Performance Evaluation of RPL Objective Functions

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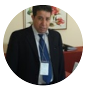
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Performance Evaluation of RPL Objective Functions

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***Abstract*— IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) is a standard for Wireless Sensors Networks. RPL uses two different 'objective functions' (OFs), namely Minimum Rank with Hysteresis Objective Function (MRHOF); and Objective Function Zero (OF0). The selection of the OF influences network topology, where a node chooses a set of potential parents towards the destination. However, there has not been any depth study for the impact of Objective Function behaviour in the RPL environment. So this paper has investigated using an extensive simulations, the impact of a number of important parameters in RPL, for example Packet Reception Ratio (RX), Random Topologies, Grid Topology under two Objective Functions. The simulation results revealed that most of these parameters have a great impact on the PDR and achieved saved energy levels in a given IoT network. Our results have also indicated that the performance of RPL is similar for OF0 and MRHOF, but within light density networks MRHOF can provide a perfect RPL behavior that OF0 could not provide. For example the average power consumption ratio of MRHOF is around 1.16% and 1.15% when we have used Random topology and Grid topology respectively. While OF0 have consumed around 1.23% and 1.20% when we have used Random topology and Grid topology respectively at different RX values.**

Keywords—RPL; OFs; Random topology; Grid topology; Packet Reception Ratio.

I. INTRODUCTION.

Technology experts and visionaries have defined the Internet of Things (IoT) as a network of real physical objects connected via the Internet. Moreover, IoT represents a collection of items in the physical world, with one sensor or more placed within or attached to these items, connected through wired and wireless Internet connections to use the internet [1]. The capability of the IoT has offered many features that make object connectivity more efficient to use via their connections. IoT aims to control and finish the steps on time. These goals are faced by many challenges, including meeting the demands placed whilst keeping the technology cost down, especially if the available number of objects is large [2]. One of the most significant challenges in IoT is the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) which is considered as a high path selection process that impacts on routing behavior. [3]. More recently, the IETF RoLL working group developed the RPL standard, which is a routing protocol targeting IPv6-based LLNs. The RPL is a distance vector routing protocol for LLN that makes use IPv6 a standard for WSN [4]. One of the key issue within RPL is selecting the Objective Function which is used to find the suitable path [3]. Also, Tao and Xianfeng have defined the OF value using available metrics, which can be used to select a parent set and a preferred parent from a node's neighbors, and how this value is used to determine a node's rank. At present, only two different OFs have been selected namely Minimum Rank with Hysteresis Objective Function (MRHOF) and Objective Function zero (OF0). The OF0 is known as a basic OF that does not require any metric to be measured but will use default configurations. On the other hand, MRHOF is slightly more complicated and can compute a node's rank based on the additive metrics [4].

In this paper, we have compared the performance of RPL engaged with OF0 and MRHOF in Random Topology and Grid Topology for light density networks. Simulation result have shown similar behavior, using different Packet Reception Ratio RX values. Also, the result have revealed that using both OFs when RX value is 60% can provide a similar Packet Delivery Ratio same as RX value equal 100% at light density network, while the power consumption is minimum compared to the network with RX 100%. Additionally, based on our experiment results, we have concluded that the MRHOF is outperforms OF0 for the most scenarios using Random or Grid Topology within light network densities.

Our paper is organized as follows. Section II: related work, Section III: performance evaluation, Section IV: results and discussion on the RPL performances, and finally conclusion of this contribution and future work.

II. II. RELATED WORK.

Routing over Low power and Lossy networks (ROLL) working group has specified that the Objective Function Zero (OF0) be used when the hop count is the only routing metric adopted, while the Minimum Rank with Hysteresis Objective Function (MRHOF)[5]. By separating OFs from the core protocol measurement, RPL can adjust to meet the demands of the wide variety of different applications of its use. An important feature of RPL is its representation of a particular routing solution for low power and lossy networks. In [7] the authors have shown the related researches effort proposed for RPL, which is included the experimental performance evaluation of RPL in different terms such as packet delivery ratio, packet loss and power consumption. However, the authors did not investigate the impact of power transmission on packet delivery ratio, overhead and the strength against node failures.

In [8] authors simulate and analyse the performance of the network formation process using a ContikiRPL simulator. Among other parameters they verify how using two different OFs influence the average number of hops and average node energy. The observed differences are insignificant due to the choice of the OFs and their specific parametrization, which result in similar outcomes when computing rank.

The authors in [9] have provided initial simulation results on the performance of RPL and Loading in centralized architecture and scenarios that used less than or equal 50 nodes. However, the traffic patterns, as well as the size of the network tested are still limited. Several researchers have also tried different methods to optimize routing metrics, and OFs for RPL to meet different requirements in specific application scenarios [10] [11]. In [12] the authors comment on a case where the two OFs were run in the simulator as well as in a remote test bed. The results of the simulation and experimental measurements revealed that a simple hop-count OF lead to a shorted path length at the cost of a higher power consumption.

