Evaluation of RPL Performance with Objective Functions for IoT Real Time Networks (LLNs)

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Abstract

A LLN has extended to various application domains includes healthcare appliances, alert systems and different applications to monitor and manage the devices. It also automates the systems by automating devices like fire, physical security devices which are helpful in different scenarios. In IoT Networks routing protocols are used to establish communication from one node to another node. In this Protocol, Objective Functions are used it to identify the route from the sender sensor node to root node or Base station based on different constraints and specifications. Most extensively used Objective Functions are: OF0 stands for Objective Function Zero and MRHOF stands for Minimum Rank with Hysteresis Objective Function. The moto of this paper is to analyse the implementation of both objective function RPL's by arranging the sensor nodes in different manner and observing the change in packet delivery ratio and power consumption of nodes. Observations are done using Cooja simulator in Contiki Operating system. The observations reveal that there exists a relationship between arrangements of nodes in a network to the performance of RPL's objective functions and power consumption of network.

Keywords: *RPL, Objective Function (OF), OF0-Objective Function 0, MRHOF- Minimum Rank with Hysteresis Objective Function, DODAG- Destination Oriented Directed Acyclic Graph Packet Delivery Ratio (PDR), IoTN.*

1. Introduction

IoT Network (IoTN) consists of sensor devices, which receives data from the physical world. As sensor devices are having low processing power, low and constrained performance with limited memory and lifetime. Because of these constraints one cannot use traditional protocols. In IoT Networks routing protocols are used to establish communication from one node to another node. In this Protocol, Objective Functions are used it to identify the route from the sender sensor node to root node or Base station based on different constraints and specifications. Most extensively used Objective Functions are: OF0 and MRHOF. The Internet Engineering Task Force (IETF) defined RPL which suits for connecting sensor nodes [1]. RPL is the standard protocol used in LLNs. With the help of the Directed Acyclic Graph, RPL constructs the topography of network. One network is connected to another by connecting their DAG's. Which results in formation of Destination Oriented Directed Acyclic Graph, and each DODAG is uniquely identified using DODAG ID [3].

RPL provides an operation to diffuse node information to another topology, such as DODAG Information Object, DIO message gives info regarding the Objective Function, rank of the node and sensor id to all over a network, which results in other node to join a network.

For establishing communication, the root node in DODAG sends a DIO message to other network nodes that are in the conception range of the root node, and they reply with a DAO message to sensor node in order to join the network. The nodes which are not in conception range communicate with a DIS message to neighbouring nodes which are in conception range of sink node. Whenever a node receives DIS message, will send the DIO message to the sender node which is not in perception range then the sender node responds with a DAO message to neighbour node which is transferred to the root node of the network [3, 5, 6]. While transmitting

ISSN: 2005-4297 IJCA

data from source node to root node, each node selects its own parent from neighbour node to transmit its data to root node. The main aim of this paper is to observe the execution of the two OF's such as OF0 and MRHOF [1, 2] by varying no of nodes from 10 to 30 and transmission ranges from 50 to 100. The main advantage of this study shows how order or arrangements of nodes over a network has an impact on Packet Delivery Ratio and Power Consumption. Since the main concentration is on the order of the arrangement of nodes over a network, consider the different scenarios of linear and random arrangements of nodes in network.

2. Methodology

2.1. Linear Arrangement of nodes

In IoT Networks if nodes are arranged in linear order, each node acts as processor as well as router for transmitting the data from one device to another device in the network. If nodes in IoT Networks are arranged in linear order there is only one path from one node to another in a network is shown in Figure 1. [7].

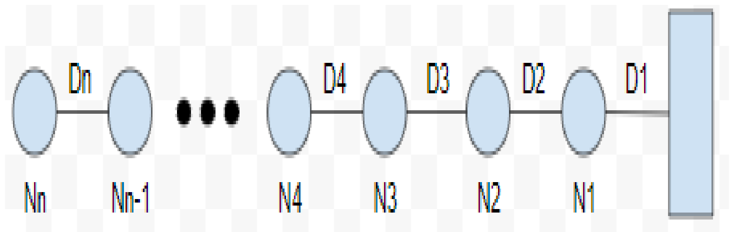

Figure 1: Linear / Grid Arrangement of Nodes

2.2. Random Arrangement of nodes

In random arrangement of nodes forms a topology that nodes are scattered from air is shown in Fig 2.. Each and every node must send the data to the root that must be centred. There are number of ways to reach from one node to another [4].

