Performance Assessment of the Routing Protocol for Low Power and Lossy Networks

Hanane Lamaazi[1], Nabil Benamar[1], Muhammad Iqbal Imaduddin[2], Antonio J. Jara[3]
1University Moulay Ismail, Faculty of Science, Meknes
Laboratory of Modeling Analysis and Control System, Meknes, Morocco
{Lamaazi.hanane; benamar73}@gmail.com
2 Telkom University, Faculty of Electrical Engineering, Bandung, Indonesia
imaduddin@students.telkomuniversity.ac.id
3University of Applied Sciences Western Switzerland (HES-SO)
Sierre, Vallais, Switzerland
jara@ieee.org

***Abstract*—RPL (IPv6 Routing Protocol for Low Power and Lossy Networks) is proposed by the ROLL working group at IETF. This protocol used in the Internet of Things is optimal for Low power and Lossy Networks (LLNs). However, the RPL network has some limits when the network is dense. In this paper we evaluate the performance of RPL in three different scenarios. We first, evaluate the characteristics of RPL with fixed nodes, (one sink and others are senders). Then we add mobility, and we compare mobile nodes to fixed nodes in order to show how mobility can influence protocol parameters. Finally, we study the behavior of RPL when the network is dense in order to assess the protocol performances. In this study, we use Contiki OS and Cooja software for all simulations. The results show that RPL performances are greatly influenced by the number of nodes, type of mobility and the topology of the network. When the number of nodes increases, all metrics increase too, especially the power consumption which arrives until an augmentation of 52,85%. Furthermore, Random Waypoint Mobility Model (RWP) gives better metrics than Random Walk (RWK) Mobility Model in terms of number of hops and Expected Transmission (ETX) value. Also, in RWP model, nodes consume 10,73% of power than RWK. Our simulations show clearly that the power consumption is directly related to the number of sink nodes in the network. The more this type of node is present in the network the less power is consumed. The power reduction may occur till 5%.**

Keywords—RPL routing protocol; ETX; Power Consumption; mobility; Wireless Sensor Networks;

I. INTRODUCTION

The main objective of Internet of Things is connecting all devices to the Internet, especially the smaller and finer devices. These kinds of devices have some limitations in electrical resources and are often connected by middling quality of radio links. For over a decade, low power wireless network has been researched to meet complexity of Internet architecture for sensor network applications. However, academic and commercial effort has invented network architecture based on Internet architecture. The Internet Engineering Task Force (IETF) designed some protocols that allow IPv6 to run over IEEE 802.15.4 link using 6LoWPAN adaptation layer [1][2] [3].

978-1-4673-8224-3/15/$31.00 ©2015 IEEE

The limitations of constrained devices lay the Internet of Things to some issues in particular routing of IP packet. The traditional routing protocols like OSPF (Open Shortest Path First) [4], AODV (Ad hoc On-Demand Distance Vector) [5] and OLSR (Optimized Link State Routing Protocol) [6] are not very suited to this situation. For this, a working group named ROLL of IETF works to find a solution to resolve the problem of routing for lightweight devices. This work provides a routing protocol called RPL [7] (Routing Protocol for Low Power and Lossy Network) which is standardized by IETF. Since the standardization of 6LoWPAN, the LoWPAN networks have a new dimension that allows them to be interoperable with the Internet. RPL conforms to the 6LoWPAN. Also, RPL is designed for networks with lossy links. By default, RPL is based on Expected Transmission Count (ETX) routing metric. The routing metric has a direct influence on delay, quality of packets, and transfer of data. This routing metric allows ensuring efficiency of network performance. However, The RPL is developed to select other metrics in order to calculate the most optimal way taking into account the number of objects connected to the network.

The other requirement of IoT is the mobility support. Most of IoT applications are based on mobility like smart grid, health care monitoring, and industrial automation. The cooperation between mobile and fixed sensor nodes is considered by many research projects and studies. For instance, in hospitals, patients have embedded sensing device that return data in real time [8] [9]. Also, in oil refineries, workers have embedded sensing device to collect vital signs in order to monitor their condition in dangerous environment [10]. Finally, in warehouse, smart embedded device used real time to locate manufacturer assets [11] [12]. In fact, many applications require reliability guarantees to transmit critical message in mobility condition.

The aim of this paper is to analyze the performance characteristics and issues of RPL in different scenarios. It makes comparison between fixed and mobile nodes. Each simulation is studied independently and combined afterwards to give critical view. The Network Topology is also considered. The remaining of the paper is structured as follow: in section 2, we present the RPL protocol to give a general idea about it. Section 3 explains the choice of mobility models used for simulation. In, section 4 we present the main metrics used in the present work to assess the performances of the routing protocol. Simulation environment and Parameters setup is presented in section 5 while analysis and evaluation are discussed in section 6. We conclude this paper by a conclusion in section 7.

