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DESIGN A NEW RPL PROTOCOL FOR THE CROWDED NETWORKS

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Abstract. The Routing Protocol for Low Power Lossy Networks (RPL) gained a lot of popularity in the research community with the advent of the Internet of Things (IoT). The RPL's Objective Function (OF) calculates the ranks of nodes on the network depending on one routing metric. Because of the single metric, both Minimum Rank with Hysteresis Objective Function (MRHOF) and Objective Function Zero (OF0) will suffer from long hops when selecting the routes to the sink. Moreover, selecting an inefficient route, like paths containing nodes with small residual energy, may consume the node's energy faster than other nodes. Also unbalanced choice of parents makes bottleneck nodes that cause more network delay and high Packet Loss Ratio (PLR) because of the high congestion nodes. This causes unreliable and inefficient networks. However, it is challenging to provide a high Packet Delivery Ratio (PDR), low power consumption, and reliable services. To solve the problem of a bottleneck, we suggested a load balance algorithm. Additionally, to solve the problem of choosing the node with little energy, we proposed a residual energy metric. To get high efficient network, we suggested an improved OF that takes into consideration three metrics (Load, Residual Energy, and Expected Transmission Count (ETX) metrics). The Cooja simulator was used in this analysis, the MRHOF suffers from high congestion and high delay, but the proposed Protocol maintains a high performance. With the network with 100 nodes the PDR, the power consumption for the proposed Protocol is 88.73%, 226.512 mW. The power consumption is 349.362 mW, while the PDR is 31.408% for the RPL MRHOF.

Keywords: RPL, Crowded Networks, Low-power and Lossy Networks, Objective Function (OF), MRHOF, Routing Protocols.

AMS Subject Classification: 68M15.

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1 Introduction

The Low Power and Lossy Networks in IoT consist of a large number of restricted nodes and communication. Node restrictions may include energy limitations (battery life), data size limitations, memory and queue limitation, processing limitations, and limited transmission ranges. Communication restrictions may include: requirement of high reliability, routing without looping, also the LLN requirements include low delay, low energy consumption, offer a redundant link, and the constantly changing topology of the network. It's difficult to come up with routing Protocols for Low-Power and Lossy Networks (LLNs) (Herberg & Clausen, 2011; Ko et al., 2011).

The Internet Engineering Task Force (IETF) Routing Over Low Power and Lossy Networks Working Group (ROLL WG) Oliveira & Vazão (2016) has extensively reviewed existing routing Protocols such as Ad Hoc on Demand Vector (AODV), Open Shortest Path First (OSPF), Intermediate System to Intermediate System (IS-IS), and Optimized Link State Routing (OLSR), and found that they fell short of LLNs requirements. As a result, based on the characteristics of

LLNs, the ROLL WG established and specified the routing Protocol for LLNs (RPL) (Gnawali & Levis, 2012). The ROLL working group has so far identified two types of Objective Functions: the OF0, which uses the hop count as the only routing metric, and the MRHOF, which uses the ETX as the only routing metric. The RPL network contains two kinds of nodes. One is the sink node, which collects the data from all the network nodes. The other nodes are the source nodes, which gather separate data from various sensors. After the RPL node routing topology is created, all the common nodes in the network will periodically send their data to the sink node.

A Destination Oriented Directed Acyclic Graph (DODAG) is the basis of the creation of RPL networks. To build and optimize the path, the OFs choose the best parent nodes. LLN has limited infrastructure integration. The LLN networks are also characterized by the diversity of traffic they carry, they don't just carry point-to-point communication, but also point-to-multipoint and multipoint-to-point traffic.

Given the complexity of these networks, finding an efficient routing system that can handle them has become a big challenge for academics. RPL was created to respond flexibly to network requirements, such as reducing energy usage and ensuring effective data reception. Furthermore, the RPL is dependent on the metrics contained within each node. These metrics are used in the DODAG to rank nodes and to optimize their location relative to their parents. RPL is a proactive routing Protocol that begins searching for routes as soon as the network is set up. RPL produces a DAG, which is a tree structure. In an RPL network, each node has a preferred parent that functions as a gateway for that node. If a node doesn't have an entry for a packet in its routing table, it simply passes the packet to its preferred parent until it reaches the destination or a common parent, which then passes the packet to the destination. The RPL's OF calculates ranks of nodes on the network depending on one routing metric, then selects and optimizes the routes.