Figure 2: Random Arrangement of Nodes

In real time random arrangement of nodes is widely used compared to linear arrangement because there is number of ways to transmit the data to root node.

Table 1: Research Issues in Network Topologies

	Approach	Advantages	Disadvantages	Research Issues
1	Sensor nodes in	Simple to implement for	Not efficient for larger	Reducing power consumption.

	Linear Order	smaller applications.	applications.	
		Low cost of implementation.	Power consumption of node is more.	Efficient way of identifying failure nodes.
				Reducing delay in data transmission.
2	Sensor nodes in Random Order	Difficult to implement but efficient for larger application.	Chance of retransmissions is more.	Measures to reduce retransmissions.
		Widely used in Real time applications.	Difficult to cope up with frequent network changes.	Adaptability of nodes during regular changes in the network.
		Power consumption of nodes is less compared to linear.		

2.3. Objective Functions in RPL

RPL specifies an objective function in order to churn the existing path and to find better path than the existing one based on the constraints defined in DODAG. The following objective functions are widely used.They areObjective Function 0[2], Minimum Rank Objective Function with Hysteresis[1], LEACH-OF, FLECH-OFand OF-FUZZY.

With the help of constraints specified, RPL constructs the Destination Oriented Directed Acyclic Graph which doesn't contain any cycle and each node in the graph is a sensor node and from one node can communicate with its neighbouring nodes and can transmit data to the sink node which is a root node in DODAG is shown in Fig 3..

2.4. Objective Function 0

The RPL specification describes Objective function for selecting potential parent nodes from their neighbour nodes. Those parent nodes are formed as a parent set. All the parent nodes from parent set are feasible successors for transferring the data from that node to root node.Objective Function Zero is used to search the closest neighbour root acts as a parent node depending on rank of each device over a network.

OF0 selects neighbour node as parent to pass on the data to the sink node and a successor which is feasible if it is present. When there are no suitable conditions to transmit a packet to parent node then the data packet is transferred to the feasible successor.

2.5 Minimum Rank Objective Function with Hysteresis

MRHOF uses another metric for finding the path from source device to the destination device. Hysteresis is metric used for selecting the route from sensor node to destination node. The metric that MRHOF can make use of are the constraints specified in the DIO Metric Container. The use of MRHOF with ETX metric identifies the least-ETX paths from the required node to a root node in the DODAG.

MRHOF uses Expected Transmission count as metric widely in many cases in WSN applications. Because MRHOF aims to reduce path costs as specified in metrics.

2.6. LEACH-OF

Low Energy Adaptive Clustering Hierarchy Objective function, which divides the into different clusters and each cluster has a cluster head which is responsible for receiving all the data from the remaining nodes in a cluster and passes it to a base station.

LEACH changes the cluster head node to distribute energy consumption of nodes in a network. But there are some disadvantages like energy consumption of nodes and security issues while implementing LEACH. In order to overcome these problems LEACH is modified and implemented in a network.

In Modified LEACH, the sensing area is in the shape of triangle cells and in each cell there is equal number of nodes and data send to a base station based on the multi hop manner through the routing path which consists second heads. Thus, modified LEACH gives better results regarding energy consumption of a network.

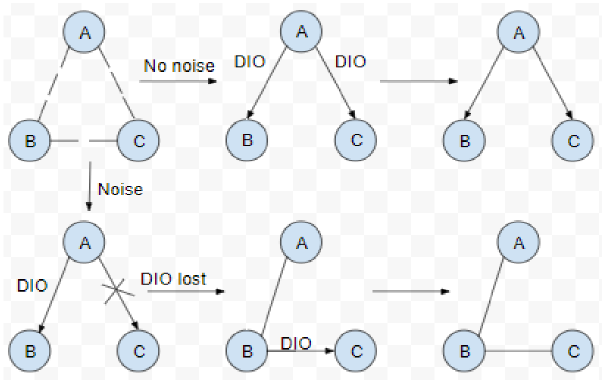

Figure 3: Construction of DODAG

2.7. FLECH-OF

In this approach Fuzzy Approach (FA) is used in selection of cluster heads to avoid the disadvantages like energy consumption. It ensures proper rotation of cluster head among all eligible nodes in a network. While selecting the cluster head one need to consider the inputs like Residual Energy, Node Centrality and Distance to the Base Station.