II. RPL PROTOCOL OVERVIEW

The network with losses and low power is another type of network used in the Internet of Things. This type of network called LLN (Low power and Lossy Network) poses constraints of integration to the infrastructure. It allows communication between devices and embedded devices such as sensors, and can contain thousands of nodes.

The LLN networks are also characterized by their diversity of traffic; they do not only use the point-to-point model, but extend to point-to-multipoint or multipoint-to-point traffic. Given the complexity of this type of networks, the need to have an enabled routing protocol has become a major challenge for researchers. Therefore, the IETF ROLL working group defined the new Protocol for Low-Power and Lossy Network (LLN), which is the RPL. RPL is a routing protocol distance vector based on IPv6. It builds topologies called Destination Oriented Directed Acyclic Graph (DODAG). To calculate the best path, RPL combines all the elements cited in [10].

RPL has been developed to reply flexibly to requirement of networks: optimize energy consumption and ensure good data reception. Moreover, the RPL is based on metrics that are available on each node. At the DODAG, These metrics calculate the ranking of the nodes to optimize their position relative to their parents.

To exchange information associated to a DODAG, RPL defines a set of ICMPv6 control messages: DODAG Information Solicitation (DIS), DODAG Information Object (DIO), and DODAG Destination Advertisement Object (DAO). Transmission of DIO messages builds and maintains upward routes of RPL. This transmission by a node uses trickle timer which allows elimination of redundant control messages.

DAO messages enable downward route and advertize prefix towards node of DODAG. DIS message can be sent by any node in RPL in order to solicit a DIO message from neighboring nodes [14].

III. MOBILITY MODELS USED

Cooja simulator does not adopt any mobility model. For this, we use Bonnmotion simulator [15] to generate Random Waypoint Model and Random Walk Model traces. These models are explained in the next section. These mobility models help us to compare mobile and fixed nodes in order to analyze the behavior of RPL.

a. Random Waypoint Model :

In Random Waypoint Model, a node selects its destination and its speed form 0 to V_{max}. We consider V_{max} as maximum speed of human walk (e.g. 6.5 km/h). The mobile node keeps moving until it reaches its destination point at that maximum speed. After reaching destination, a new one is chosen from the uniform distribution independently of all previous destinations. The node may suspend upon reaching each destination based on pause time. If this latter is zero, it starts travelling to the next destination, immediately. If it selects a very remote location and the speed is low, it takes too much time to reach the destination. Otherwise, if it selects a place too close of its location and the speed is high, it takes a very limited time to reach the destination [16].

b. Random Walk Model :

Random Walk Mobility Model (RWP) behaves similarly to the Random Waypoint Mobility Model. Random Walk (RWK) model represents a less memory of mobility pattern. Each step is calculated without any information of the previous step. Because of its memory-less pattern, the direction and the speed of the node can be updated, in very unrealistic behavior such as sudden stops or sharp, to turn in any speed. Initially, mobile nodes are distributed randomly in the area at the beginning of the simulation. For smaller simulation areas, nodes are likely to move through to the center point of simulation area which can cause localized density areas [17].

IV. METRICS AND ROUTING PROCESS

A. Metrics and Routing process:

Three main metrics are considered to evaluate our study: Expected Transmission Count (ETX), Routing Metrics (Rtmetric) and Power Consumption. After the presentation of these metrics, we explain the process of the routing in Contiki collect.

a. ETX

Implementation of RPL reposes on Expected Transmission (ETX) as a routing metric. The minimum ETX value specifies the path that is selected by RPL. ETX is a maximum number of retransmissions needed to deliver the individual packet successfully toward destination. For example, a packet needs two transmissions to reach destination, evidently the best path has minimum ETX that is equal to 1. For sink node, ETX is equal to zero. ETX is calculated by two elements, link estimator which is responsible to calculate ETX for neighbors and neighbors that calculate their own ETX by accumulating all ETX in the path from neighbors to root. The first one called 1 hop ETX (ETX_{1hop}) and the second one called multi-hop ETX ($ETX_{multi-hop}$). Each node can estimate for each route the cost ETX by adding the multi-hop ETX and 1 hop ETX. If the cost calculated is low means that it is the desirable route [18].

