Performance Analysis of Minimum Rank with Hysteresis Objective Function for Internet of Things

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Abstract – **Protocol for Low-power-lossy (RPL) is Internet Protocol version 6 (IPv6) routing protocol for Low-Power and Lossy Networks standardized by the Internet Engineering Task Force (IETF). RPL uses two objective functions: Objective Function zero (OF0) and Minimum Rank with Hysteresis Objective Function (MRHOF). This paper investigates the effects of some important parameters on performance of MRHOF by using different topologies: random, linear and ellipse topology, based on some metrics such as: Hop Count (HC), Expected Transmission Count (ETX), lost packets, received packets and power consumption within 10 min, 20 min and 30 min. The results have shown the maximum and minimum values for each metrics within different times.**

Keywords –**Internet of Things (IoT), Protocol for Low-power-lossy (RPL), Minimum Rank with Hysteresis Objective Function (MRHOF).**

I. Introduction

Internet of Things (IoT) is also called Internet of Everything. IoT allows smart devices to communicate with each other without human intervention [1] through sensors, Radio Frequency IDentification (RFID) tags, mobiles, etc. [2]. To connect these smart devices and integrated them with traditional Internet in a secure and efficient network, there is a need for a routing protocol to organize that communication requirement in which reduces power loss in the network [3]. So, The Internet Engineering Task Force (IETF) developed a Protocol for Low-power-lossy networks (LLNs) called RPL, which is an Internet Protocol version 6 (IPv6) routing protocol used in IPv6 over Low -Power Wireless Personal Area Networks (6LoWPAN).

Also, RPL uses two kinds of Objective Functions (OFs) to select the optimal route from the parent node towards the root node [4]. The first one is Objective Function zero (OF0), and the other is Minimum Rank with Hysteresis Objective Function (MRHOF). OF0 is used to find minimum Hop Count (HC) as a path to reach the root node, while MRHOF is used to find the minimum Expected Transition count (ETX) as a path to reach the root node [5].

MRHOF is designed to find the paths with the smallest path cost by two mechanisms. The first mechanism, called hysteresis, could switch the path to minimum rank if it is shorter than the current path. The second mechanism finds the minimum cost path.

This paper presents the evaluation of performance for MRHOF based on some metrics including: ETX, HC, received packets, lost packets and power consumption to compare the results when using different kinds of topologies such as random, liner and ellipse within different times.

The rest of paper is organized as follows: Section II gives related works. Section III describes performance evaluation and Section IV analyzes results of evaluation. Section V concludes the paper.

II. Related Works

Medium Density Network is used in [4] to compare the performance of both objective functions by using various topologies such as random and grid topology. The PDR, RX, and power consumption in the fixed RX values were computed. Shown results for both objective functions had the best performance in PDR and power consumption when they are equal 60 %, when the number of motes is between 50 and 65 motes for the RX equal 60% in random and grid topology.

The authors simulated in [5] both objective functions in Cooja simulator to show which has better performance in the network. So, they used some parameters to compare them. They measured the power consumption, Hop Count (HC), Packet Delivery Ratio (PDR), the time of networks convergence, the latency, Expected Transmission Count (EXT) in mobility node. The results have shown that: the performance of MRHO is better than OF0; OF0 maintains the PDR value of mobility, so it is more suitable in mobility network; OF0 is faster in network convergence; MRHOF consuming more energy than the OF.

In [6], the authors analyzed the performance of Routing Protocol for RPL based on objective functions: MRHOF and OF0 in three scenarios. The first one is when the network is scalable, the second scenario is using four topologies to change the position of motes, and the last one evaluated in two mobility model in two density network to measure the average ETX, average HC, average energy, average lost packets and control traffic overhead. They used one sink mote and multi motes and transition range was 100m within 21 minutes. The results were shown that in scalable network

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energy was consumed more slightly in OF0 than MRHOF, the value of control traffic in MRHOF was very high compared with OF0 when the network is large, and when the HC is increasing then the average ETX will be increased.