The main contribution of the paper can be summarized as follows: Proposing an efficient Protocol by designing a new objective function that combines three metrics: ETX, residual energy, and load metric. The Objective Function (OF) determines how to construct the DODAG and selects the parents, in the RPL network to optimize the path. In every node, when constructing the DODAG and selecting the parent from the candidate parent nodes, the node that has minimum ETX, minimum load metric, and maximum node residual energy (max RE + min ETX + min Load) should be selected.

The tool used in this paper is the Cooja simulator, The remainder of this paper is organized as follows. First, in Section 2, the problem statement is explained, Section 3, we reviewed the related work that attempts to improve the RPL objective function. Section 4 defines the proposed Protocol model to enhance the RPL Protocol. In Section 5, the simulation results are evaluated with three network scenarios (50, 70, and 100 nodes) and show the results of the proposed Protocol and compare it with the RPL MRHOF in terms of the PDR, average packet loss ratio, and total power consumption. Finally, Section 6 concludes the paper.

2 Problem Statement

Sensor nodes are battery-operated, and these batteries have limited capacity. The main causes of energy expenditure in LLN are the communications between sensor nodes, congestion, collision, and retransmission. Because of the single metric, both MRHOF and OF0 will suffer from long hops when selecting the routs to the sink. Selecting inefficient routes like paths containing nodes with small residual energy may cause consume the nod's energy faster than other nodes. The other problem of RPL is the unbalanced choice of parents that makes bottleneck nodes cause more network delay and high packet loss ratio because of the high congestion nodes, especially the nodes located near the sink node. In addition, a flocking effect can be a result of the parent selection scheme in RPL, which referred to the incidence of attracting nodes and continuously switching from one parent to another. In consequence, this flocking phenomenon would have a major effect on QoS provisioning, which essentially restricts the services of the IoT application.

3 Related Work

In Wang et al. (2014), the authors stated that the"ETX metric used in RPL is inefficient in quantifying link quality as it only reflects a single link quality". The study proposes a quality-conscious link routing Protocol for LLN networks named LQA-RPL to resolve this problem. LQA-RPL measures the rank of each node based on the consistency of the paths with all the neighbors, this is derived from the ETX and is described as the probability of failed transitions predicted. When a node's father set has more than one father, it utilizes multi-path forwarding, choosing the parent with the most remaining power as the preferred parent relay node to the sink node in the network. In terms of the packet delivery ratio, energy usage, and network lifetime, LQA-RPL is evaluated and contrasted with RPL with a hop count (OF0). The published findings showed that, in terms of PDR, LQA-RPL outperforms RPL, which is due to an increased number of preferred parents. It also demonstrates that the proposed Protocol can balance power usage by dispersing congestion to various preferred parents based on remaining power, hence, extending the network's lifetime. An apparent problem with the proposed Protocol is that, while the issue statement focuses on illustrating the inappropriateness of the expected transmission count parameter to measure the efficiency of connections, it is compared to the OF0 objective function. Thus, comparing the suggested combined metric with ETX would seem to be more reasonable as a measure for connection reliability.

In Bekelman et al. (2003), "the authors combined three linguistic variables (routing metrics), namely latency, ETX, and energy, using a two-stage fuzzy method". The latency and ETX are mixed in the first step to compute QoS. In the second step, the energy and measured Quality of service (QoS) values are integrated. On an actual testbed network of twenty-eight sensor nodes, the suggested fuzzy-based method is then compared against the ETX-MRHOF objective function of the RPL. In terms of a lost packet (PLR), power usage, and network stability (total amount of preferred parent changes), the two Protocols are compared. According to the researchers, the fuzzy-based technique beats ETX-MRHOF by up to 20% in terms of a lost packet (PLR) and slightly increases end-to-end latency. In addition, the proposed solution is successful to create a network of high stable paths with an average change per hour of (6.63) parents compared to ETX-MRHOF with an average change of (43.522) parents per hour.