The ETX values can be calculated by a specific formula using a forward and reverse delivery ratios of the link, the formula can be described as follows: ETX= 1/(Df*Dr). The forward delivery ratio, DF, is the measured probability that a packet is received by the neighbor while the reverse delivery ratio, Dr, is the measured probability that an acknowledgment packet is successfully received. The ETX value may be a discrete value and not an integer. Otherwise, the ETX value can be determinate as the inverse of the link PDR (Packet Delivery Ratio). Consequently, the ETX and the link PDR have inversely proportional relation. If the PDR is higher, the Expected number of transmission may be as low as 1. However multiple transmissions are needed if the PDR is low. Despite the mobility, the ETX can choose a good path if the routing protocol transmits quickly enough the route metrics and in the case of availability of measures of accurate link [19] [20].

b. Routing Metric

In the network, there are many routes between two nodes.
Each route uses different links, which means the route has different throughputs. The routing protocol chooses to select route with the highest throughput.
A route metric is a number affected to each route. Routing protocol selects the route with the best metric. Route metric allows routing protocol to choose which route to use between two nodes. Some properties of route influenced the choice of routing metric. Also routing protocol can choose a route with minimum hop-count which is the number of links in a route. There are many minimum hop-count; the choice will be with an arbitrary manner [21].

c. Power Consumption

The most important parameter taken into account by researchers in wireless sensor network is the power consumption. Power Consumption is based on some mechanisms and protocols. The development and understanding of this mechanism and protocol is difficult because simulators in general don't provide a visualizing support for power consumption [21].
Cooja simulator provides most of the applications that calculate power like CollectView, PowerTrace and PowerTracker applications. Also, it provides a TimeLine module, which allows visualizing both network traffic and power consumption of sensor network [22].

d. Routing process

To transport data sent by any nodes to the sink nodes, the routing mechanism builds a routing tree, which organizes the position of all nodes. The latter is defined by a 16-bit rtmetric value. The top of tree is the position of the sink node, which has as an rtmetric value 0. For the nodes situated at the low level of tree, they have an increasing rtmetric value. The node that minimizes the expected number of transmission to the sink is the parent of node and it constitutes the best neighbor of node. At the beginning, the sink node has value 0 for rtmetric; this value is assigned by the application using the collect protocol. In exception of the sink node, all nodes have a maximum value of rtmetric which is set to 225 not all 16 bits are used. At particular event, the rtmetric is updating and the tree is created dynamically. The node announces the sent out of the packets for neighbor discovery, which contain the rtmetric value. Each receiving node stores the neighbor's rtmetric value in the neighbor table. The node then calculates its own rtmetric value based on the rtmetric value of the best neighbor node. The node that provide path with smallest number of expected transmission to the sink node is the best neighbor [23].
The update of rtmetric value is based on four main events: Incoming announcement packet, designation of a node as a sink node, data packet acknowledgement and data packet time-out. Since the neighbor table is limited in size to 8 neighbors, a timer triggers periodic scan every second and then remove all old neighbors that haven't heard from during the previous 120 seconds. Additionally the neighbor table stores also the ETX values for each node's neighbors. These values are calculated each time a data packet is sent to a neighbor. To deliver packets, it requires a number of transmissions which is reported to the link estimator when the sent packet is ACK'ed. The neighbor table kept each of the last eight transmission counts. The average over this eight transmission count is the link ETX value from a node to the neighbor. The maximum number of transmission is cumulated with the current history entry in the case of transmission times out [23].

V. SIMULATION ENVIRONMENT

In this section we present the simulator chosen in the current work, namely Cooja, and then we illustrate the different scenarios that we have used. Also, we define the metrics used to evaluate our study.

A. Cooja Simulator:

Cooja is developed to simulate sensor nodes based on Contiki OS [24]. It can use specific hardware of several platforms running over Contiki like Tmote Sky, TelosB, native, Z1 etc. This diversity of platforms constitutes one of several advantages of Cooja. Cooja offers the possibility to simulate each node independently using either hardware or software. It allows simulating a variety of levels of the system. Cooja operates on network level, operating system level, and the machine code instruction level. Thus, Cooja is defined like a cross-level simulator. Cooja is a flexible simulator; it allows adding some extension in the simulator [24].
For our study, we need open source simulators in order to easily implement our scenarios. We choose to simulate RPLcollect File, which contains a source code of sink and sender nodes. This file is already implemented in the Cooja simulator. The simulated platform is Tmote Sky. We use the Unit Disk Graph Medium (UDGM) as the radio model [25].

B. Simulation and Parameter Setup:

In this section we present the parameters setup chosen for simulation described in Table 1. Then we discuss the different results obtained at the time of simulation.

We compile the contiki OS for the Tmote Sky platform. We use Unit Disk Graph Medium (UDGM) with Distance Loss as a propagation model [25]. This model take into account two parameters, the first one is the interference. If there is interference between packets, they are lost. The second defines the success rate of transmission and reception. It includes two probabilities: SUCCESS RATIO TX for transmission and SUCCESS RATIO RX for transmission. In the case of failure, the probability of SUCCESS RATIO TX is that none get a packet, while the probability of SUCCESS RATIO RX is only the corresponding node will not receive the packet. All parameters used for simulation are described in Table1[26].