In mobility model, which has two models, the first one is called Random Waypoint (RWP) and allows the nodes to move separately in the random way. The second model is called Reference Point Group Mobility Model (RPG) and allows the nodes to move as group on a dependent way. The results in this scenario was shown that both objective functions have the same value of ETX and HC in RPG model. In the other side, in RWP model, when the MRHOF is increasing, the HC and ETX at OF0 will decrease in dense network. The OF0 consumed large energy compared with MRHOF in RPG, but in RWP the OF0 consumed less energy than MRHOF. In addition, the values control traffic in RPG model in both OF have the same value. With RPG model the RPL can operate better than RWP model.

At the last scenario, in all positions both OFs have the same values in all metrics instead of the Control Traffic overhead and Average Energy in linear position. In Random, Linear and Manual positions both OFs have nearest values in EXT, but in Ellipse position they need higher value of EXT and HC. However, MRHOF works much better in random and manual position than OF0.

The number of energy metrics loses of the MRHOF energy and ETX metrics with OF0 HC was measured in [7]. Tmote Sky type of mote was used to perform four tests. The first and second test consist of twenty-four senders and one sink, the third and fourth test consist of forty-nine senders and one sink. All tests were over 10 minutes and 20 minutes and used a tree topology in the first and third tests, and a circular topology in the second and fourth tests. The greatest amount of energy metrics loses motes was in the first test when the transition was 50/100 m and time was 20 minutes. In the second and third tests, the energy metric loses the largest number of motes when the transition was 50/100 m within 10 minutes. In the fourth test, the number of losses nodes reduced by increasing the time.

In [8], the authors evaluated the performance of RPL function by using multi sink motes. They measured the number of loss packets and energy consumption by using one sink mote and multi sink motes. The results showed that is better to use more than one sink mote because that reduce the energy consumption and the number of loss packets. When they used one sink, they got 1% for HC (0,95% for ETX), with five sink motes they got 0,4% for HC (0,2% for ETX) of improving the performance of RPL and increasing the number of deliver packets.

A new trust based RPL routing protocol to address the network from the blackhole attacks is proposed in [9]. In an experiment the authors used these parameters: Contiki/Cooja 3.0, 3600 seconds for simulation run time, 70m x 70m for Simulation coverage area, 30 motes of Tmote type, 1 sink mote, 3 nodes of blackhole attack nodes, 50 m for wireless transmission range, RPL routing protocol. The results have shown that this system can address the blackhole attacks with no need for an overhead on the network traffic.

The performance of both objective functions were studied in [10]. The mobile-random and static grid topologies with three different tests included 25, 49, and 81 senders' motes and one sink mote for each are used. In addition, each test is done with various transition ranges: 11, 20, and 50 meters in sparse, dense, and moderate networks. The test is compared by using different metrics like average HC, average power consumption, average duplicate packets, convergence time, changes in Destination Oriented Directed Acyclic Graph (DODAG) tree structures, average churn in the network, Average Listen Duty Cycle, Average Transmit Duty Cycle, Average received packets, and average lost packets. The results have shown that the performance of OF0 is better than MRHOF in fixed network.

The effect of SybM attack on RPL based on some parameters, like packet delivery ratio (PDR), control overhead, and how much RPL consume the energy of SybM attackers, is analyzed in [11]. The results were shown that RPL is sensitive for this attack. However, the authors proposed a Trust-based IDS as a solution to solve this problem. It can control messages multicast, handles the mobility, and handles identity.

The authors assessed in [12] the RPL performance by evaluating some metrics like count Round Trip Time (RTT) and Packet Delivery Ratio (PDR). They used four different topologies: linear, manual, random and elliptical to compare the results. They used in their experiment 10 clients and server motes, 1 sink mote, type of motes is Sky mote, TX Range is 100 m, INT Range is 100 m, Packet Reception Ratio (RX) is 10 to 100, and maximum packet per simulation is 10. The results have shown that the performance of PRL with RTT and PDR with manual topology outperform on the other topologies.

III. Performance Evaluation

This section presents the performance evaluation for MRHOF using a Simulation Environment called Cooja [13] that based on Contiki-2.7 Operating System, which is available and open-source, organized to Network Setup and Network Topologies.

