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Performance of Static Iot Networks using RPL Objective Functions

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Abstract: Internet of Things, abbreviated as IoT is a network used mainly for the communication where different devices are connected for the retrieval, examination and execution of the necessary task. One of IoT's biggest challenge is that, they are resource-constrained. Hence, it is essential to use an efficient data transmission protocol for routing. An effective routing protocol for static IoT network is the Routing protocol for Low Power and Lossy Networks (RPL). It is essential to assess the effectiveness of the RPL with the selection of best objective function for different static model. In this paper, the performance of different routing algorithms is compared in connection with different static topologies. Hence, the objective function's performance is compared for different topologies i.e., Butterfly, Ring and Umbrella topologies. We consider two objective functions: namely Minimum Rank with Hysteresis Objective Function (MRHOF) and Objective Function Zero (OF0). MRHOF considers Expected Transmission Count (ETX) as its metric and the metric considered under OF0 is hop count. It is observed that the objective function OF0 performs better than MRHOF for the metric of energy and successful receiving of data.

Keywords: Internet of Things, Routing Protocol for Low power and Lossy networks, Minimum Rank with Hysteresis Objective Function, Objective Function Zero.

I. INTRODUCTION

Internet of things is a network, which connects and establishes communication between heterogeneous objects. The components used in this network are power constrained, so the protocol used in this must belong to low power and lossy network (LLN) group. One of the efficient routing protocol for LLN group is Routing protocol for low power and lossy networks (RPL). It uses the topological concept called Destination Oriented Directed Acyclic Graph (DODAG) to construct tree structure. This DODAG can be constructed using specific objective function. Hence selection of right objective function plays an significant role to save the power of node and to enhance the network lifetime [4].The two commonly used objective functions are MRHOF and OF0. In this MRHOF uses metric of ETX and OF0 uses hop count as its metric. As objective function plays an important role in efficient construction of DODAG and as it also helps in efficient utilization of routing protocol, it is necessary to select best objective function. Few research work has been carried out to compare the existing objective function, but researchers cannot select the best objective function for the particular application.This paper is structured as follows: The section 2 explains literature survey and develops the motive for this research. Section 3 introduces the simulation configuration, and Section 4 gives the simulation outcomes and a model for predicting the network's conduct. Finally, the conclusion is provided in Section 5.

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II. LITERATURE SURVEY

A. Low Power and Lossy Networks (LLN)

The Internet Engineering Task Force setup a working group called Low Power and Lossy networks. It standardizes IPv6-based LLN routing protocol [1].

The characteristics of LLNs are (i) Energy constrained nodes, that is nodes are powered with low battery, low processing capability and memory. (ii) Limited bandwidth or low data rates. (iii) High Bit Error Rate and Lossy links and (iv) low Packet Delivery Ratio (PDR).

LLN supports the following types of traffic flows: (i) Point-to-point(P2P), which considers the flow within the LLN between appliances. (ii) Point to multipoint(P2MP), which refers to data flow from the center to a subnet of devices in the LLN. (iii) Multipoint to point (MP2P), which takes into account the flow to the main control point from the systems inside the LLN. Through these features and support for distinct kinds of traffic flows, LLN is more appropriate for the IoT [2] [3].

B. Routing Protocol for Low Power and Lossy Networks(RPL)

The RPL is one of the LLN's effective routing protocols for IPv6 networks. RPL is intended to be extremely adaptable to network circumstances and offers alternative paths when routes are not accessible by default. RPL utilizes the topological notion called Destination Oriented Directed Acyclic Graph (DODAG), extracted from the Directed Acyclic Graph notion to define a tree structure. Logical routing tree is constructed in DODAG over a physical network depending on specific Objective function(OF). DODAG is rebuilt periodically using the trickle timer method to allow global re-optimization [6].

RPL works primarily in two stages. They are:

i) route discovery: creating fresh paths (routes)
ii) route maintenance: to maintain the route.

RPL uses the following approaches to identify the topology changes:

Trickle timer: RPL utilizes trickle timer to balance the trade-off between overhead control messages and modifications in topology.

The concept is to raise the trickle timer to its highest value depending on network topology stability and reset the value to its minimum if an inconsistency is found. The trickle timer value is determined by the interval [I_{MIN}, I_{MAX}] where, minimum timer value=2^{I_MIN} (in milli seconds) and the calculation of maximum timer value is done using configurable value known as doubling factor $I_{doubling}$ [5].