TABLE I. COOJA PARAMETER SETUP

Settings	Table Value
Propagation Model	UDG Model with Distance Loss
Mote Type	Tmote Sky
TX Range	50m
Simulation Time	70 min
Number of Nodes	20, 40, 60
Topology	Point-to-multipoint, Multipoint-to-multipoint
Nodes Position	Random
Speed	No limit speed
Mobility Model	Random Waypoint Model, Random Walk Model

C. *Scenarios :*

Three scenarios are considered: increasing number of fixed nodes, mobile nodes using different mobility model, and mobile nodes with different topologies.

a. *Case of fixed nodes:*

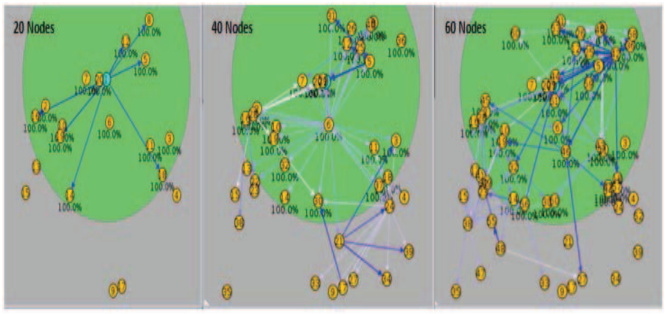
The topology adopted in this case is point-to-multipoint. It uses one sink node and 20 sender nodes. Then, we increase the number of nodes to analyze the performance of RPL when the network is denser.

b. *Case of mobile nodes:*

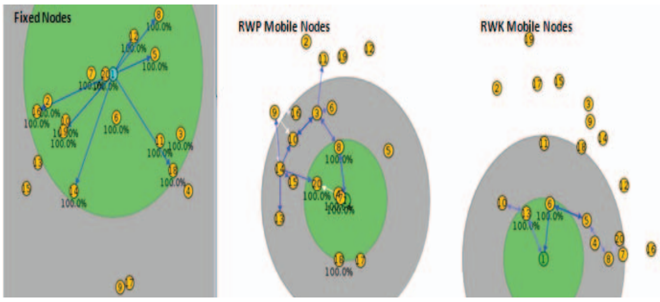
The topology used in this case is similar to the previous case, but we need to add mobility of nodes. That's why, we have added mobility plugin in Cooja simulator, and used other simulator which is bonnmotion [15]. This simulator helped us to generate different mobility model traces. Also, we have developed a script that allows the file generated by bonnmotion to be deployed by Cooja simulator. In our simulation, all nodes move under Random Waypoint Model (RWM) and Random Walk Model.

c. *Case of multipoint topology*

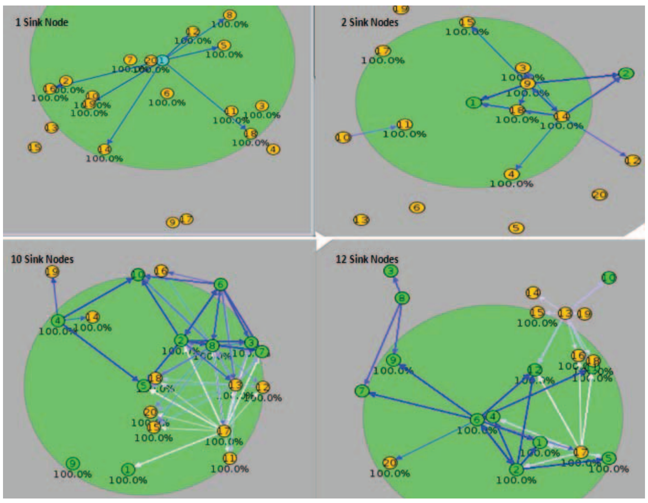
In this case, we use a multipoint-to-multipoint topology to study the interaction between nodes especially sink nodes.



(a) Fixed nodes and increasing number of nodes



(b) Fixed nodes compared to the mobile nodes using RWP and RWK Mobility Models



(c) Increasing of number of sink nodes

Fig 1. Simulation Scenarios

VI. EVALUATION AND DISCUSSION

It is clear that each chosen metric offers an individual side to study the routing protocol. In addition, the different scenarios used in this study have also an important impact on both

protocol and network behavior. It is therefore important to take into consideration all these metrics simultaneously to optimize the packets delivery and to select good routes without consuming more power.
In all figures, the simulations are focusing on analyzing the performance of RPL considering the number of received and lost packets, number of hops, routing metric, Expected Transmission (ETX), and Power Consumption. The results are also compared with two different mobility models .The results show the performance for mobility models with respect to the parameter that have been selected previously.