A. Network Setup

One sink mote is used and 30 senders of sky mote type to compare the performance of the MRHOF applying it on three different topologies within various period of times. In addition, the metrics used to compare the performance are: Expected Transmission Count (ETX), which represent the quality of link such as number of transition data; Hop Count (HC), the number of hops between sink and sender [14]; Received packets, as number of deliverable packets successfully; and Lost packets, representing number of sent packets minus number of received packets which is estimated to the number of dropped packets [6]. The simulation parameters are summarized in Table I.

TABLE I
TEST PARAMETERS

Operating System	Contiki-2.7
Simulation Environment	Cooja
Objective Function	MRHOF
Number of sink mote	1
Number of sender mote	30
Topology	Random, Linear, and Ellipse
Metrics	ETX, HC, Received, Lost, and power
TX Ratio	100 %
TX Range	50 m
RX Ratio	100%
Mote Start up Delays	1.000
Simulation Time	10 min, 20 min, and 30min.

B. Network Topologies

B1. Ellipse topology

The first evaluation of MRHOF by using the ellipse topology is shown in Fig. 1. This topology is also called circle topology. The nodes are distributed in a circular shape. In this case, one sink mote and 30 sender motes of type sky mote are used.

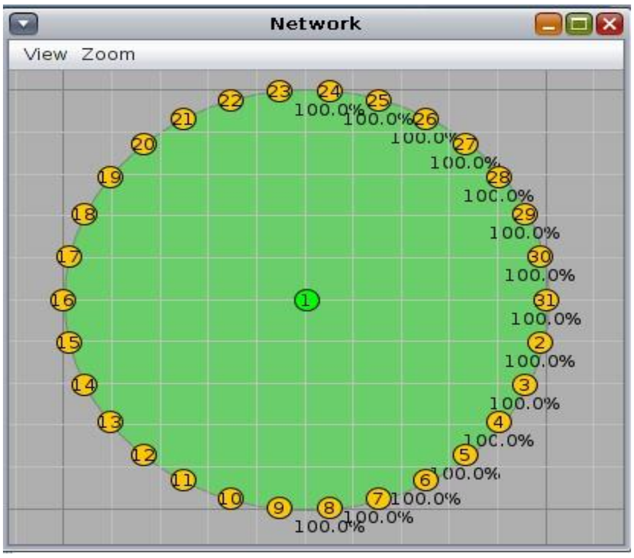

Fig. 1. Ellipse topology

In addition, the sink node can connect directly with half number of the sender's nodes and the other senders can connect with other nodes to reach the sink node.

B2. Random topology

The second distribution of nodes with random shape for evaluation the performance of MRHOF is shown in Fig. 2. In this shape, the 30 senders' nodes are distributed randomly around the sink mote, which can connect directly or indirectly with the sink node depending on shape they are distributed in.

Fig. 2. Random topology

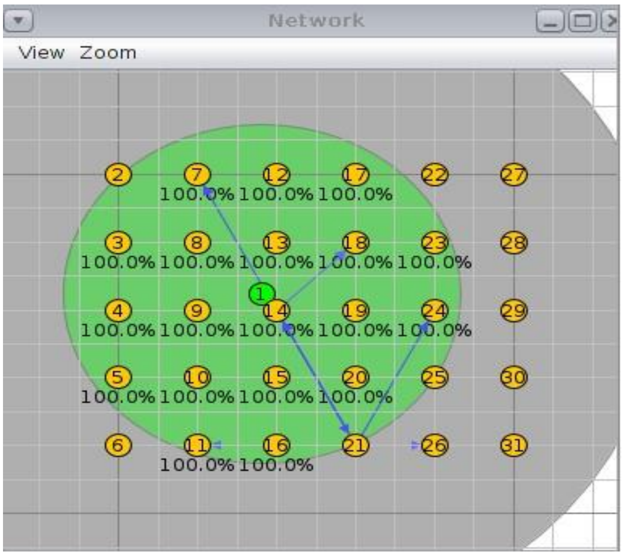

Fig. 3. Linear topology

B3. Linear topology

The third topology used in this study is linear topology. In this topology, the nodes are distributed in linear way and sink mote in a random way. The sender nodes need to connect with other nodes, which are connected directly to the sink node to reach the sink node. This is presented in Fig. 3.