In Iova et al. (2015a) and Iova et al. (2015b), the advantages of incorporating multi-path forwarding methods into the RPL Protocol were underlined by the authors. Multi-path methods have been shown to offer a wide range of benefits, including improved fault tolerance, increased dependability, reduced congestion, and improved QoS. The authors proposed RPL based on a multi-path routing technique that allows the Protocol to route traffic to a large number of different parents. According to the research, a routing measure must: (1) capture changes in link quality; (2) utilize power-efficient routes to maximize end-to-end stability; and (3) reduce power consumption for the most power-intensive nodes (the bottleneck nodes). A new parameter is suggested in this regard. It is called the Expected Lifetime Metric (ELT) which aims to balance energy consumption between network nodes and optimize the lifetime of the bottleneck nodes. The network lifetime is defined as the time before the first node dies (runs out of energy). The ELT of a node is calculated by: 1- calculating the node's capacity based on its load as well as a load of its children nodes; 2- multiplying the average number of retransmissions by the traffic determined; 3- multiplying the average amount of retransmissions by the load determined; 4- based on the data transfer rate, determining the time ratio necessary for transmission; 5- calculating power consumption depending on the radio transmission energy only; 6- calculating the ELT as the ratio between the residual power of the node and the power calculated in the preceding step. The congested nodes (bottleneck nodes) are first identified along with the topology, based on the value determined by the ELT, then a multi-parent, power-balanced topology is constructed, in which traffic between parents is balanced with thoughtful consideration of congested nodes. Since several parameters (retransmission count, data rate, transition energy, throughput, and remaining power) need to be exchanged to determine the rank, this method increases the length of a control DIO message, raising the risk of division. This is an issue in LLNs when multi-path routing is used as separate paths taken by two fragments that belong to the same packet which raises the possibility of errors and packet loss. Additionally, the monotonicity property does not hold for the ELT metric; thus, the study suggests using ETX to create the DODAG and ELT to calculate node rank. For an already confusing Protocol, this adds more complexity.

In Bekelman et al. (2015), the authors identified the problem of RPL being a single parameter routing Protocol and also the inability to provide multipath routing for target functions. The ultimate objective of the research is to provide multi-path routing functionality for RPL, this must allow the Protocol to react effectively to the traffic in the network. The researchers suggest an extension named a multipath RPL (M-RPL) that offers many temporary ways of congestion. In M-RPL, the forwarding nodes detect congestion using the packet delivery ratio (PDR). When a forwarding node on a routing path senses that the PDR has dropped below a certain level, it utilizes DIO messages to deliver a congestion warning to its children. The child node that receives the notification about congestion advertising initiates multipath routing by halving its forwarding rate. Only a second packet is sent to the initial congested parent, while the others are sent to each of the other parents on the parent list. In terms of throughput, latency, and energy consumption, Cooja is used to assess the proposed Protocol and compared it to RPL-MRHOF. Their simulation findings demonstrate that M-RPL has greater performance and lower power consumption than RPL due to its splitting mechanism. The results reveal that while the M-RPL delay is initially compared to the RPL, it changes with the occurring of congestion. When several routes are included, M-RPL has increased latency at first, but this decreases as the network stabilizes. Because DAO messages are transmitted end-to-end, they are inefficient in terms of energy consumption and overhead.

In Tang et al. (2016), the authors propose a hybrid metric-based multi-path forwarding strategy. The authors point out that in situations where a sudden rise in traffic value creates congestion, resulting in substantial delay and PLR, the objective functions of the single-metric RPLs are vulnerable. The authors propose a multipath routing Protocol for congestion avoidance, called CA-RPL, whose primary objective is to allow the network to quickly and reliably respond to sudden events. To minimize the average latency towards the DODAG sink, known as DELAY ROOT, they built a mixed routing parameter in the Contiki-Mac duty-cycle Protocol. A node saves time just by learning the wake-up stage of its candidate parents under this parameter and then sends the packets to a first awake parent. To measure the route weights, CA-RPL is a hybrid multi-path routing metric that combines the current proposed DELAY ROOT with both the number of packets received and ETX. Cooja with Contiki OS is used to equate DODAG root's proposed method with the standard RPL in terms of, throughput, PLR, latency, and packet reception number (PRN) per unit time. The simulation results show that the CA-RPL decreases network traffic and increases the PRN by up to 50 percent, the throughput by up to 34 percent, the packet loss by up to 25 percent. Compared to RPL, the average delay was 30 percent. The Protocol proposed is based on Contiki-Mac which assumes that all nodes have identical wake-up intervals that may not be present in all LLN networks.