Recently, several RPL simulations and implementations have been provided. In order to increase the lifetime of the network as well as the efficient packet delivery ratio, both the energy metric of nodes as well as the link quality metric should be used in the OF to obtain an energy efficient network performance. However, if the energy routing metric has been used alone in the OF then it may result in a high packet loss ratio. [13]

III. PERFORMANCE EVALUTION.

It is necessary to evaluate OFs first, and then evaluate RPL performance in terms of performance metrics for one preferred OF. As a result we need to implement a Cooja simulation experiment in order to fill the lack of the paper statement:

A. SIMULATION AND NETWORK SETUP.

We have used a Cooja simulator in our implementation [14]. Cooja is a flexible java-based simulator 8 which supports C program language as the software design language by using Java Native Interface. We have chosen a Cooja simulator as it is a very useful tool for software development in wireless sensor networks, and will provide a suitable method in which to set the environment needs.

In this study we have simulated a network with a single sink node, and we have used Random and Grid topology in order to distribute nodes in a squared area with a side L= 1000 meters, with the sink placed at the center. We have designed RPL network using OF0 and MRHOF by setting the experiments under different light densities: RPL network containing (20, 30, 40, and 45 nodes) including the sink node.
Also, we varied the RX values (20, 40, 60, 80, and 100%) and investigated the RPL behavior in terms of packet delivery ratio and power consumption. The main default RPL parameters used in the simulations are listed in Tab. 1.

Table 1 SIMULATION PARAMETERS

Parameters	Value
OF	OF0, MRHOF
TX Ratio	100%
TX Range	100m
RX Ratio	20-40-60-80-100%
Mote Start up Delays	1.000
Topologies	Random, Grid
Simulation Time	900 second
squared area	1000 meters

B. OBJECTIVE FUNCTION.

RPL uses OF to construct the DODAG. OF is also used to define the rank of a node, which is a node's distance from a DODAG root node. RPL determines the whole topology by building the DODAGs within instances, where each instance is associated with a specific OF [15]. OF combines the metrics and constraints to find the best path. However, RPL's main specification has no default OF. Therefore, OF0 is designed as a default function that is common to all implementations and provides interoperability between different implementations. [5]

C. PERFORMANCE METRICS.

We have used two standard performance metrics: Energy consumption and Packet Delivery Ratio (PDR), to evaluate the performance of RPL.

The first metric performance is Energy Consumption. To make a good energy estimation we use different percentages of packet reception ratio which dominates the power usage in sensor nodes. Furthermore we take the constant percentage of RX in order to compare two OFs for all the nodes in the whole network setup. To compute the power consumption we use the mechanism of Power-trace system available in Contiki [16]. Using power state tracking, Power-trace provides an estimation for a system's power usage. Structures known as energy capsules are also used to assign energy usage to processes such as packet transmissions receptions. [16]

The second metric is Packet Delivery Ratio (PDR) which is defined as the number of received packets at the node to the number of sent packets to the node. We have averaged PDR of all the packets received successfully at the node. In order to compute the average PDR we have measured the number of sent packets from all the nodes to the sink and divide it by the number of successfully received packets at the sink.

D. NETWORK TOPOLOGIES.

RPL supports several types of application requirements through multiple objective functions (OFs), ContikiRPL is part of the Contiki operating system [5]. In the light density network, the number of nodes varies from 20-45 nodes which are classified to their distribution around the sink.

- RANDOM TOPOLOGY.

We have used Random topology in our experiments, as show in Fig.1, it is a distribution nodes in randomly forms that allow nodes to reach the sink directly or contact each other in order to reach the sink, especial nodes in the edges. However, many 'real world' applications use this type of topology. Such applications use wireless sensors that are dispersed or scattered in a specific areas of interest with the purpose of gathering data from that environment. This topology consists of two types of node, the node number 1 with the blue colour is representative of the Sink node, and is placed at the centre (50.50, 50.50) which is the most used position to form a well-balanced DODAG. The non-sink (sender) nodes have been placed randomly in the limited area consists 1000 meter. These nodes are yellow coloured, and are representative of sender nodes in our experiments.

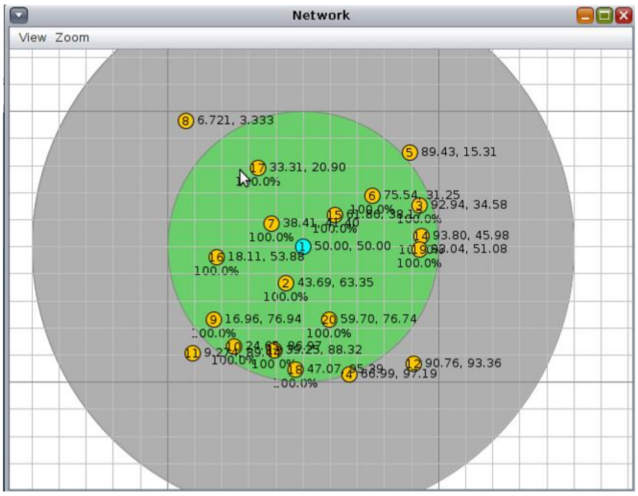


Fig 1: Random Topology.

- GRID TOPOLOGY.

