferred parent. The threshold named Threshold_FTM is an essential parameter to avoid instability in the preferred parent changes. Fig. 3 describes the rank processing in the DODAG.

**Step 4:** At this stage, if the node n decide to change its preferred parent, it update the metric container and rank in the DIO message and broadcast the new DIO. Algorithm 1 describes the FTC-OF objective function.

*Algorithm 1*: Rank processing with FTC-OF

```
Require: DIO message from candidate parent cp
begin:
 When node n receive a DIO message from cp
if (cp ! = NULL) then
  base rank = cp.dio.rank;
  RSSI = cp.dio.rssi + rssi(n,cp);
  HC = cp.dio.hc + 1;
  IRSSI = -RSSI;
  rank_increase = α*FTM + IRSSI + HC;
  if (Best parent == NULL) then
    Best parent = cp;
    rank = base rank + rank_increase;
  else
    if (base rank + rank_increase< Bestparent.rank+
FTM_Threshold) then
      Best parent = cp;
      rank = base rank + rank_increase;
    else
      Best parent do not change
      exit;
    end if
  end if
/* Generate a new DIO message
dio.mc.rssi = RSSI;
dio.mc.hc = HC;
dio.rank = rank;
Broadcast updated DIO message
end if
    end;
```

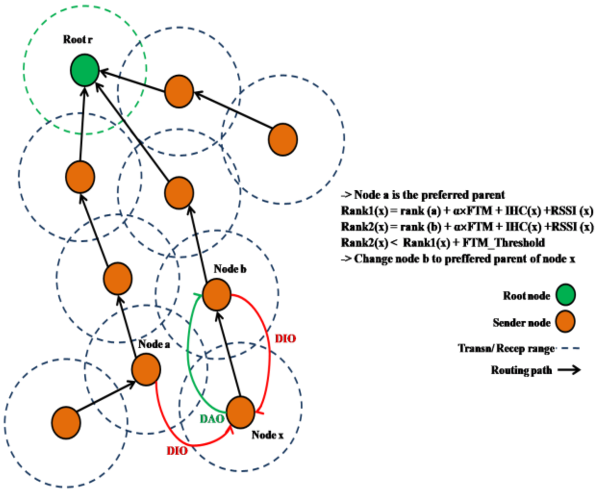


Fig. 3. Rank processing with FTC-OF.

## IV. Evaluation of Proposal and Discussion

### A. *Simulation Environment*

The performance of FTC-OF objective function injected in the core of the RPL protocol is evaluated under COOJA Network simulator, it is considered as an emulator due to the code testing capacity running on real IoT nodes hardware Sky motes with CONTIKI as an embedded operating system.

Furthermore, it gives a large flexibility in evaluating topologies, propagation models and radio environments. For the radio propagation model, we use the Unit Disk Graph Model: Distance Loss.

The Sky nodes are used with a transmission range of 70 meters and distributed randomly in an area with 200m each side. The density is set to 25 and 50 sender nodes with a single sink that collects all the data in the network. In the application layer, sender nodes are programmed to allow UDP messages to be propagated to the root varied from 1 to 6ppm.

The performances of the proposal are compared against the Standard RPL based on ETX metric and EC-OF which is RPL based on energy consumption. The network performances are evaluated for the number of preferred parent changes, packet delivery ratio, power consumption and the network balancing. The simulation parameters are summarized in Table I.

TABLE I: SIMULATION PARAMETERS

| | |
|---|---|
| Network simulator | Cooja |
| Embedded operating system | Contiki 2.7 |
| Radio environment | Unit disk graph medium - DL |
| Emulated nodes | Sky |
| Network area | 200 x 200 m ² |
| Deployment of nodes | Random |
| Number of senders | 25,50 |
| Number of sinks | 1 |
| CC2420 radio threshold | -45 dBm |
| Transmission/interference ranges | 70/100 m |
| Objective functions | RPL-standard, EC-OF, FTC-OF |
| Threshold_FTM | 400 |
| Propagated UDP messages | 1,2,4,6 ppm |
| Simulation time | 600000ms |

### *B. Results and Analysis*

#### *1) Number of parent changes (Churn)*

The number of parent changes by each node in the network is a parameter that several research papers neglect, whereas it is very essential for evaluating the routing protocol performances. The goal is to minimize it as much as possible with non-zero values, in order to not affect the network stability, consuming less energy and balancing the network with slightest parent changes.