C. RPL for Stable nodes

A lot of study has been done using the RPL protocol on IoT for stable nodes [14], which demonstrates that RPL is an effective protocol for IoT stable nodes. The performance of RPL for mobile nodes is evaluated by various researchers in [8] [9] [10] [11]. Long et al [15], compares the performance of RPL and Collection Tree Protocol (CTP) [16]. It shows how RPL is better in terms of scalability. The results of RPL (ContikiRPL) is compared with CTP (ContikiCollect) by considering Packet Reception Ratio (PRR) and power parameter. It showed that CTP is better in small networks. While RPL dominates with larger networks with more data traffic. But limited research has been done to select the best objective function in RPL which is suitable for most of the stable topologies.

In Qasem et al [1] the performance evaluation of objective function is done for the sparse network and not for dense network. In this the power consumption of the IoT network is calculated based on RX values for random and grid topology. They have proved that when RX value is 60%, the performance of both objective functions are best for power consumption and PDR metric. It is also proved that in some cases MRHOF performs better than OF0 in grid and random topology. In the paper by Mardini et al [13], the objective functions are compared for the dense network along with the sparse network. But they have considered only grid topology under static category and they have not considered the Radio on time as the comparison parameter. The method of power calculation in their research is not specified clearly.

Abuein et al. [16], focused on the Packet Delivery Ratio and Energy Consumption metrics in non-mobile network. These two metrics were tested under two different topologies “fixed and random”. Their results prove that PDR is more efficient with OF0 in lower density networks. While MRHOF has better energy consumption with higher density networks.

In all the above papers, it can be noted that the comparison is done either on grid or random topology, but the performance of the objective function was not evaluated on Butterfly, Ring or Umbrella topology. In this work along with the power consumption and successful packet received, the Radio on parameter is also considered for all the three topologies mentioned above. The Radio on parameter helps to calculate the power consumption of the network more effectively.

III. SIMULATION PURPOSE

The simulation is carried out with the aim of assessing the efficiency of the RPL protocol for distinct node scalability. The main aim of this paper is to study the performance of the two objective functions used in the RPL protocol that is OF0 and MRHOF in Contiki operating system for different network topologies.

A. Simulation Setup

The proposed work is simulated using the Cooja simulator. The version of simulator used is 2.7 and the operating system used for this is the Contiki [6] [7]. Cooja is a tool which supports both emulation and simulation. Contiki is a widely used open source operating system. It is light weight, highly portable and is mainly used for wireless sensor network and IoT applications. The MAC layer protocol used by contiki is ContikiMAC [12].

Table 1: Cooja Simulation parameter

SI No	Parameters	Simulation model
1	Mote Type used	Sky Mote
2	Transmission range (TX)	50m
3	Transmission ratio (TX Ratio)	100
4	Receiving ratio (RX Ratio)	100
5	Maximum number of nodes	70
6	Scalability level (Number of nodes)	10, 20, 30, 40, 50, 60, 70
7	Simulation time	20 minute for each scalability level

In this three static topologies are considered. They are Ring, Butterfly and Umbrella. In all the three topologies the sender nodes are arranged according to the topology and the sink node will be placed at the center. The topologies are tested using both OF0 and MRHOF parameter. The simulation is performed ten times and the average result of all ten simulations is noted down in result section.

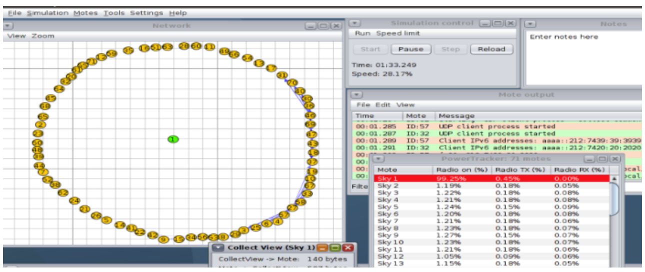

Figure 1: Simulation setup of ring topology.

The simulation of different topologies is shown in Figure 1, Figure 2 and Figure 3. In ring topology all the sender nodes are arranged in ring format and sink node is deployed in the center as plotted in Figure 1.