We have used the grid topologies show in Fig. 2a-2b, it is a distribution nodes in forms that allow nodes to contact each other in order to reach the sink, especial nodes in the edges. This topology consists of two types of node, node number one in Fig. 2a is colored green and represents the Sink node. It is placed at the center (50.50, 50.50) which is the most used position in forming a well-balanced DODAG. The non-sink (sender) nodes are yellow colored and have ordered methodically around the sink. However the topologies differ based on the number of nodes. We can see from Fig. 2a: that the distance between any two nodes is 20m, in this case we have distributed 20 nodes. The distance changed if we distributed a different quantity of nodes such as in Fig. 2b: 30 nodes has been distributed and the distance between the nodes is 15m. However, the form taken by Grid topology would not change despite the increased nodes quantity.

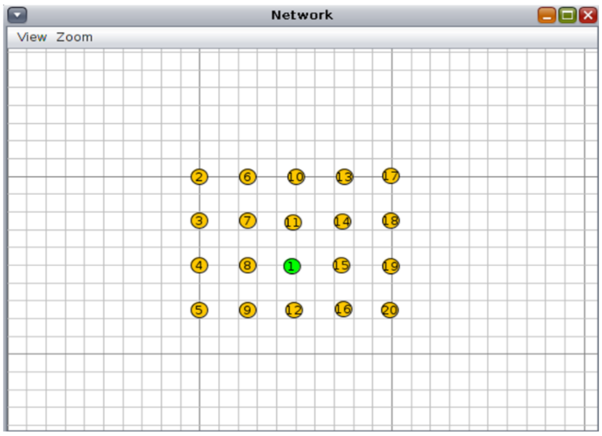


Fig. 2a: 20 Nodes in Grid Topology.

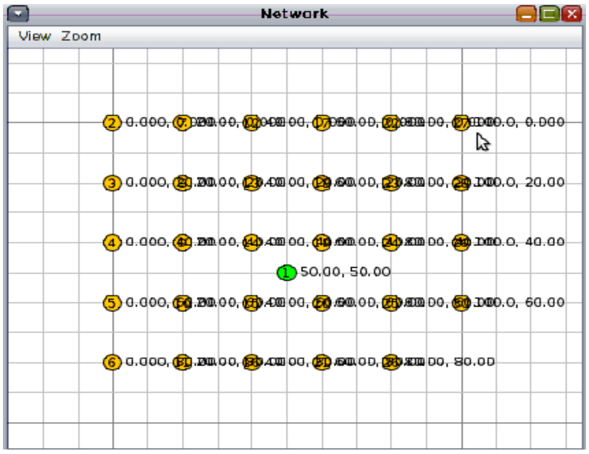


Fig. 2b: 30 Nodes in Grid Topology.

IV. RESULTS AND DEDUCTION.

This section presents the experimental evaluation study of RPL using the data collected from the Cooja simulator. The objective of the experiments is to evaluate the two objective functions: OF0 and MRHOF, in terms of packet delivery ratio and energy consumption. Experiments are performed with different numbers of nodes and different topologies in order to check the effect of these factors on RPL performance. These factors will be analysed by using experimental data that is obtained from the simulation. Therefore new results have been observed and it has noticed in order to provide a good comparison MRHOF and OF0.

A. RPL PERFORMANCE IMPLEMENTATION RELY ON OF0.

We have set the experiments under different network densities (20, 30, 40, and 45 nodes), using Random and Grid topologies thus we will observe the performance of OF0 for different values of RX. We will vary the RX values (20, 40, 60, 80, and 100%) and investigate the RPL behavior in terms of delivery ratio and power consumption. The result of this simulation is obtained from the nodes installed OF0.

- PACKET DELIVERY RATIO.

Fig.3-6 show the behavior of the PDR based on varied RX levels for Random topology. The PDR values increased as the RX values increased. Furthermore, we have noticed that the PDR value approximately reached 100% when RX was greater than or equal to 60%. This means that we can use the value of RX 60% instead of 100% because RPL provides a good Packet Delivery ratio of more than 98% when RX is equal or higher than 60. The reason for this is that the value of RX is not sensed after 60 which is sufficient to deliver the frequent messages of the LLN. Fig.7-10, show similar behavior of the PDR based on varies RX levels for Grid topology.

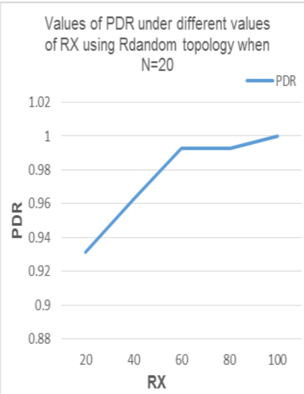


Fig. 3: PDR under different RX When N=20.

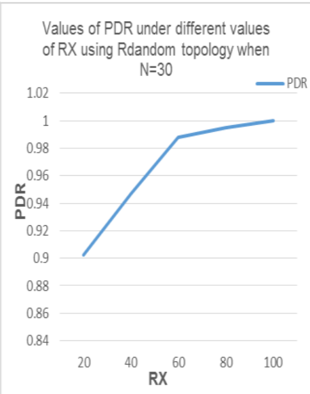


Fig. 4: PDR under different RX When N=30.