As can be seen in Fig. 4 and Fig. 5, our method aim to balance the workload for each without much parent changes due to the stability introduced by FTM_Threshold, while standard-RPL show a high churn because it always aim to choose preferred parents with better ETX link quality, which can lead to routes with high workload through those nodes. EC-OF tend to choice better parents with less energy consumption which leads to non optimized routes regarding the network performances.

#### *2) Packet delivery ratio (PDR)*

The PDR is a parameter that gives an idea of the network reliability in terms of delivering packets to the sink. It is calculated by the number received packets to sink over the total number of sent packets by all the nodes of the network.

As can be seen in Fig. 6 and Fig. 7, our proposed method allows a high packet delivery ratio against Standard RPL and EC-OF, especially when the number of packets increases and the congestion phenomenon occurs. This comes down to that FTC-OF always try, in its preferred parents selection, to balance the workload of each node in the network, which makes possible to increase the chances of failure transmissions by avoiding the congested routing paths opted by other objective functions if their metrics are minimized along these paths.

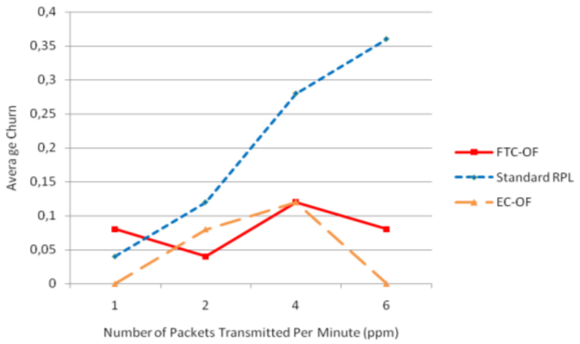


Fig. 4. Average churn in density of 25 nodes.

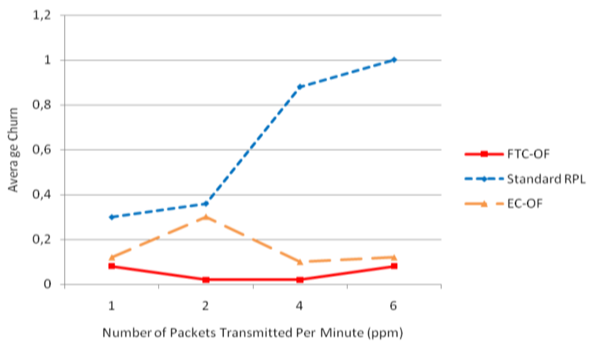


Fig. 5. Average churn in density of 50 nodes.

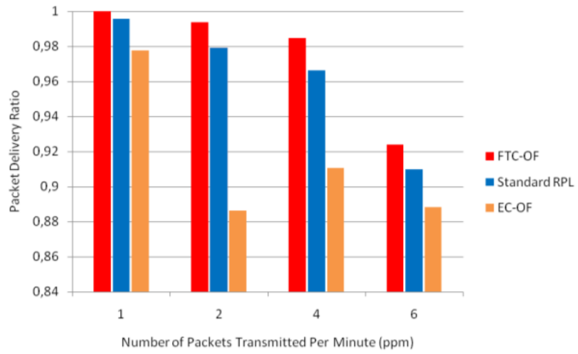


Fig. 6. PDR in density of 25 nodes.

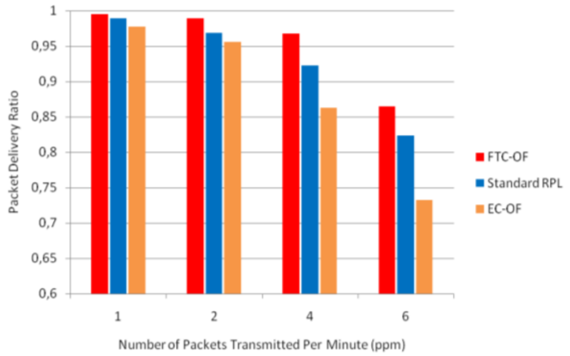


Fig. 7. PDR in density of 50 nodes.