Residual Energy: The cluster head need to have more energy because it needs to receive the data from the remaining sensor nodes in a network. The higher the residual energy of a node the higher probability of node becoming the cluster head.

Node Centrality: It is defined as the position of node in a network and finds whether it is in middle among neighbours in a network. The lower the NC values the node that becomes the cluster head.

Node Degree: It is defined as Number of neighbours within the communicated Radius Rc and network dimension value M.

Distance to Base Station: Calculates the distance from a sensor node to a base station.

The output of the FLECH is Chance, which determines the CH capability. The higher the chance value the higher the probability of electing the node as cluster head.

2.8. OF-FUZZY

The important factors of an IoTN is efficiently managing the energy of sensor nodes present in a network and maximizing the lifetime of nodes present in a network. Hence one needs to implement an RPL objective function by combining several essential routing metrics by using fuzzy logic. The possibility of combining metrics like energy, latency, throughput.

Inorder to combine several metrics in RPL inorder to improve the QoS has categorized into two forms of combination: additive and lexicographic. In order to take advantage of fuzzy logic to improve the performance of RPL by considering multiple objectives.

In Fuzzy logic, there are 4 steps. They are:

Fuzzification: Take a value as input and need to determine its degree of membership.

Fuzzy inference: Apply combination rules to the output of Fuzzification to it as input and get the output.

Aggregation: It combines all the rules and unifies into one and produces the single output.

Defuzzification: Converts the fuzzy output into a single output value.

By comparing the objective function, OF0 requires less processing compared to MRHOF because in MRHOF one must calculate the ETX results in more power consumption of nodes over a network that uses MRHOF objective Function. So MRHOF takes more processing time compared to OF0 for finding the path from one device to another device in a network.

3. Simulation Setup

3.1. Packet Delivery Ratio

PDR is based on number of data packets successfully delivered from nodes to the root node of IoT Network by number of data packets originated by the nodes over a network [3, 5, 6].

$$\textbf{PDR} = \frac{\textbf{No.of.packets delivered to root node}}{\textbf{No.of packets originated from source node}} \quad (1)$$

PDR can be calculated based on the lost packets and the packets generated in the network. With the help of the PDR one can calculate the efficiency of an IoT network is is shown in Table 3.

3.2. Power Consumption

In IoTN nodes are sensors that are having less processing power and low power consumption nodes. As power consumption plays an important role in IoTN.

Generally, as number of nodes increases, the load on each node increases as a result it consumes more power to transmit information from one node to another node.

Power consumption of nodes is observed by varying number of nodes and receiving capacity of nodes in a network[8].

For observing the power consumption of nodes parameters like LPM, listen power, transmit power and CPU power are considered which are resulted from simulation.

Cooja simulator is a network simulator designed to implement the wireless sensor network used to do observations andanalyse the performance of RPL Cooja is an adaptable java-based simulator developed for creating system of sensors operated in the Contiki OS. It uses C language as software design language by making use of Java Native Interface. Coojacan work on various levels; for instance, network level, operating system level. It executes on various platforms for example Sky, TelosB, native, and so on. It is disseminated as an open source and incorporates numerous situations and open source code that can be accessed by any other application.

ISSN: 2005-4297 IJCA

Table 2: Network Simulation Parameters

Settings	Table Value
Propagation Model	UDGM with DL
Mote Type	Sky Mote
Tx Ratio	100%
Rx Range	50m, 75m, 100m
Simulation Time	1800000 ms
Number of Nodes	10, 20, 30
Topology	Grid, Random
Squared Area	100m * 100m
Objective Functions	OF0, MRHOF

Table 3: Packet Delivery Ratio For Two Topologies With Different Receiving Capacities

Objective Function	Topology	Receiving Capacity	Number of Nodes		
			10	20	30
			PDR		
MRHOF	Grid	Rx50	100	99	96
		Rx75	99	98	98
		Rx100	100	100	100
	Random	Rx50	100	98	92
		Rx75	100	100	98
		Rx100	100	100	100
OF0	Grid	Rx50	99	99	99
		Rx75	100	99	99
		Rx100	100	100	100
	Random	Rx50	100	100	99
		Rx75	100	100	98
		Rx100	100	100	100