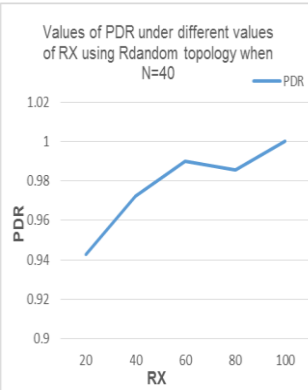


Fig. 5: PDR under different RX When N=40.

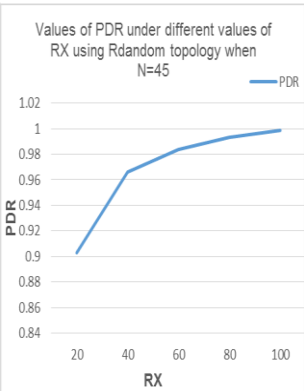


Fig. 6: PDR under different RX When N=45.

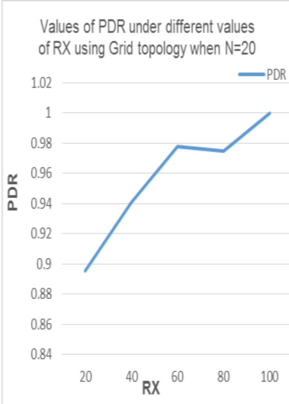


Fig. 7: PDR under different RX When N=20.

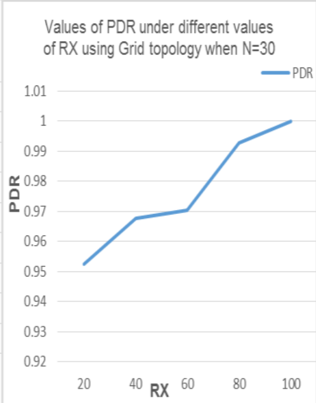


Fig. 8: PDR under different RX When N=30.

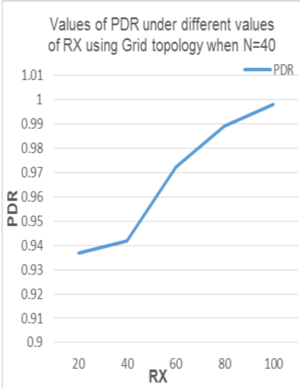


Fig. 9: PDR under different RX When N=40.

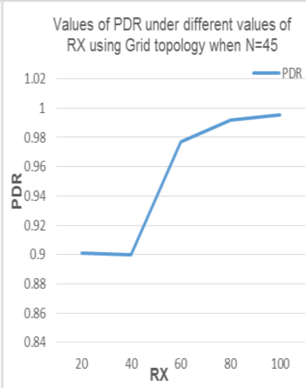


Fig. 10: PDR under different RX When N=45.

- POWER CONSUMPTION.

Fig.11-14 show the behavior of the power consumption based on varied RX levels for random topology. The power consumption values decreased in linear fashion as the RX values increased. Moreover, we have noticed that the average power consumption value is fair, when RX is greater than or equal to 60%. This means that we can use the value of RX 60% instead of 100%, because as we already mentioned, as a result of previous section, RX 60% value reached approximately 100% of PDR value. Furthermore, it consumes 1.22% which is less power consumption than the RX 100%. However, in Fig.15-18, RPL provides a similar average power consumption ratio for grid topology, approximately 1.20 % when RX is equal 60%. The reason is that the value of RX is not sensed after 60% which is sufficient to reduce the power consumption while deliver the required frequent messages of the LLN.

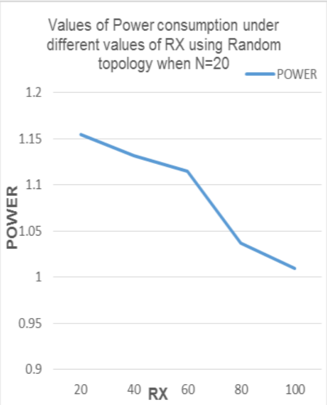


Fig. 11: Power under different RX When N=20.

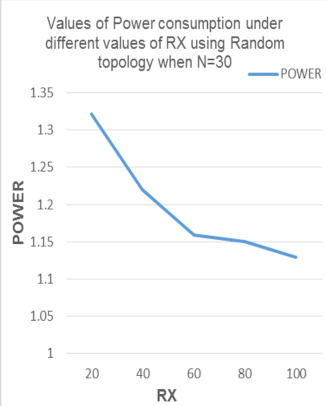


Fig. 12: Power under different RX When N=30.

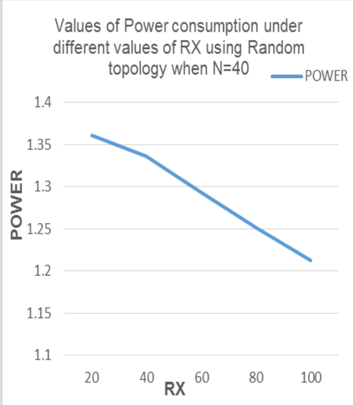


Fig. 13: Power under different RX When N=40 .