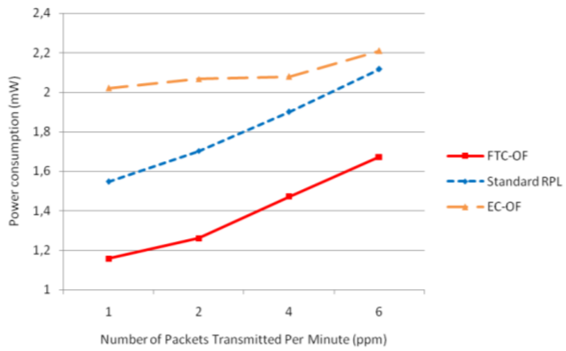


Fig. 8. Power Consumption in density of 25 nodes.

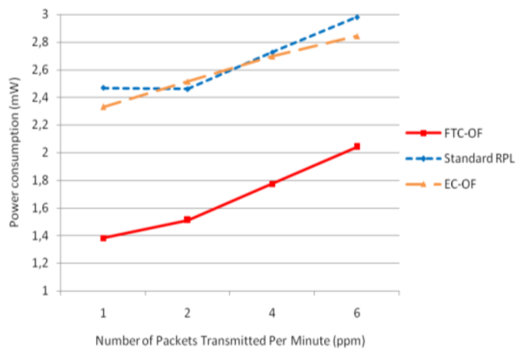


Fig. 9. Power Consumption in density of 50 nodes.

#### *3) Power consumption*

The energy consumption of a node can be stated by processing, medium listening and transmitting communications. It is very essential to decide on the network performances and network longevity service that can provide the routing protocol since the nodes are constrained by their batteries supply.

As seen in Fig. 8 and Fig. 9, FTC-OF can significantly reduce power consumption due to the minimized churn ensuring too the workload balancing between nodes, which helps to avoid overconsumption of energy in the preferred parent changes instability, while Standard RPL is focus to find paths with good link quality without carrying about their energy cost. In addition, our proposed method relies on a hop count metric, which allows it to find shorter paths and therefore limit the cost of energy consumption in term of multi hops packet retransmissions.

*4) Network balancing*

It is a parameter that gives an idea on the workload balance imposed on each node in the network. For that reason, we analyzed the impact of FTC-FC on the routing tree. In our work, we were interested in the direct descendants of the sink due to their importance either in the link with the collector or in ensuring the continuity of network connectivity.

TABLE II-A: NETWORK BALANCING FOR 25 NODES WITH 6PPM

| **FTC-OF** | Sink | | |
|---|---|---|---|
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 4 | 11 | 7 |
| Managed nodes at simulation end | **7** | **8** | **7** |
| **Standard RPL** | Sink | | |
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 9 | 9 | 4 |
| Managed Nodes at simulation end | **7** | **13** | **2** |
| **EC-OF** | Sink | | |
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 0 | 19 | 3 |
| Managed nodes at simulation end | **0** | **19** | **3** |

TABLE II-B: NETWORK BALANCING FOR 25 NODES WITH 1PPM

| **FTC-OF** | Sink | | |
|---|---|---|---|
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 4 | 11 | 7 |
| Managed nodes at simulation end | **8** | **6** | **8** |
| **Standard RPL** | Sink | | |
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 6 | 14 | 2 |
| Managed nodes at simulation end | **7** | **13** | **2** |
| **EC-OF** | Sink | | |
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 0 | 17 | 5 |
| Managed nodes at simulation end | **0** | **17** | **5** |

As seen in Table II-A and Table II-B, our proposal can split the workload management of children equally with a difference of one or two nodes which is n almost perfect load balance of charge. However, Standard RPL show a considerable load imbalance with a difference of 6 and 11 nodes due to preferred parent selection based only on ETX without carrying about the workload. Also for EC-OF, the imbalance is more visible as seen for node A that have no children contrary to the node B that have 17 nodes to manage. Also, as shown in Table II-C and Table II-D, even if the network traffic has increased, FTC-OF show a balance with a workload difference with 2 or 3 nodes while Standard RPL and EC-OF show poor traffic management manifested in a large difference of workload. Indeed, our method achieves a good balance for the sink descendants by assigning them a very slightly different node traffic management workload and guaranteeing good reliability over a short path due to the multiple metrics considered in the objective function.