In Alishahi et al. (2018), the authors suggest "an optimization based on virtualization and software-defined networking techniques for RPL known as Optimized Multi-Class RPL (OMC-RPL)". According to the study, when it comes to maintaining QoS, traditional RPL has two fundamental flaws. The first is the lack of an objective function that is complete and thorough. Because all packets travel the same routes with the least delay, an objective function may improve latency at the price of greater power use. The second issue is that RPL will not accept a data categorization system, which is required for QoS to be maintained. As a result, a comprehensive, objective feature that can handle a wide range of data kinds is required. The OMCRPL steps are as follows: first, the nodes use one-hop communication to transmit the messages needed to construct their virtual DODAG to the SDN controller; second, the SDN controller uses a specific weighted-metric parameter objective function to determine the node ranges in the network by each traffic class. "The Propagation Delay (PD), Node Congestion (NC), and Link Congestion (LC) are the key parameters of the proposed objective function". Energy considers a secondary parameter and is thus integrated into the OF in such a way as to exclude or consider it as desired. The weight values of such objective function parameters were calculated using the Particle Swarm optimization process. OMC-RPL is simulated with four diverse load traffic groups and Objective Function Parameter weight values were found using the Particle Swarm Optimization (PSO) algorithm. Compared to the regular MRHOF objective function in terms of end-to-end latency, PLR, the network lifespan, and overhead traffic. In terms of the end-to-end delay for the traffic class that needs minimal delay, OMC-RPL then outperforms RPL and also shows better performance than RPL in terms of packet delivery ratio for the traffic class that needs reliability. It is also found that because it can use a backup parent to change a dropped one, OMCRPL responds better to network failures. In terms of network life, OMC-RPL outperforms RPL by up to 41 percent. The paper states that the combination of the SDN with OMC-RPL Protocol decreases the number of control messages exchanged by approximately 62 percent compared to both OMC-RPL and MRHOF Protocol and decreases power usage by up to 50 percent compared to MRHOF Protocol. For SDN-based OMC-RPL, the reporting period to the SDN is not specified, even though it may have a significant influence on the overhead control plane.

In Sousa et al. (2017), for IoT systems that include energy efficiency and transmitting data reliability, the paper suggests an ERAOF Protocol that combines node energy and link quality metrics. An Energy-Efficient and Path Reliability Aware Objective Function is proposed in this article (ERAOF). ERAOF is a modern RPL objective feature that focuses on node energy and link quality that seeks to simplify the routing mechanism to satisfy the needs of applications that demands energy efficiency and network performance. ERAOF is dependent on combining two metrics: ETX, and energy consumed (EC) as previously mentioned. ERAOF uses EC to make the RPL aware of network power usage. As a result, the Protocol will choose a route with a low chance of connection loss due to energy exhaustion. Simultaneously, using the ETX and ERAOF helps the RPL evaluate the connection quality between network nodes. This function will help improve network efficiency by reducing the usage of links with fewer conditions. The disadvantage is that the results didn't test the Protocol performance with the random deployment of the nodes; only the grid deployment is tested.