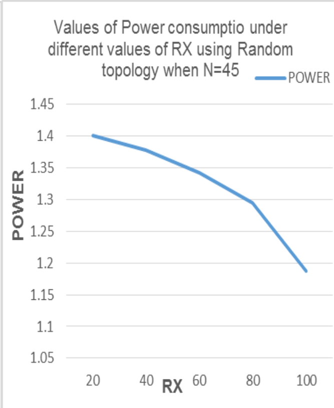


Fig. 14: Power under different RX When N=45.

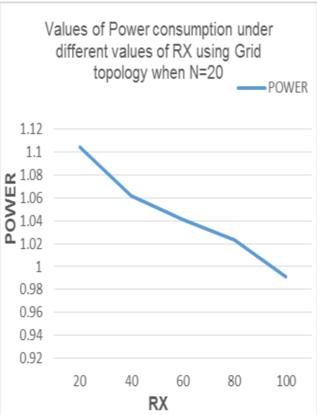


Fig.15: Power under different RX When N=20.

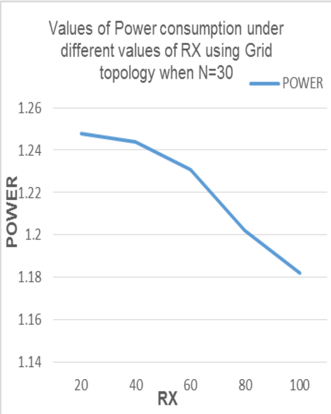


Fig. 16: Power under different RX When N=30.

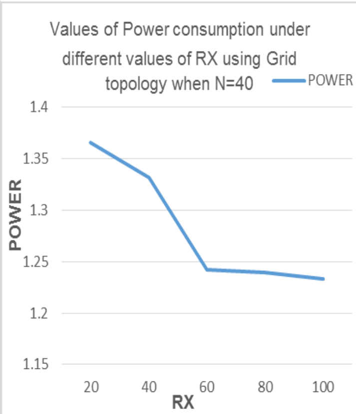


Fig. 17: Power under different RX When N=40 .

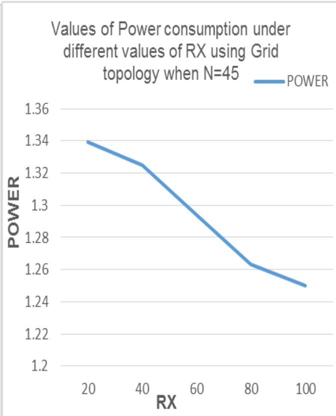


Fig. 18: Power under different RX When N=45.

B. RPL Performance Implementation Rely On MRHOF.

We have set the experiments under different light network densities (20, 30, 40, and 45 nodes) using Random and Grid topologies so to observe the performance of MRHOF for different values of RX. We vary the RX values (20, 40, 60, 80, and 100%) and investigate the RPL behaviour in terms of delivery ratio. The result of this simulation is achieved from the nodes installed MRHOF.

- PACKET DELIVERY RATIO.

Fig. 19-22 show the behaviour of the PDR based on varied RX levels for Random topology. The PDR values increased as the RX values increased. Furthermore, we noticed that the PDR value approximately reached 100% when RX is greater than or equal to 60%, meaning that we can use the value of RX 60% instead of 100%. RPL provides a Poor Packet Delivery ratio of around 97% when RX is equal to or higher than 60 from the nodes installed MRHOF. We also observed that PDR increased steadily from (60-100). A similar result of PDR was achieved when using grid topology in Fig.23-26. However, the result was not satisfying.

- POWER CONSUMPTION.

Fig. 27-30 show the behavior of the power consumption based on varied RX levels for random topology. The power consumption values decreased in linear fashion as the RX values increased. Moreover, we noticed that the average power consumption value is fair, when RX is greater than or equal to 60%. This means that we can use the value of RX 60% instead of 100%. As we mentioned as a result of the previous section, RX 60% value reached approximately 97% of PDR value. Furthermore, it consumes 1.14% which is less power consumption than the RX 100%. However, in Fig.31-34, RPL provides a similar average power consumption ratio for grid topology, approximately 1.16 % when RX equal 60%. The reason for this is that the value of RX is not sensed after 60% which is sufficient to reduce the power consumption while deliver the required frequent messages of the LLN.

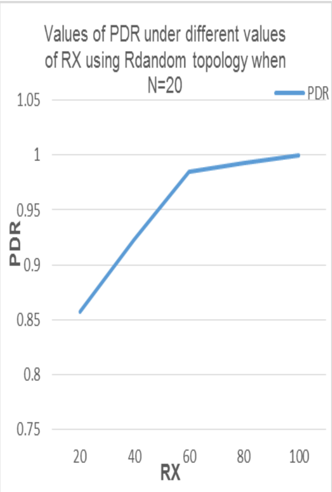


Fig. 19: PDR under different RX When N=20.

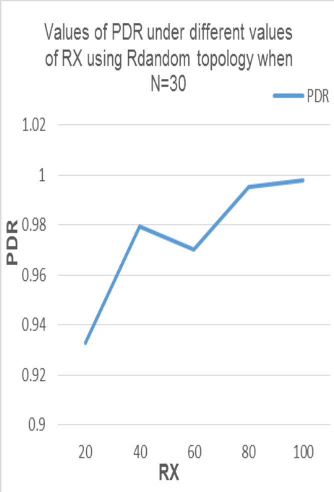


Fig. 20: PDR under different RX when N=30.