IV. RESULTS OF EVALUATION

This section presents the results of applying: power consumption, the EXT, HC, lost and received packets in Cooja simulator.

A. Power consumption

This subsection shows average computing power for these topologies presented in Fig. 4.

As we can see from this figure that maximum value of average power consumption was in ellipse topology after 10 min, and minimum value was in linear topology.

B. Expected transition count

Expected Transition Count represents the number of transmission and retransmission of data that successfully deliver to the destination. This refers to the quality of the link.

Fig. 5. shows the experiment of the average ETX on three topologies: linear, random, and ellipse within 10 min, 20 min, and 30 min. As we see the ellipse topology after 10 min got large value. However, the random topology got the smallest amount of average ETX after 30 min. When the time is increasing the value of average ETX is decreasing.

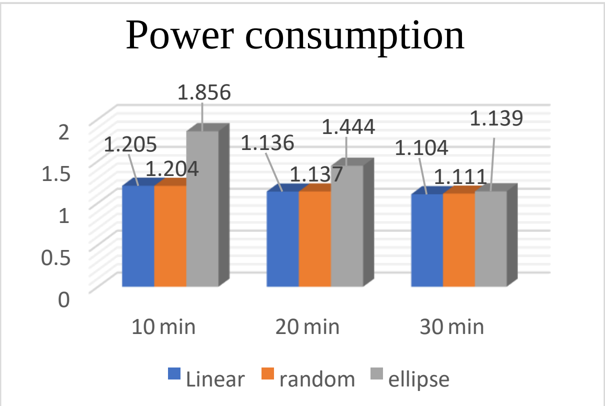

Fig. 4. Power consumption

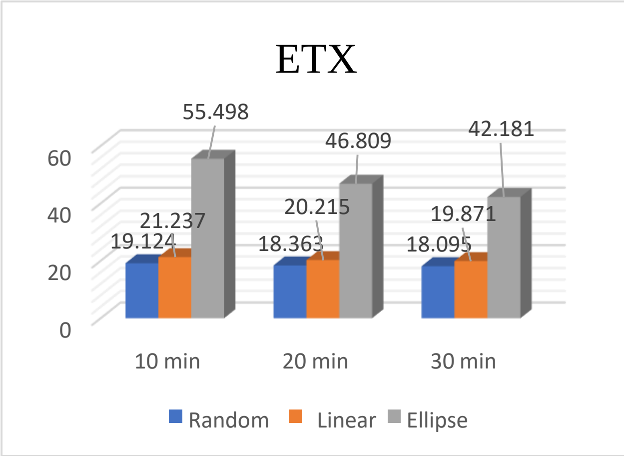

Fig. 5. ETX experiment

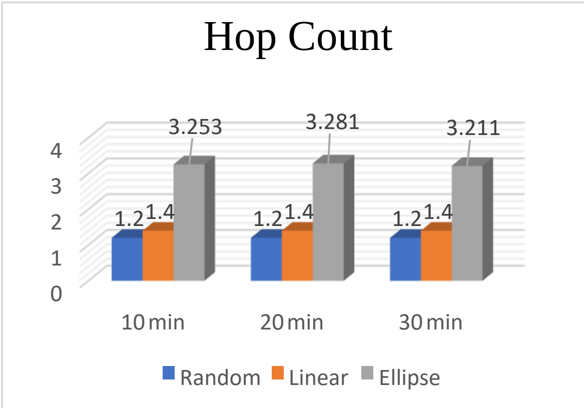

Fig. 6. Hop Count experiment

C. Hop Count

Hop Count represents the number of hops through the path between the sink node and sender nodes. Fig. 6. represents this scenario. One can see that the value of HC in random topology has the same value within10 min, 20 min and 30 min as in the linear topology. However, the ellipse topology differs by the time. Its maximum value was after 20 min and the minimum value was after 30 min.

D. Lost packets

If we see Fig. 7, we can observe that the number of lost packets in the random topology is equal zero. This is what we need, but we cannot get this result always because this topology has random distribution of nodes. However, the maximum average of lost packets was in ellipse topology after 30 min. In this topology, when the time is increasing, the value of average lost is increasing. In the linear topology, it has a stable value.