In Saaidah et al. (2019), by integrating multiple metrics of fuzzy logic, an improved (OF), OFRRT-FUZZY, is proposed. The suggested OFRRT-FUZZY considers link and node metrics. Received Signal Strength Index (RSSI), Residual Power (RE), and Throughput (TH) are the parameters. The OFRRT Protocol was developed with fuzzy logic to improve the efficiency of standard OFs and choose the most effective path to the sink node. The fuzzy inference process (FIP) is used in this proposed Protocol, which is defined as "a process of mapping from a given input to an output using fuzzy set theory" (Negnevitsky, 2005). The suggested solution uses three input linguistic variables to calculate a single output linguistic variable: (RE), (TH), and (RSSI). It includes four stages in the process 1- crisp input fuzzification, 2- rule evaluation, 3- rule output aggregation, 4- defuzzification. The OFRRT-FUZZY Protocol has a better performance in terms of energy consumption and PDR, but the performance of the Protocol was neither tested in large networks (smart big buildings environment) that contain more than 50 nodes nor for the Protocol performance with the random deployment of the nodes.

In Lamaazi et al. (2019), using the additive composition approach, the Protocol proposes a new flexible Objective Function dependent on Consumed power, ETX, and Forwarding delay (OF-ECF). This method allows for the development of a new composite metric that the nodes use to choose the right parent. Instead of many metric choices, it returns a single definitive point. The OF-ECF Protocol has a good performance in terms of PDR, but the results show that this Protocol consumes more energy than OF0 and MRHOF Protocols. We can conclude that this proposed Protocol is not suitable for Low Power and Lossy Network environments because it consumes large power than the original RPL Protocol.

In Lamaazi & Benamar (2019), the researcher proposes a new method for evaluating RPL efficiency. The OF and the trickle algorithm are the two key components, the RPL-FL means RPL based on the flexible trickle algorithm, and the RPL-EC means RPL-based combined ETX and power consumption. They introduce a new RPL objective function combination called OFEC in their paper, "objective function based combined metric using the fuzzy logic method". They use the hop count to route nodes to the root after combining two key metrics: power consumption and ETX. The method divides into 4 steps: first, the fuzzification process, which determines the membership degree of input parameters for fuzzy sets; second, the fuzzy intervention process, which measures the output based on merged inputs; third, the aggregation process, which unifies the outputs; and finally, the defuzzification process, which transforms the fuzzy outputs into a single defined value.

All the previous works did not take into account the load fmetric to divide the load between the nodes in the network, so we see that it did not solve the loss problems efficiently, while in our work we used the load metric and saw that it has a significant impact on the efficiency and stability of the network. In the proposed Protocol, we suggest a load metric depending on the number of children in each preferred parent. Based on that, we suggest a new OF that depends on three metrics (ETX, residual energy, and load metric) for the rank calculation. Each node should choose a node that has the maximum node residual energy, minimum ETX, and minimum load metric ($maxRE + minETX + minLoad$) when determining the parent, and building the DODAG from the preferred parent nodes. To increase the efficiency of the networks in IoT environments.

4 Proposed Protocol

The Objective Function (OF) determines how to construct the DODAG and selects the parents in the RPL network to optimize the path. The proposed objective function consists of three metrics to increase energy efficiency. This objective function focuses on issues like data traffic in multi-point to point communications. The bottle-neck occurs nearby the sink node. Becoming a chosen parent, for more children means unbalanced load, high congestion, more loss packet, and more overhead, thereby wasting its energy even faster than other preferred parents did. A load metric has been proposed to solve this problem and to solve the problem of flocking phenomena; providing each chosen parent with the number of children they have. Based on that, in the rank measurement, we take into consideration the number of children. We proposed a new objective function that takes many metrics (RE, Load, ETX) when calculating the rank. Every node when it selects parent and constructs the DODAG from the candidate parent, nodes should select the node that has minimum ETX, minimum load metric, and maximum node residual energy ($maxRE + minETX + minLoad$).

In general, ETX over the link can be defined as the expected number of transmissions that are required to send a packet over the communication link successfully. The ETX metric is calculated as follows Eq. (1):

$$ETXover = \frac{1}{DF \times DR} \tag{1}$$

Where DF: represents the probability of receiving a packet from the neighbor node successfully. DR: is the probability of receiving an acknowledgment successfully.

The ETX metric is additive, it adds ETX of each link as follows:

$$ETXlink(nodea, sinks) = ETXlink(nodea, nodeb) + ETXlink(nodeb, nodec) + ... \\ +ETXlink(noder, sinks) \quad (2)$$

When the value of ETX decreases, this means that the link quality increases.