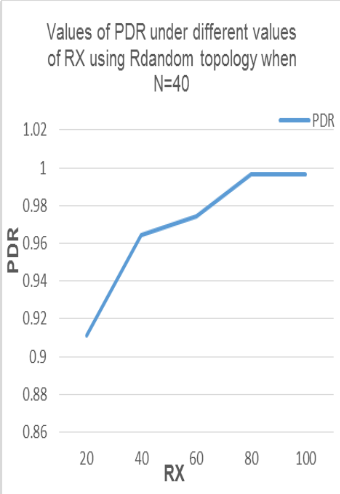


Fig. 21: Power under different RX when N=40 .

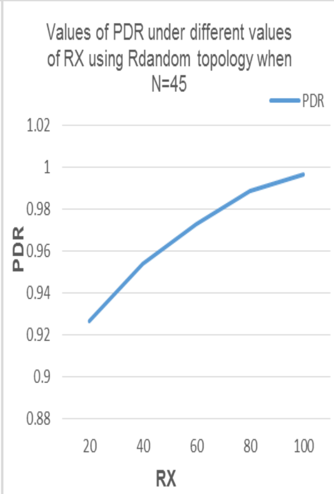


Fig. 22: PDR under different RX when N=45.

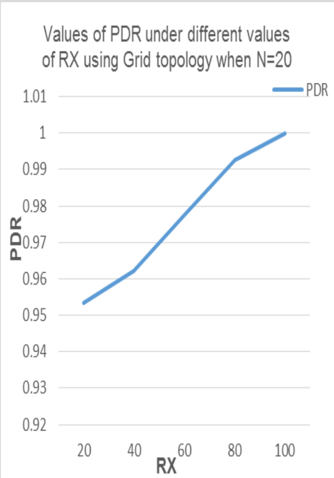


Fig. 23: PDR under different RX When N=20.

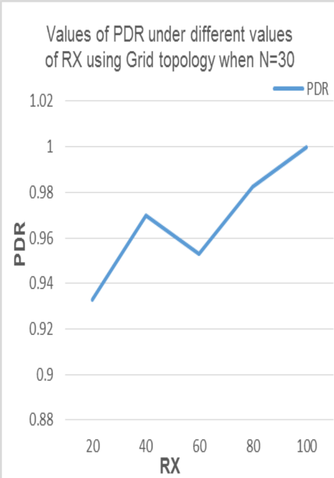


Fig. 24: PDR under different RX When N=30.

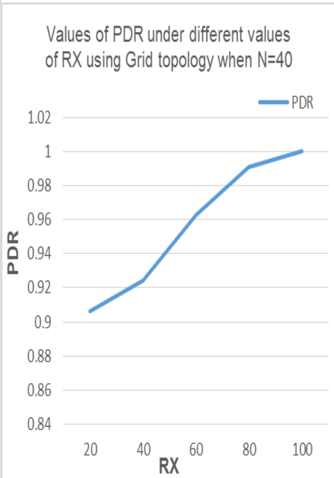


Fig. 25: Power under different RX When N=40 .

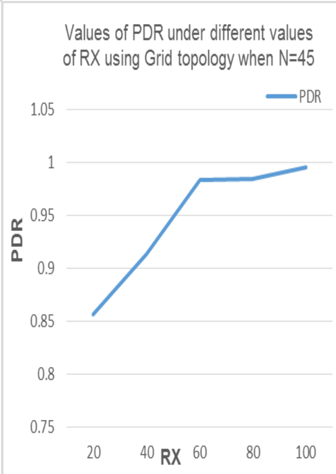


Fig. 26: PDR under different RX When N=45.

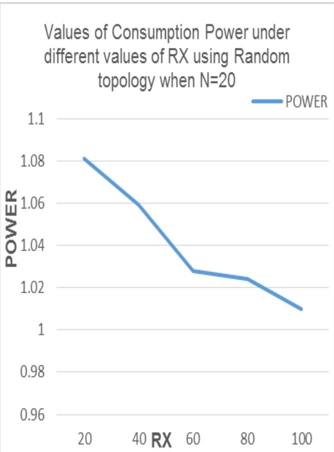


Fig. 27: Power under different RX When N=20.

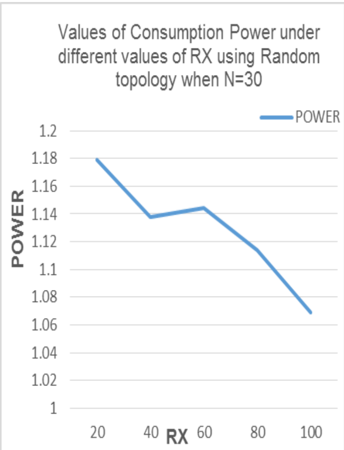


Fig. 28: Power under different RX when N=30.