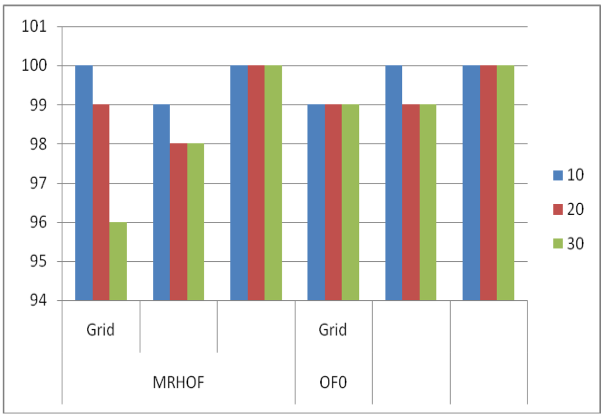

Figure 4: Graph Between MRHOF and OF0 In Grid Topology With Different Receiving Capacities

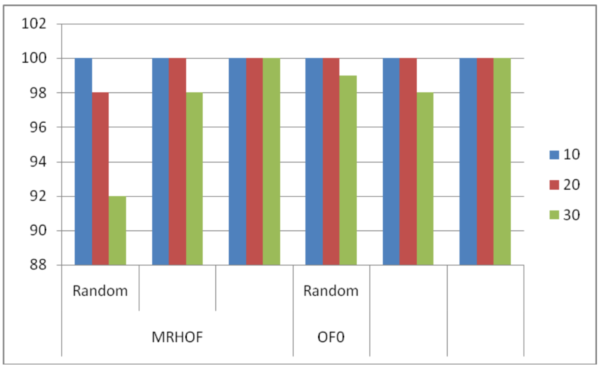

Figure 5: Graph Between Grid And Random Topology In MRHOF With Different Receiving Capacities

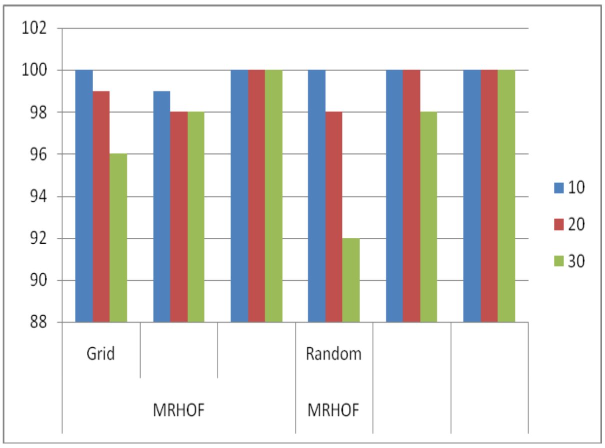

Figure 6: Graph Between MRHOF And OF0 In Random Topology With Different Receiving Capacities

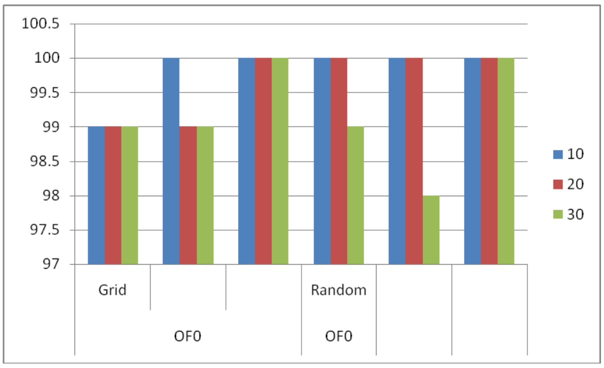

Figure 7: Graph Between Grid And Random Topology In OF0 With Different Receiving Capacities

In Grid / Linear topology using MRHOF, as receiving capacity increases, PDR is increasing is shown in Fig 5. But in random topology, which node having highest receiving capacity has more PDR. In Grid topology using OF0, there is no consistent behaviour regarding PDR is shown in Fig 6. In random topology using OF0, which node having greater receiving capacity, it will have more PDR is shown in Fig 7.