As a representation of the network lifetime, we used the residual energy metric (RE). Therefore, when constructing DODAG and selecting a parent, every node should not select a parent that has low residual energy. Based on its various operating modes, the energy consumption of each node is calculated. These modes (as calculated in the cooja simulator) are usually listen mode which includes (listen +receive (RX) + idle modes), transmission mode (TX mode), processing mode (CPU mode), and low power mode (sleep mode). The current energy consumption can be calculated as Eq. (3) (Bhandari et al., 2020).

$$\begin{aligned} Econ(x) = P_{sleep}(x) \times T_{sleep}(x) + P_{Tx}(x) \times T_{Tx}(x) \\ +P_{cpu}(x) \times T_{cpu}(x) + P_{les}(x) \times T_{les}(x) \end{aligned} \quad (3)$$

Where, Econ(x)is the energy consumed by node x. P_{mode} is the power consumption modes (P_{les}, P_{Tx}, P_{cpu}, P_{sleep}). T_{mode} is the duration of time in each mode (T_{les}, T_{Tx}, T_{cpu}, T_{sleep}).

Tmode means the time duration that the node spends in each operating mode; while Pmode represents the power consumed in the corresponding mode in the given time. Then we can calculate the residual energy (RE) as the difference between the maximum node energy (Emax) and the current node energy consumed (Econ). Eq.(4) calculates RE (Bhandari et al., 2020).

$$RE(x) = EMax(x) - Econ(x) \quad (4)$$

Where RE(x)is the residual energy of the node (x), EMax(x)is the maximum energy of the node (x).

The network data traffic is a quantity of data transmission at a specific amount of time across the network. The load metric can be used to make a balance of the data traffic in the network. Depending on the number of children present throughout the parent node, the load is calculated Qasem et al. (2016). The DODAG nodes broadcast all participant nodes with a DIO message. The participant node or sender node computes each preferred parent for the number of children. Finally, based on the cumulative children number present, the DODAG generates the rank. The participant node selects the parent from the candidate parent list, based on the load metric. The load metric can be calculated as Eq. (5) and Eq.(6). Eq. (5) calculate the Load on path Px along the route between the current node and the sink node

$$L(Px) = \sum_{N=1}^{n} NT(N) \quad (5)$$

n is the number of nodes along the route between the current node and the sink node. Calculating node traffic based on the total number of children Eq.(6).

$$NT = \sum_{i=1}^{n} CN(i) \quad (6)$$

Where L(Px) represents the load on path x, NT represents the Node Traffic, and CN represents the Children Number. The load balance algorithm is represented below, i is the children number of the node.

In the proposed protocol we added 8 bytes to the DIO message, 4 bytes for the load metric, and 4 bytes for the RE metric.

Figure 1 represents the DODAG build and parent selection procedure.