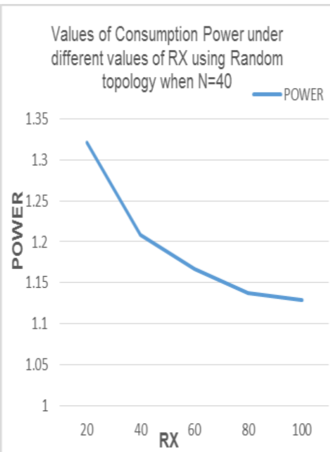


Fig. 29: Power under different RX when N=40 .

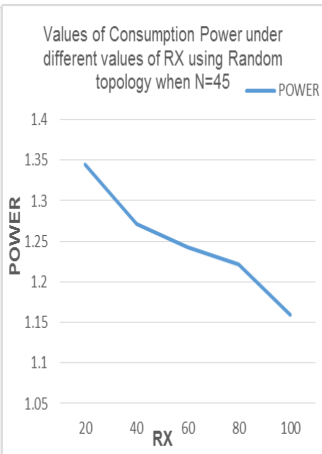
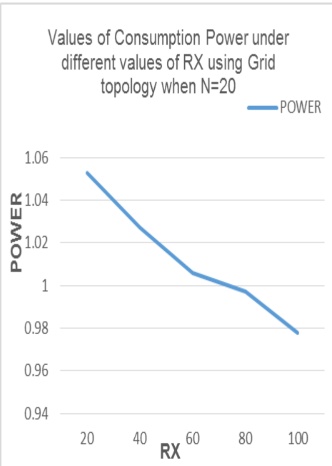
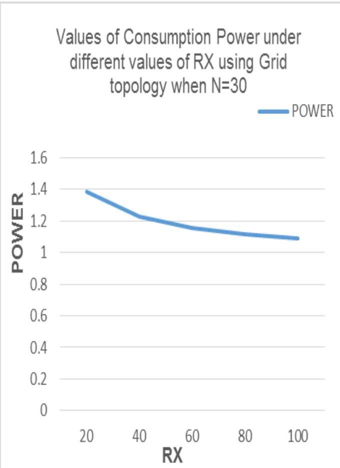
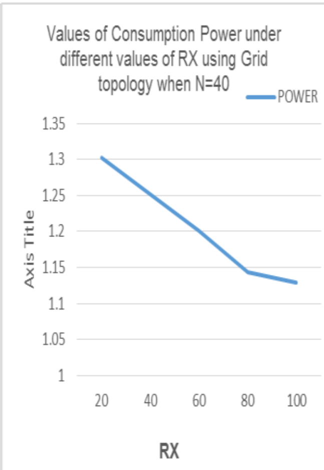


Fig. 30: Power under different RX when N=45.







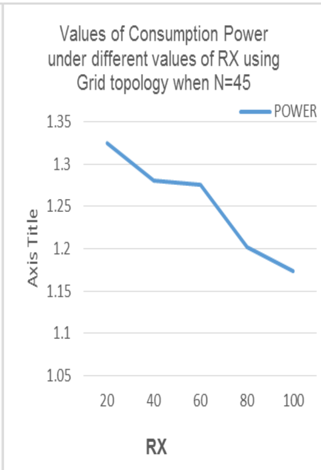


Fig. 31: Power under different RX **Fig. 32: Power under different RX** **Fig. 33: Power under different RX** **Fig. 34: Power under different RX**

C. Impact of RX on RPL Performance reliance on OF0 and MRHOF.

By keeping the node packet reception ratio constant, a useful result of this simulation is achieved from the nodes that have installed OF0 or MRHOF by setting a different number of nodes, we can obtained topologies that have given us the chance to observe the OFs under different network densities. Therefore, we have thoroughly compared the main effects of using OF0 and MRHOF to evaluate the behaviour of RPL through computing the PDR and Power consumption for each of those topologies.

- PACKET DELIVERY RATIO.

In Fig.35 a random topology was used and found that the average packet deliver ratio of OF0 is approximately 0.99%, and that the average packet deliver ratio of MRHOF is approximately 0.98%. In Fig.36 we have used Grid topology to represent the average packet deliver ratio, and the results show similar behaviour, where average packet deliver ratio of OF0 is approximately 0.98% and the average packet deliver ratio of MRHOF is approximately 0.97%. By contrast, the PDR collection from the simulation results observed that the OF0 and MRHOF have given a good PDR where OF0 outperforms MRHOF. This is due to a simple difference in the light density network that we used. In these results, we observed in the network configured by 20-45 nodes that the average PDR is best when the network density is between 30-40 nodes for RX 60 using Random or Grid topology. Moreover, we found that the RPL standards-based produces similar behaviour of PDR for both OFs in this light density network.

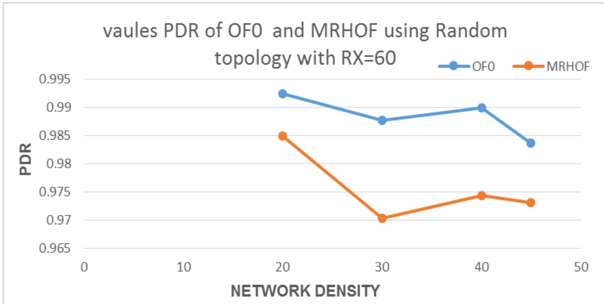


Fig. 35: PDR of OF0 and MRHOF using Random topology.