A. Number of received and lost packets and number of Hops

In the first scenario, we increase the number of nodes and we use only fixed nodes. Figure 2 shows the average number of received and lost packets and number of hops. These three metrics help us to understand how the data is transported into the network. Also, it shows how many packets are received in the destination and how many are lost or dropped during the simulation. As shown in Figure 2, when the number of nodes increases, the number of received packets and number of hops increase too. Unlike, we notice that we have zero value for lost packets meaning all packets are received at their destination. It means that the performances of RPL are better when it is used in the fixed environment even if the network is denser.
In figure 3, we have conserved the value of the 20 fixed nodes. Then, we have moved all nodes, sink and senders, by using two mobility models namely, RWK and RWP. The number of received packets increases depending to the movement of nodes, fixed or mobile, and the model of mobility. In addition, we notice that some packets are lost during their transmission. In Random Walk model we have more packets lost than Random Waypoint, which means that some mobility models could be optimal for RPL than others. For number of hops, in the two figures 2 and 3, we show that the number of nodes is slightly increased.
In scenario 3, we conserve the same number of nodes which is 20. Then we increase the number of sink nodes until it exceeds the number of the sender nodes. This increase is divided in four cases: 1 sink node vs 19 sender nodes, 2 sink nodes vs 18 sender nodes, 10 sink nodes vs 10 sender nodes and 12 sink nodes vs 8 sender nodes. This division allows us to distinguish the behavior of sender nodes.
In Figures 4 we note that all packets sent to the sink nodes are received, no packets lost. Besides, the number of hops decrease when the number of sink nodes increase, which means that the routing protocol calculate number of hops between only the nearest sink node and all sender nodes.

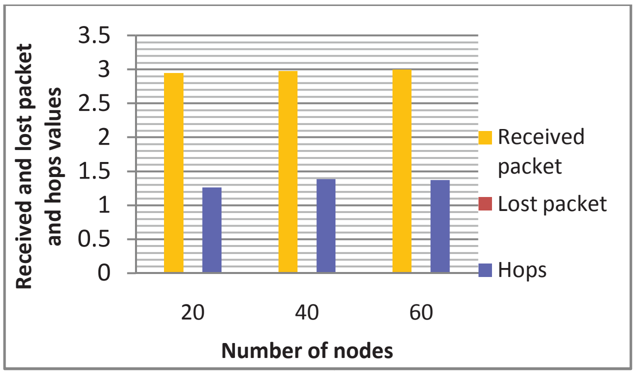


Fig 2. Average number of receive, lost and hops Vs number of fixed nodes.

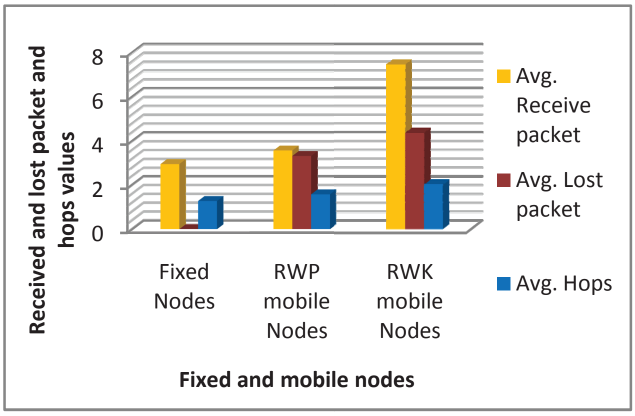


Fig 3. Average number of receive, lost and hops for fixed nodes Vs mobile nodes.

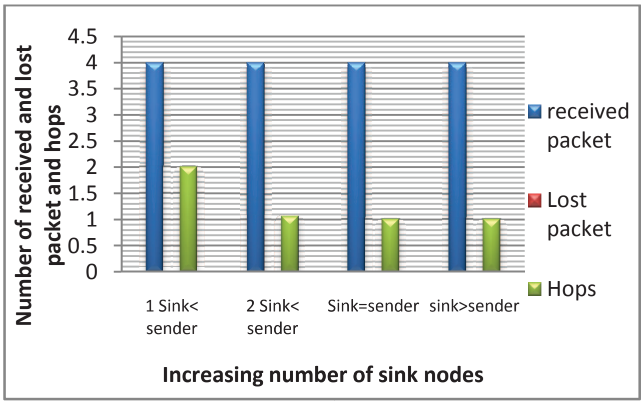


Fig 4. Average number of receive, lost and hops vs number of sink nodes.

B. ETX and Rtmetric

This section provides the results obtained from the evaluated of Expected Transmission Count and Rtmetric for all 3 scenarios.
The Rtmetric of the sink node is equal to zero, which is assigned by the application using by the collect protocol, so for all figures we show the Rtmetric value of all nodes except the sink nodes.
In Figure 5, the routing metric value increases weakly with the number of nodes, this Rtmetric value is calculated based on

the previous Rtmetric value of the best neighbor. This best neighbor is designed by the ETX value; more this value is small more the neighbor is better and the Rtmetric is better too. But in our case, the ETX value remains constant, which means that the number of nodes have no influence on ETX value.

In mobile scenario, RWP provides better ETX and Rtmetric value than RWK model, which is proved in Figure 6. But, fixed nodes award the best ETX and Rtmetric value; because mobile nodes need a long time to calculate the value of ETX and Rtmetric. In addition, for the sink node, the value of ETX is equal to zero, which explains the best value of ETX is provided when the number of sink nodes is greater than sender nodes, which is confirmed in Figure 7.