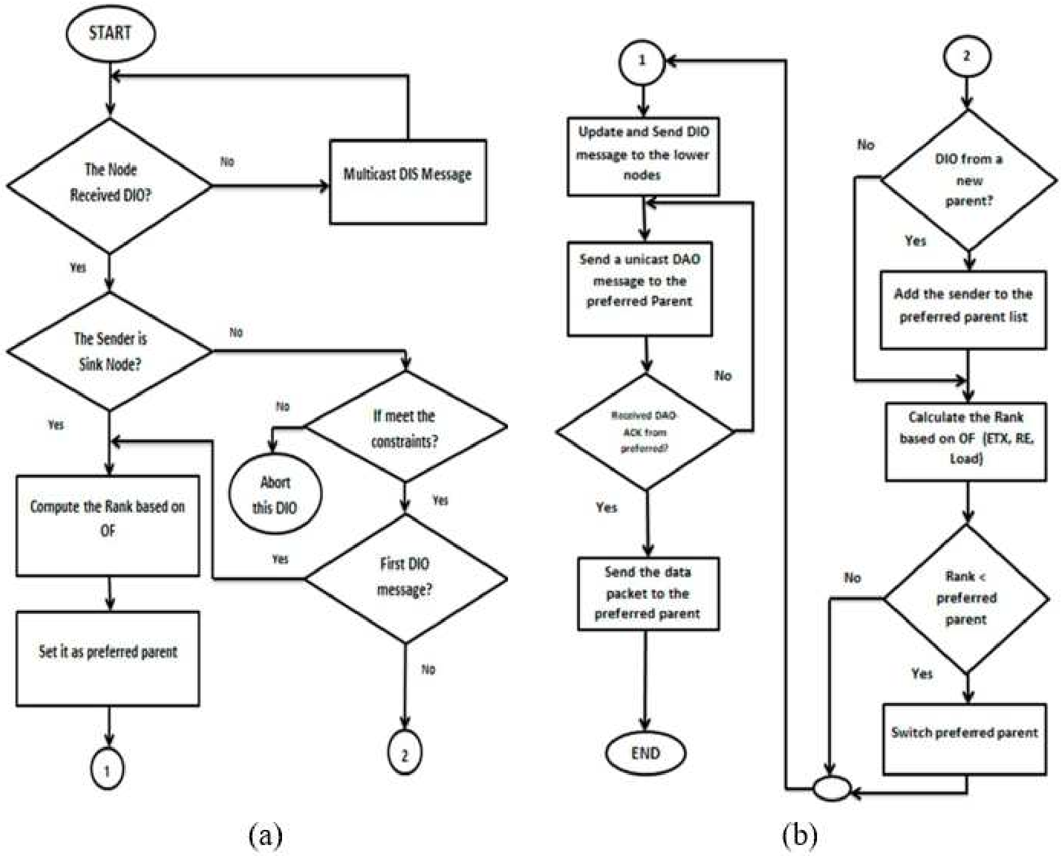

Figure 1: Proposed Protocol Network Build DODAG, Parent Selection, and Data Forwarding Mechanism

5 Simulation Result Analysis

In crowded networks, the MRHOF Protocol suffers from a very high delay and High packet loss ratio, but the proposed Protocol maintained high performance even in congested networks where the PDR was high and the packet loss ratio, the power consumption stayed low. The simulation area is 100 m2, simulation time is 1200 s. We implemented three topologies 50, 70, and 100 nodes with one sink node on the top of the network, because of the long hops, bottleneck problems, and high flocking phenomena, the network with MRHOF Protocol will suffer from high congestion, low PDR, high PLR, high retransmission, high delay, and high network power consumption, especially in the networks with 70, 100 nodes. Because of the highest efficient route selection in the newly proposed Protocol, the Protocol succeeded in solving these problems and maintaining high performance in all networks.

5.1 Packet Delivery Ratio (PDR)

Figure 2 shows the packet delivery ratio with the number of nodes. Each node sends 1 packet per minute in all scenarios.

In the crowded network (100 nodes) in the 100m2 simulation area, fig. 3 shows the received packet by the sink node for the MRHOF Protocol (PDR is 31.408 %). The network suffers from high packet delay and high retransmission, which causes duplicated packets (14 duplicated packets received by the sink node). Moreover, there are up to 20 nodes that don't deliver any packet to the sink node. While fig. 4 shows the received packet by sink node (PDR is 88.73%), the high performance of the proposed Protocol is shown clearly with high PDR.