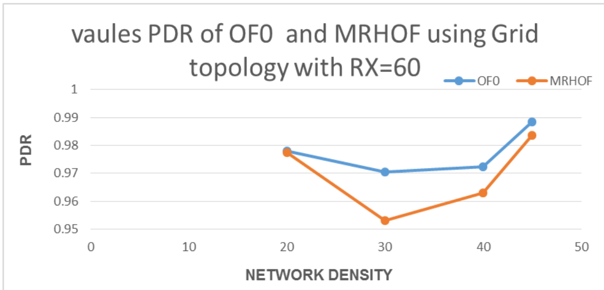


Fig. 36: PDR of OF0 and MRHOF using Grid topology.

- POWER CONSUMPTION.

In Fig.37, the results show that the average power consumption of OF0 is approximately 1.23% and the power consumption of MRHOF is approximately 1.15% when using Random topology. A similar average power consumption behavior of both OFs was achieved when we used Grid topology in Fig.38. The average power consumption has a steady increase for both OFs when the network's light density is RX 60. Simulation results revealed that the OF0 consumes more power than MRHOF, and the average power consumption for both OFs is best when the network density is between 30-40 nodes. Moreover we have found that the standards-based RPL produces similar behaviour of PDR for both OFs in this light density network and that the average power consumption of OF0 outperforms MRHOF.

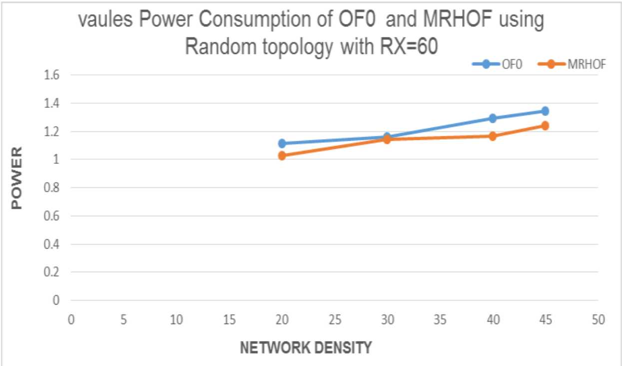


Fig 37: POWER of OF0 and MRHOF using Random topology.

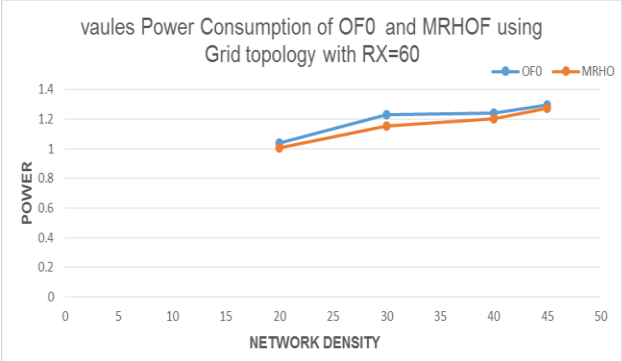


Fig 38: POWER of OF0 and MRHOF using Grid topology.

In table. 2 and table. 3, we have presented all the accounted results of the average of PDR and the average power consumption for both OF0 and MRHOF in Random and Grid topology, in order to compare their effect on RPL behaviour when RX 60%. The Simulation results have noticed that the PDR and the Power Consumption for RPL are not clearly sensitive to the OF0 and MRHOF in the light density network. Which the average power consumption of OF0 is 1.23% which is greater than the average power consumption of MRHOF which is 1.15%. While RPL provides average LESS PDR of around than 97% when RX is equal to or higher than 60% from the nodes that have installed MRHOF in Grid topology. Which is not a satisfying result. On other hand, the simulation results have shown that there is no doubt that the OF0 uses more energy than MRHOF. Simulation results have shown that there are differences in the values of PDR for both OFs when the values in the reception ratio decrease. Therefore we conclude that MRHOF provides better routes than OF0 by taking into account the energy saving which consequently provides better a network lifetime because the MRHOF selects the best routes, which has better paths than the minimum hop path selected by OF0. In the light density network, the best paths ensure less re-transmissions and radio collisions across the network and this provides better PDR and energy consumption.

Table 2: the Comparison of OF0 and MRHOF in Random topology

Metrics	OF0	MRHOF
PDR	0.99	0.98
POWER	1.23	1.15

Table 3: the Comparison of OF0 and MRHOF in Grid topology

Metrics	OF0	MRHOF
PDR	0.98	0.97
POWER	1.20	1.16

CONCLUSION.

We have revealed that the RPL performance is very challenging when using OF0 or MRHOF, in terms of PDR and energy consumption in the configuration of parameter values for the light network density. Also, we have shown that the RPL performance for both OFs is best in relation to PDR and power consumption values when we use the RX 60% for the majority of circumstances, where the PDR average when using RX 60% is quite similar to that when using RX 100%, but with a lower power consumption meaning we save power when we use the RX 60%. We have also observed that the RPL performance is best for both OFs when the network density is between 30-40 nodes for RX 60% using Random or Grid topology in the light density network. Natural continuation of research work would be to investigate the effects of other important system parameters which have not been considered in this research. For instance, medium network density and heavy network density.

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