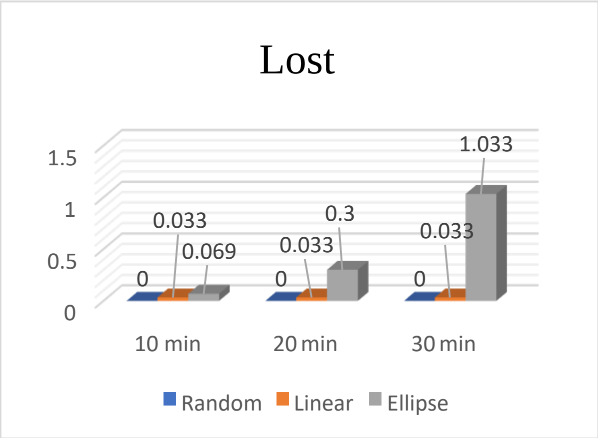

Fig. 7. Lost packets

E. Received packets

If you look in Fig. 8, it can be noted that presents the number of average received packets in topologies. The minimum average of the received packets was in ellipse topology within 10 min, 20 min, and 30 min. However, the random topology had the maximum average at 10 min and 30 min. Besides, the linear topology had approximated values to the random topology.

A comparative review of obtained performance for all five analyzed metrics is presented in Table II. The maximum and minimum values are given for each of three analyzed topologies.

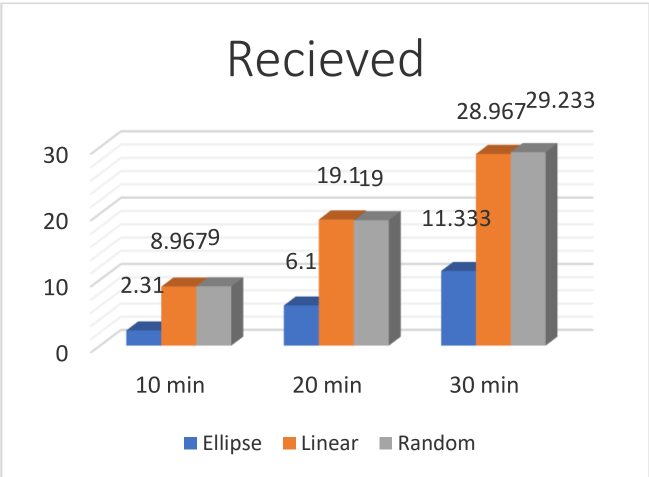

Fig. 8. Received packets

TABLE II
RESULTS EVALUATION

Metrics	Maximum and minimum values of each metric.
Received	The maximum value of average received packets was in random topology after 30 min. Averages of received packets are increasing by increasing the time for all topologies. The minimum value of average received packets was in ellipse topology.
Lost	The maximum value of average lost packets was in ellipse topology after 30 min. The minimum value of average lost packets was in random topology; it was zero.
ETX	The maximum value of average Expected transmission count was in ellipse topology after 10 min. While the time increasing, the value of average ETX is decreasing. The minimum value of average Expected transmission count was in random topology after 30 min.
Hop Count	The maximum value of average Hop Count was in ellipse topology after 20 min. The minimum value of average lost packets was in random topology.
Power Consumption	The maximum value of average power consumption was in ellipse topology after 10 min. Average power consumption is decreasing by increasing the time for all topologies. The minimum value of average power consumption was in linear topology after 20 min.

V. Conclusion

Protocol for Low-power-lossy is an IPv6 routing protocol used for Low-Power and Lossy Networks and defines a generic Distance Vector protocol. This paper presents the performance of HC, power consumption, ETX, lost and received packets for three topologies. The results have shown which scenario has the best value versus which criteria. So, the best value of average received packets was in random topology after 30 min, minimum value of average lost packets was in random topology, minimum value of average power consumption was in linear topology after 20 min, minimum value of average hop count was in random topology.

Also, the average of EXT value has the minimum value in the random topology. In this experiment the best results were obtained by random topology.

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