In butterfly topology, all the sender nodes are deployed in the butterfly format, placing the sink node at the center as depicted in Figure 3. Similarly, in Umbrella topology, the sender nodes are arranged in the umbrella format by placing the sink at the center as shown in Figure 2.

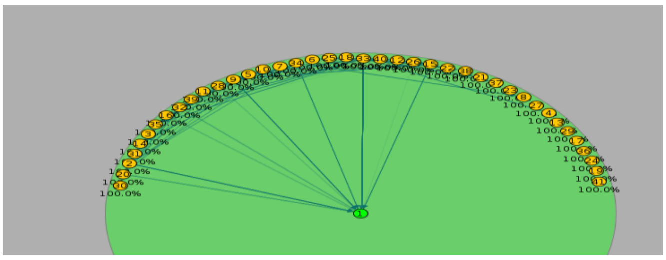

Figure 2: Simulation setup of umbrella topology

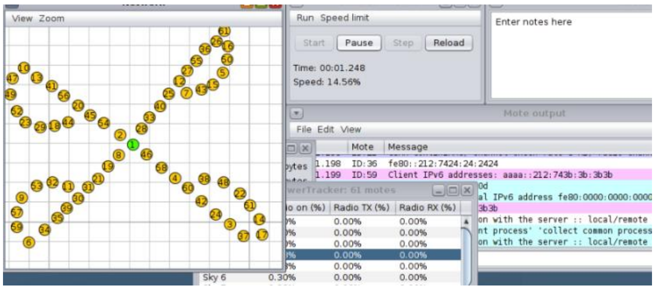

Figure 3: Simulation setup of Butterfly topology.

IV. RESULTS

The performance of objective function is evaluated for the following three parameters. They are power, radio on and the number of packets received under different static topologies.

A. Power

One of the important parameters considered by most of the researchers is power consumption. i.e., The network considered for these nodes is LLN, the resources of which are energy constrained. In this experiment, it is essential to consider the metric of power.

The collect view of Cooja simulator provides the tabulated details of the power consumption of each node in all the four levels: namely CPU power, LPM power, Radio on time power and Listen time power. It is also possible to find the four levels of energy consumption individually and collectively using this interface. The energy is calculated based on the following formula:

CPU power: cp = c*1.8/tm; where c is the CPU time.

LPM power: lp = l*0.0545/tm; where l is the low-power mode sensor time.

Transmit power: lt = t*17.7/tm; where t is the transmit time.

Listen power: lr = r*20/tm; where r is the Listen time.

Total power:tp = cp+lp+lt+lr;

The power consumption of ring topology using the objective function MRHOF and OF0 is listed in the Table 2.

Table 2: Power in Ring topology

Number of nodes	MRHOF	OF0
10	1.004	0.995
20	1.132	1.091
30	1.23	1.185
40	1.32	1.262
50	1.45	1.382
60	1.50	1.440
70	1.46	1.439

It is observed that the power consumption is more in MRHOF as compared to OF0 in all the three topologies like Ring, Butterfly and Umbrella as shown in Table 2, Table 3 and Table 4 respectively. The power consumption for all the said topologies are depicted as shown in Figure 4, 5 and 6.

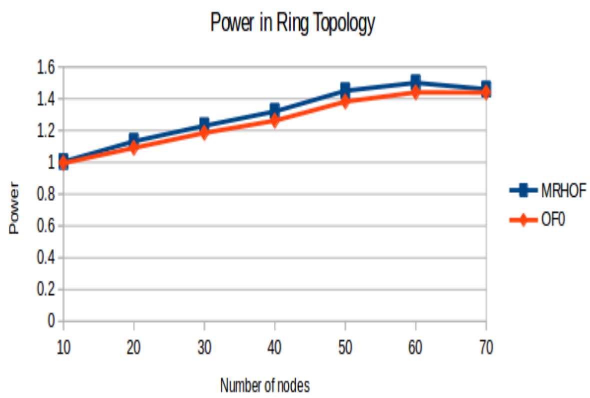

Figure 4: Power consumption in ring topology

Table 3: Power in Butterfly topology

Number of nodes	MRHOF	OF0
10	1.09	1.08
20	1.1	1.1
30	1.22	1.20
40	1.3	1.3
50	1.48	1.41
60	1.58	1.53
70	1.59	1.50

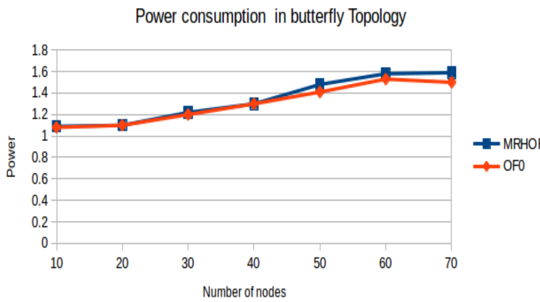

Figure 5: Power in Butterfly Topology.