Table 4: Power Consumption for two topologies with different receiving capacities

Objective Function	Topology	No. of Nodes	Receiving Capacity	Power Consumption				
				LPM	Listen	Transmit	CPU	Power
MRHOF	Grid	10	Rx50	0.151	0.618	0.315	0.42	1.504
		20		0.15	0.682	0.367	0.449	1.648
		30		0.145	1.11	0.622	0.626	2.504
		10	Rx75	0.151	0.521	0.174	0.399	1.245
		20		0.15	0.595	0.266	0.434	1.445
		30		0.146	0.869	0.391	0.594	1.991
		10	Rx100	0.152	0.472	0.1	0.389	1.113
		20		0.151	0.558	0.2	0.423	1.331
		30		0.147	0.62	0.185	0.552	1.504
	Random	10	Rx50	0.15	0.535	0.179	0.43	1.294
		20		0.147	1.019	0.605	0.55	2.332
		30		0.148	0.659	0.276	0.51	1.594
		10	Rx75	0.151	0.721	0.52	0.427	1.819
		20		0.149	0.597	0.196	0.485	1.427
		30		0.147	0.847	0.407	0.561	1.961
		10	Rx100	0.152	0.481	0.119	0.395	1.146
		20		0.149	0.61	0.2	0.474	1.433
		30		0.147	0.637	0.194	0.554	1.531
OF0	Grid	10	Rx50	0.151	0.593	0.273	0.412	1.43
		20		0.151	0.563	0.213	0.424	1.351
		30		0.147	0.748	0.302	0.557	1.754
		10	Rx75	0.151	0.517	1.223	0.397	0.861
		20		0.151	0.553	0.197	0.421	1.322
		30		0.147	0.629	0.194	0.544	1.514
		10	Rx100	0.151	0.491	0.109	0.359	1.105
		20		0.151	0.495	0.119	0.409	1.173
		30		0.147	0.564	0.142	0.538	1.391
	Random	10	Rx50	0.152	0.553	0.23	0.394	1.329
		20		0.149	0.592	0.212	0.484	1.437
		30		0.147	0.702	0.26	0.56	1.669
		10	Rx75	0.152	0.513	0.182	0.368	1.216
		20		0.15	0.543	0.167	0.446	1.305
		30		0.147	0.68	0.234	0.541	1.601
		10	Rx100	0.151	0.497	0.115	0.41	1.172
		20		0.149	0.497	0.102	0.487	1.235
		30		0.147	0.536	0.116	0.535	1.333

ISSN: 2005-4297 IJCA

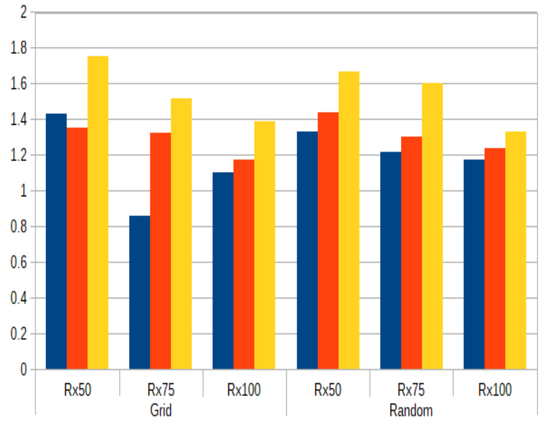

Figure 8: Graph between grid and random topology in MRHOF with different receiving capacities

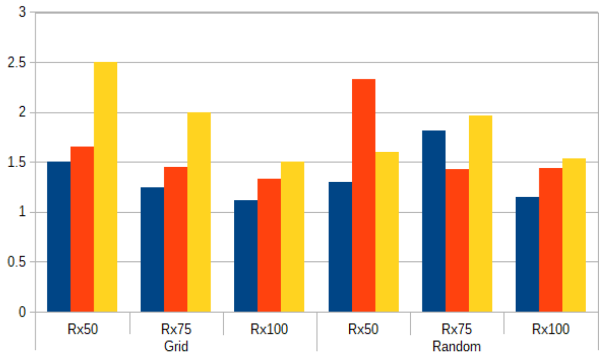

Figure 9: Graph between grid and random topology in OF0 with different receiving capacities

As receiving capacity increases the power consumption of nodes decreases, LPM decreases by an increase in number of nodes and all other parameters like Listen, transmission and CPU power consumption increases is shown in Fig 8 and Fig 9.With respect to topology the grid kind of networkconsumes more power compared to random topology network.

4. Conclusion

In this paper the exhibition of the standard RPL's OFs in two situations has been assessed to observe the behaviour of nodes with respect to power consumption and PDR. In the first situation, the topology is fixed,and the transmission ranges are changed, and in the subsequent situation, the transmission ranges and the topology are changed. By observing the arrangement of nodes in a network with different objective functions with different receiving capacities with an increase in receiving capacity PDR also increased. But in OF0 the difference between PDR is less compared to MRHOF**.** Regarding the power consumption of nodes in a network OF0 is efficient than MRHOF.

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