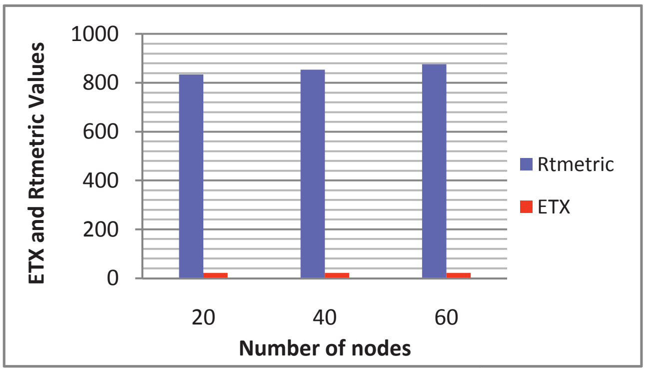


Fig. 5: Average value of Rtmetric and ETX Vs number of fixed nodes.

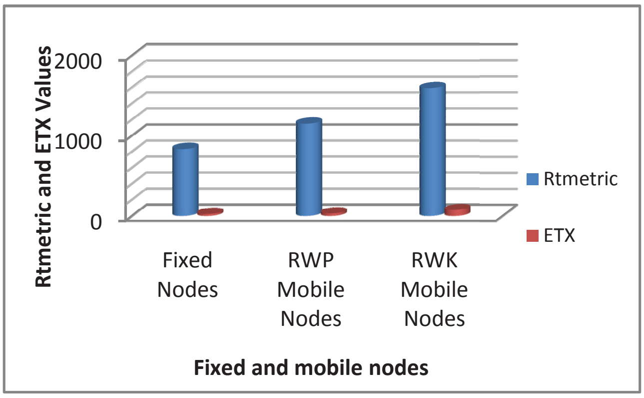


Fig 6. Fixed nodes compared to Mobile nodes considering Rtmetric and ETX Value.

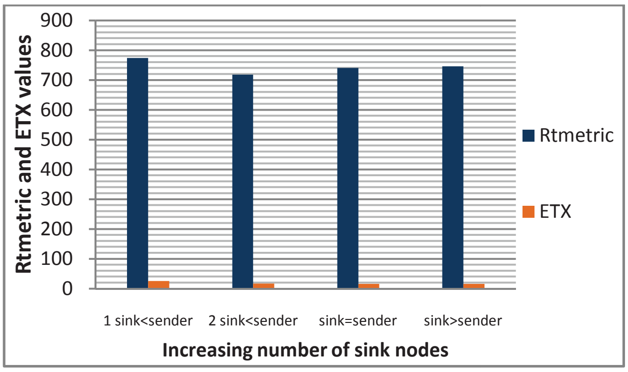


Fig 7. Average value of Rtmetric and ETX vs number of sink nodes.

C. Power Consumption

In Figure 8, we show a higher consumption of power when number of nodes becomes greater. In the second scenario, we include two mobility models to show if RPL metric changes versus the movement of nodes and of mobility model.

However, Figure 9 shows that the RWP consumes lots of power than other cases. Finally, Figure 10 shows that when the number of sink nodes exceeds the number of sender nodes, it consumes less power than other cases in this scenario, this prove that when the nodes is a sender it consume more power than sink. Focusing on the power consumption of the increasing of number of sender nodes (Figure 8) and sink nodes (Figure 10), the experiment shows that the result between the two scenarios is inversely proportional. When the number of sender nodes is higher, it consumes more power until an augmentation of 52.85%. Unlike, when the number of sink nodes is higher it consumes less power with a reduction may occur till 5%.

Additionally, by considering the movement of nodes, the fixed nodes consume less power than mobile nodes. This consumption of power is depending also on the model of mobility. As shown in Figure 8, the RWP model consumes more power than RWK with an augmentation of 10.73%.

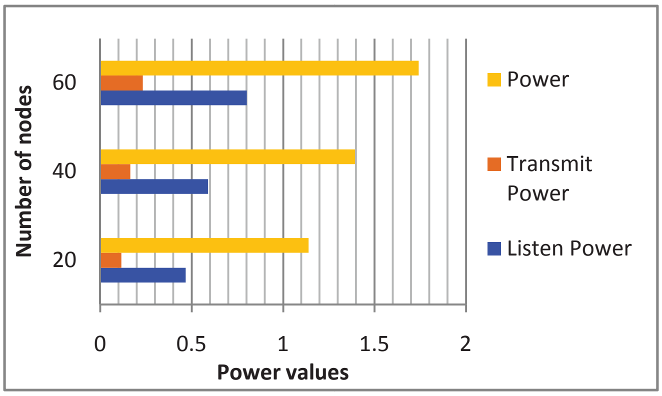


Fig. 8. Power Consumption Vs number of fixed nodes.