Table 4: Power in Umbrella topology

Number of nodes	MRHOF	OF0
10	0.99	0.99
20	1.0	1.0
30	1.14	1.14
40	1.3	1.3
50	1.93	1.40
60	1.74	1.56
70	1.80	1.52

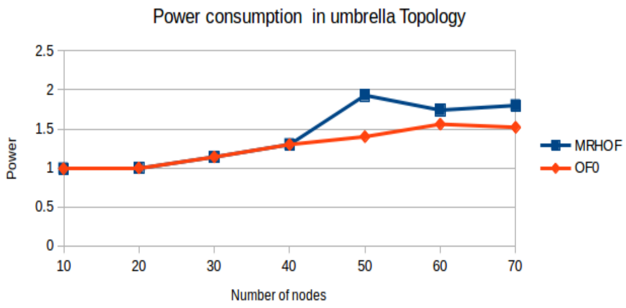

Figure 6: Power consumption in Umbrella topology.

B. Radio on

The radio on time of the node decides each node's power consumption. If the node is ON for long duration, then the power consumption is more. Hence it is necessary to observe the Radio on time of the node to calculate each node's power consumption, and in turn to calculate the total power of the network.

The radio on time in MRHOF is more in Ring, Butterfly and Umbrella topology as shown in Table 5, Table 6 and Table 7 respectively, which indicates that the power consumption is more in MRHOF than OF0.

Table 5 : Radio on in Ring topology

Number of nodes	MRHOF	OF0
10	9.86	9.85
20	5.71	5.38
30	4.23	4.17
40	3.59	3.32
50	3.3	3.3
60	3.07	2.9
70	2.86	2.72

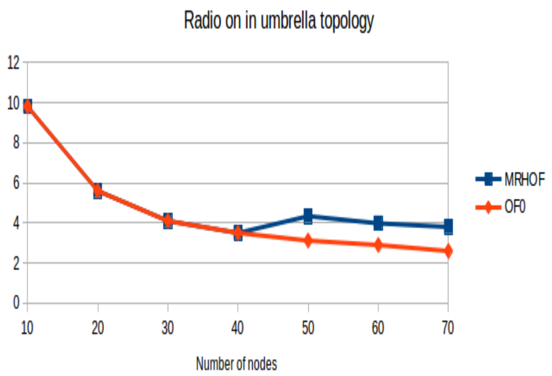

Figure 7: Radio on in Ring Topology.

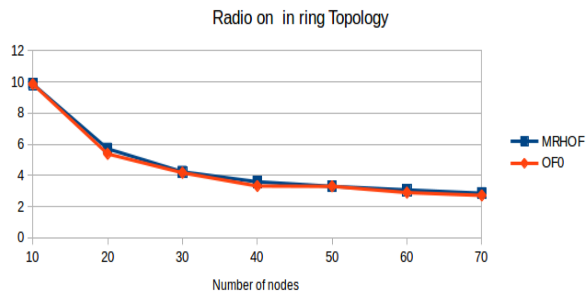

Figure 8: Radio on in Butterfly Topology.