TABLE II-C: NETWORK BALANCING FOR 50 NODES WITH 6PPM

| **FTC-OF** | Sink | | |
|---|---|---|---|
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 25 | 5 | 17 |
| Managed nodes at simulation end | **16** | **14** | **17** |
| **Standard RPL** | Sink | | |
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 3 | 23 | 21 |
| Managed nodes at simulation end | **3** | **19** | **25** |
| **EC-OF** | Sink | | |
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 4 | 8 | 35 |
| Managed nodes at simulation end | **4** | **9** | **34** |

TABLE II-D: NETWORK BALANCING FOR 50 NODES WITH 1PPM

| **FTC-OF** | Sink | | |
|---|---|---|---|
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 25 | 5 | 17 |
| Managed nodes at simulation end | **16** | **14** | **17** |
| **Standard RPL** | Sink | | |
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 3 | 23 | 21 |
| Managed nodes at simulation end | **2** | **29** | **16** |
| **EC-OF** | Sink | | |
| Direct children nodes of sink | Node A | Node B | Node C |
| Managed nodes after convergence | 2 | 20 | 25 |
| Managed nodes at simulation end | **2** | **23** | **22** |

## V. CONCLUSION

In this paper, we proposed a new objective function for RPL routing protocol designed for Internet of Things named Forwarded Traffic Consciousness OF. It is based on the combination of three different metrics in order to improve the performance of this protocol. The major problem from which the RPL suffers is the load balancing between the nodes, for that reason a new metric called FTM has been introduced in order to become aware of the traffic managed by each node. The results of our proposal showed that the load balancing is obtained with a certain change of preferred parents stability due to an introduced threshold called FTM_Threshold, thus allowed to increase the number of packets received by the sink while avoiding the bottleneck in the routing paths and finally a significant decrease in energy consumption. As future work, we will interested to combine other metrics with FTM metric in order to cope with more constraints.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Abdelhadi Eloudrhiri Hassani, as the corresponding author, has designed the proposed FTC Objective Function for RPL. Also, he has simulated the proposal using COOJA emulator. Aicha Sahel and Abdelmajid Badri have supervised the written paper and providing necessary complement analysis of results. All authors approved the final version.

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## REFERENCES

[1] L. M. Ang, K. P. Seng, A. M. Zungeru, and G. K. Ijemaru, "Big sensor data systems for smart cities," *IEEE Internet Things J.*, vol. 4, no. 5, pp. 1259–1271, 2017.

[2] S. E. Bibri, "The IoT for smart sustainable cities of the future: An analytical framework for sensor-based big data applications for environmental sustainability," *Sustain. Cities Soc.*, vol. 38, no. 1, pp. 230–253, 2018.

[3] A. Boukerche, B. Turgut, N. Aydin, M. Z. Ahmad, L. Bölöni, and D. Turgut, "Routing protocols in ad hoc networks: A survey," *Comput. Networks*, vol. 55, no. 13, pp. 3032–3080, 2011.

[4] M. Abdelgadir, R. A. Saeed, and A. Babiker, "Mobility routing model for vehicular ad-hoc networks (VANETs), smart city scenarios," *Veh. Commun.*, vol. 9, pp. 154–161, April 2017.

[5] J. Park, K. H. Kim, and K. Kim, "An algorithm for timely transmission of solicitation messages in RPL for energy-efficient node mobility," *Sensors (Switzerland)*, vol. 17, no. 4, pp. 1–21, 2017.