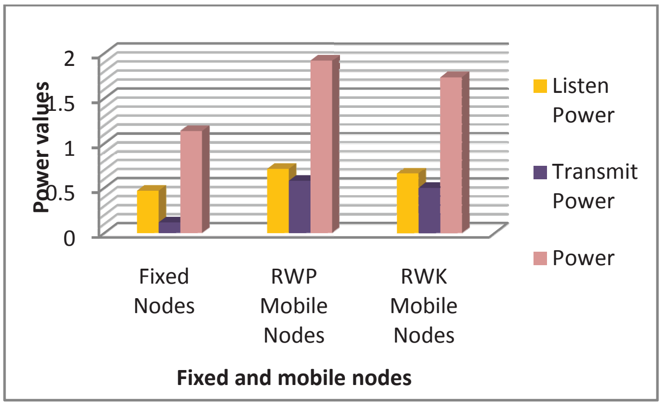


Fig 9. Power consumption for fixed nodes compared to mobile nodes.

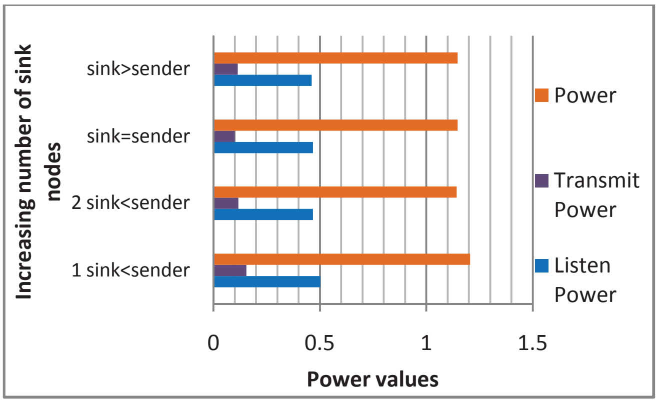


Fig 10. Power consumption vs number of sink nodes.

VII. CONCLUSION

In this work, we have measured the performances of RPL in different scenarios and for different metrics. The experimental results illustrate the increasing of RPL performances. Furthermore, the performance of the protocol is clearly influenced when the network is dense. In this paper, comparison has been made using five metrics: number of receive and lost packets, number of hops, Rtmetric, ETX and Power Consumption. The results show that these metrics increase proportionally with the number of nodes. When the number of nodes increases, the metrics value increase too. Furthermore, the type of mobility has a direct impact on received packets; Mobile nodes can lose packets when they move in contrast to fixed nodes where the packets are all received to their destination. Additionally, we confirm that the mobile nodes consume more power than fixed nodes. The results show that the consumption of power is related to the number of sink nodes. The more this type of node is present in the network the less power is consumed.

As a future work, it would be interesting to investigate the behavior of RPL in more mobility models. We conserve the two mobility models that we have choose in this paper which are RWK and RWP. Then we will choose other different mobility models as RPGM (Reference Point Group Mobility), Nomadic and SLAW (Self-Similar Least Action Walk). This diversity of models allows us to make a perfect comparison between different metrics. Also it gives us a better evaluation of the RPL performances. We will be faithful to Cooja simulator to realize this future works.

Future work will also address the experimentation and testing of this implementation of RPL in the best mobility model to evaluate its performance in real deployment. We will investigate the case of mobile sinks, representing a server that manages access to a centralized resource and keeps all data collected by the sender nodes.

REFERENCES

[1] H. Lamaazi, N. Benamar, A. J. Jara, L. Ladid, and D. El Ouadghiri, "Challenges of the Internet of Things□: IPv6 and Network Management," in *International Workshop on Extending Seamlessly to the Internet of Things (esIoT-2014), Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2014 Eighth International Conference on*, 2014, pp. 328 – 333.

[2] H. Lamaazi, N. Benamar, A. Jara, L. Ladid, and D. El Ouadghiri, "Internet of Thing and Networks' Management□: LNMP , SNMP , COMAN protocols," *first Int. Work. Wirel. Networks Mob. Commun. (WINCOM 2013)*, pp. 1–5, 2013.

[3] J. Hui and A. R. Corporation, "6LoWPAN: Incorporating IEEE 802.15.4 into the IP architecture," *Internet Protoc. Smart Objects Alliance White Pap.*, pp. 1–17, 2009.

[4] M. E. Khedr, M. S. Zaghloul, and M. I. El-desouky, "Wireless Adhoc Multi Access Networks Optimization Using OSPF Routing Protocol Based On Cisco Devices.," *Int. J. Comput. Networks Commun.*, vol. 7, no. 2, pp. 59–69, 2015.

[5] S. Goswami, C. Agrawal, and A. Jain, "Location based Energy Efficient Scheme for Maximizing Routing Capability of AODV Protocol in MANET," *Int. J. Wirel. Microw. Technol.*, vol. 5, no. 3, pp. 33–44, 2015.