Table 6: Radio on in Butterfly topology

Number of nodes	MRHOF	OF0
10	9.8	9.8
20	13.84	5.62
30	4.25	4.15
40	3.52	3.45
50	3.16	3.14
60	3.02	2.93
70	3.10	2.69

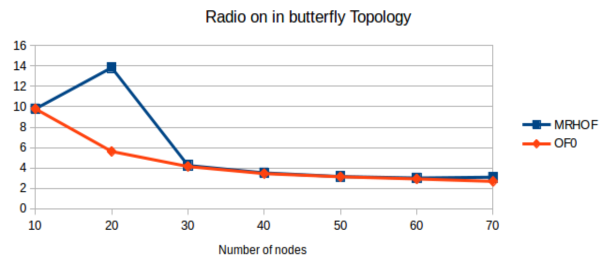

Figure 9: Radio on in Umbrella topology

Table 7:Radio on in Umbrella topology

Number of nodes	MRHOF	OF0
10	9.8	9.8
20	5.6	5.6
30	4.1	4.1
40	3.5	3.5
50	4.34	3.12
60	3.98	2.9
70	3.8	2.6

C. Received

To determine the protocol's performance, it is necessary to consider the number of packets which are successfully received by the sink. Hence the number of packets successfully received is considered as one of the parameters to test the performance of objective function.

In Ring topology the number of packets received in OF0 and MRHOF is almost equal for sparse network and in dense network. OF0 receives more packet than MRHOF as shown in Table 8 and Figure 10.

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In Butterfly topology there is no much difference between OF0 and MRHOF for the metric number of packets received. The same is depicted in Figure 11 and tabulated in Table 9. The performance of Umbrella topology is similar to Ring topology as shown in Table 10 and Figure 12.

Table 8: Packet received in Ring topology

Number of nodes	MRHOF	OF0
10	14.08	14.2
20	14.03	14.05
30	13.98	14.04
40	14	13.94
50	13.72	13.84
60	13.26	13.82
70	12.55	13.48

Table 9: Packet received in Butterfly topology

Number of nodes	MRHOF	OF0
10	13.96	13.98
20	14	14.02
30	13.53	13.60
40	13.98	13.98
50	12.96	13.92
60	13.94	13.95
70	13.53	17.03

Table 10: Packet received in Umbrella topology

Number of nodes	MRHOF	OF0
10	14	14
20	14	14
30	13.96	13.96
40	13.9	14.12
50	11.10	13.98
60	9.33	13.96
70	8.54	13.98

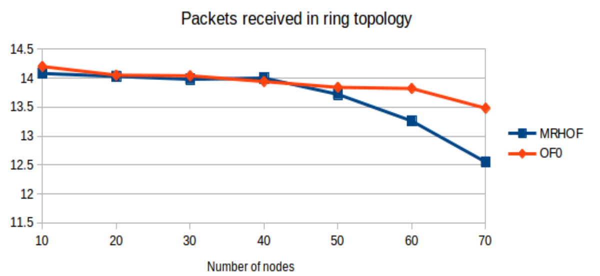

Figure 10: Packet received in Ring topology

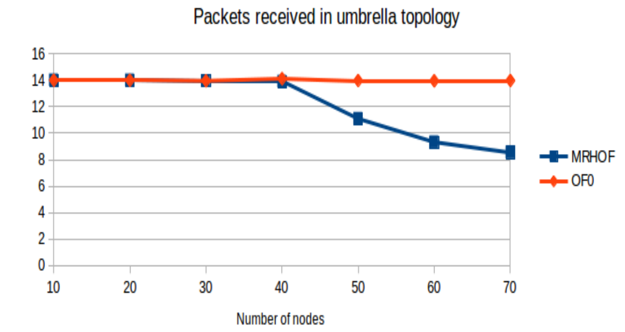

Figure 11: Packet received in Butterfly topology

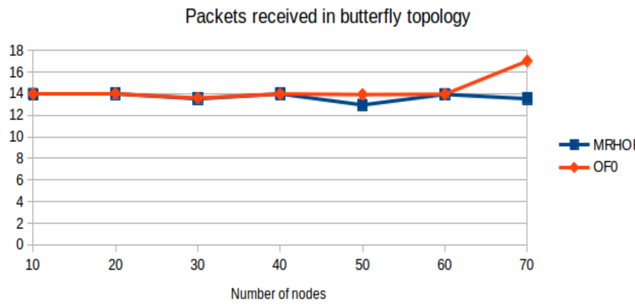

Figure 12: Packet received in Umbrella topology

V. CONCLUSION

The performance of RPL is evaluated for static network with the usage of different objective functions. For the evaluation, three important parameters are considered. They are: power consumption, Radio on time and number of packets successfully received. By the experiment it is noted that the objective function OF0 is performing better than MRHOF in all the three static topologies both in sparse and dense network. In future, the performance of objective function can be evaluated for mobile nodes.

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