[6] A. E. Hassani, A. Sahel, and A. Badri, "A new objective function based on additive combination of node and link metrics as a mechanism path selection for RPL protocol," *Int. J. Commun. Networks Inf. Secur.*, vol. 12, no. 1, pp. 63–68, 2020.

[7] A. Oliveira and T. Vazão, "Low-power and lossy networks under mobility: A survey," *Comput. Networks*, vol. 107, pp. 339–352, October 2016.

[8] O. Gnawali and P. Levis, "RFC 6719 - The minimum rank with hysteresis objective function," *Internet Eng. Task Force*, September 2012.

[9] P. Thubert, "RFC 6552 - objective function zero for the routing protocol for low power and lossy networks," *Internet Eng. Task Force*, March 2012.

[10] A. E. Hassani, Aïcha Sahel, and A. Badri, "Impact of RPL objective functions on energy consumption in Ipv6 based wireless sensor networks," *Colloque sur les Objets et Systèmes Connectés*, HAL-Archives, Jun 2019, pp. 1-6.

[11] 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," *Electron.*, vol. 8, no. 2, pp. 1–23, 2019.

[12] H. Lamaazi, N. Benamar, and A. J. Jara, "Study of the impact of designed objective function on the RPL-based routing protocol," *Lect. Notes Electr. Eng.*, vol. 397, pp. 67–80, 2016.

[13] A. E. Hassani, A. Sahel, and A. Badri, "Assessment of a proactive routing protocol RPL in Ipv6 based wireless sensor networks," in *Proc. 3rd Int. Conf. Intell. Comput. Data Sci.*, 2019, pp. 1-7.

[14] P. Sanmartin, A. Rojas, L. Fernandez, K. Avila, D. Jabba, and S. Valle, "Sigma routing metric for RPL protocol," *Sensors (Switzerland)*, vol. 18, no. 4, 2018.

[15] O. Iova, F. Theoleyre, and T. Noel, "Exploiting multiple parents in RPL to improve both the network lifetime and its stability," in *Proc. IEEE Int. Conf. Commun.*, 2015, pp. 610–616.

[16] P. O. Kamgueu, E. Nataf, T. Djotio, *et al.*, "Energy-based routing metric for RPL," Research Report, Inria, 2013.

[17] P. Gonizzi, R. Monica, and G. Ferrari, "Design and evaluation of a delay-efficient RPL routing metric," in *Proc. 9th Int. Wirel. Commun. Mob. Comput. Conf.*, 2013, pp. 1573–1577.

[18] S. N. Mishra, M. Elappila, and S. Chinara, "EHA-RPL: A composite routing technique in IoT application networks," *Adv. Intell. Syst. Comput.*, vol. 1045, pp. 645–657, 2020.

[19] K. S. Bhandari and G. H. Cho, "A resource oriented route selection framework using contextual information based on fuzzy logic," *Electron.*, vol. 8, no. 9, 2019.

[20] H. Lamaazi and N. Benamar, "OF-EC: A novel energy consumption aware objective function for RPL based on fuzzy logic," *J. Netw. Comput. Appl.*, vol. 117, pp. 42–58, September 2018.

[21] H. da S. Araújo, R. H. Filho, J. J. P. C. Rodrigues, *et al.*, "A proposal for IoT dynamic routes selection based on contextual information," *Sensors (Switzerland)*, vol. 18, no. 2, pp. 1–16, 2018.

[22] M. Ha, K. Kwon, D. Kim, and P. Y. Kong, "Dynamic and distributed load balancing scheme in multi-gateway based 6LoWPAN," in *Proc. IEEE Int. Conf. Internet Things*, 2014, pp. 87–94.

[23] B. K. T. B. Oliveira, P. H. Gomes, and D. G. Gomes, "ALABAMO: A LoAd BAlancing MOdel for RPL," in *Proc. Brazilian Symposium on Computer Networks and Distributed Systems*, Salvador, 2016.

[24] A. Seyfollahi and A. Ghaffari, "A lightweight load balancing and route minimizing solution for routing protocol for low-power and lossy networks," *Comput. Networks*, vol. 179, October 2020.



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