[6] S. Choudhary and A. Bhatt, "A survey of Optimized Link State Routing (OLSR) Networks Using NS-3," *Int. J. Sci. Res. Sci. Eng. Technol.*, vol. 1, no. 2, pp. 407–415, 2015.

[7] J. P. Vasseur, N. Agarwal, J. Hui, Z. Shelby, P. Bertrand, and C. Chauvenet, "RPL: The IP routing protocol designed for low power and lossy networks," *Internet Protoc. Smart Objects Alliance*, p. 20, 2011.

[8] P. M. M. Carlos Abreu, Manuel Ricardo, "Energy-aware routing for biomedical wireless sensor networks," *J. Netw. Comput. Appl.*, vol. 40, pp. 270–278, 2014.

[9] P. Caldeira, J.M.L.P.□; Rodrigues, J.J.P.C.□; Lorenz, "Toward ubiquitous mobility solutions for body sensor networks on healthcare," in *Communications Magazine, IEEE*, 2012, vol. 50, no. 5, pp. 108–115.

[10] F. B. Ricardo Silva, Jorge Sa Silva, "A proposal for proxy-based mobility in WSNs," *Comput. Commun. Sci. Direct J.*, vol. 35, no. 10, pp. 1200–1216, 2012.

[11] J. L. MARTINEZ, Jaacán and LASTRA, "Application of 6LoWPAN for the Real-Time Positioning of Manufacturing Assets," *Interconnecting Smart objects with the Internet*, p. 3, 2011.

[12] W. Di, T. Zhifeng, Z. Jinyun, and A. A. Abouzeid, "RPL Based Routing for Adcvanced Metering Infrastructure in Smart Grid," *Communications Workshops (ICC), 2010 IEEE International Conference on*, Capetown, pp. 1–6, 2010.

[13] M. A. H. Fotouhi , D. Moreira, "mRPL□: Boosting mobility in the Internet of," *CISTER Reasearch Center, Polytechnic Institue of Porto (ISEP-IPP)*, Portugal, p. 21, 2014.

[14] O. Gaddour, A. Koubâa, and M. Abid, "Quality-of-service aware routing for static and mobile IPv6-based

low-power and lossy sensor networks using RPL," *Ad Hoc Networks, Sci. Direct J.*, 2015.

[15] N. Aschenbruck, "A Mobility Scenario Generation and Analysis Tool," Osnabruck, Germany, 2013.

[16] F. R. D. Perdana , Sari, "Performance evaluation of corrupted signal caused by random way point and Gauss Markov mobility model on IEEE 1609.4 standards," in *Next-Generation Electronics (ISNE), 2015 International Symposium on*, 2015, pp. 1–4.

[17] Y. Zhang, J.; Fu, L.; Tian, X.; Cui and M. Authors, "Analysis of Random Walk Mobility Models with Location Heterogeneity," *Parallel Distrib. Syst. IEEE Trans.*, vol. PP, no. 99, p. 1, 2014.

[18] A. Nirapai and S. Chantaraskul, "Centralized Control for Dynamic Channel Allocation in IEEE 802.15.4 Based Wireless Sensor Networks," *Eng. J.*, vol. 18, no. 4, pp. 151–164, 2014.

[19] D. S. J. De Couto, D. Aguayo, J. Bicket, and R. Morris, "A high-throughput path metric for multi-hop wireless routing," *Wirel. Networks*, vol. 11, no. 4, pp. 419–434, 2005.

[20] J. Vasseur;, M. Kim;, K. Pister;, N. Dejean;, and D. Barthel;, "Routing Metrics Used for Path Calculation in Low-Power and Lossy Networks," *rfc 6551*, 2012.

[21] M. R. Khan, "Performance and route stability analysis of RPL protocol," University of Stockholm, Sweden, 2012.

[22] F. Österlind, J. Eriksson, and A. Dunkels, "Cooja TimeLine: a power visualizer for sensor network simulation.," *Proc. 8th ACM Conf. Embed. Networked Sens. Syst. (SenSys 2010)*, pp. 385–386, 2010.

[23] W. Van Heddeghem;, "Cross-layer Link Estimation For Contiki-based Wireless Sensor Networks," Free University Brussels, FACULTY Engineering Sciences, 2009.

[24] A. Dunkels, J. Eriksson, N. Finne, and N. Tsiftes, "Powertrace: Network-level Power Profiling for Low-power Wireless Networks Low-power Wireless," *SICS Tech. Rep. T201105*, p. 14, 2011.

[25] A. Camacho Martínez, "Implementation and Testing of LOADng: a Routing Protocol for WSN," 2012.

[26] H. Bitencourt, A. da Cunha, and D. da Silva, "Simulation Domains for Networked Embedded Systems," pp. 3–6, 2012.