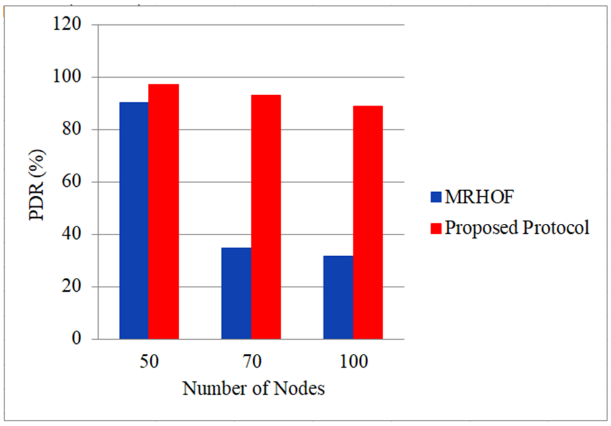

Figure 2: PDR of the Crowded Networks

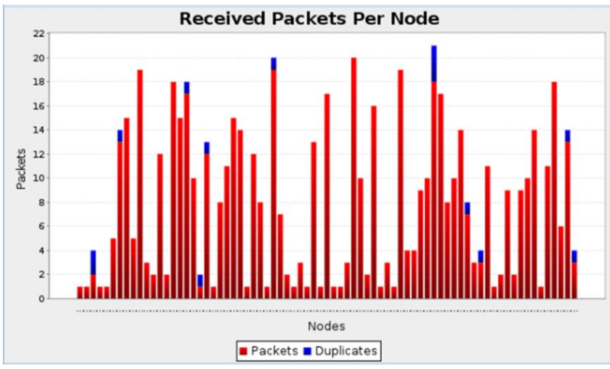

Figure 3: PDR of the MRHOF with 100 Nodes

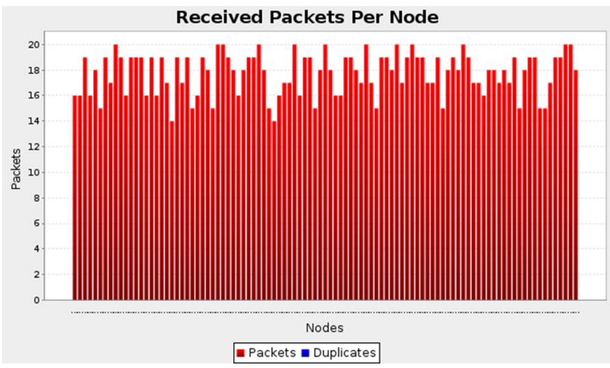

Figure 4: PDR of the Proposed Protocol with 100 Nodes

5.2 Packet Loss Ratio

Figure 5 shows the PLR with the number of nodes.

5.3 Total Power Consumption

Figure 6 shows that the Proposed Protocol consumes less power than the MRHOF Protocol, for various network topologies (50, 70, 100) nodes, the MRHOF Protocol is still performing poorly in terms of power consumption because of the high congestion causes high retransmission and high power consumption. Figure 7 shows the total power consumption for the MRHOF Protocol is 349.362 mW, the bottleneck nodes consume large power, which causes consumption of these nodes faster than others. Figure 8 shows that the total power consumption of the proposed Protocol is 226.512 mW and shows that in the proposed Protocol there is load balancing in the network, therefore, the node's power consumption is close together.

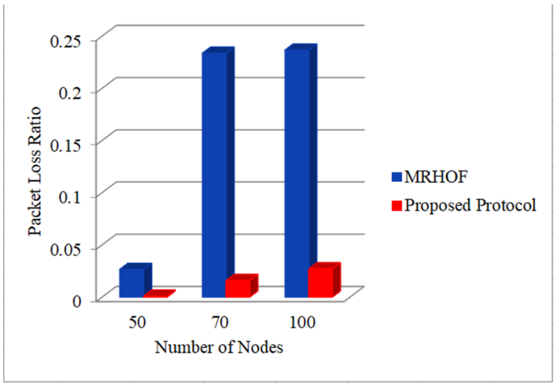

Figure 5: Packet Loss Ratio of the Crowded Networks

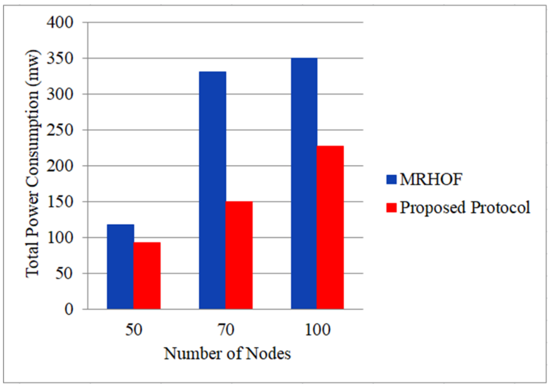

Figure 6: Total Power Consumption of the Crowded Networks

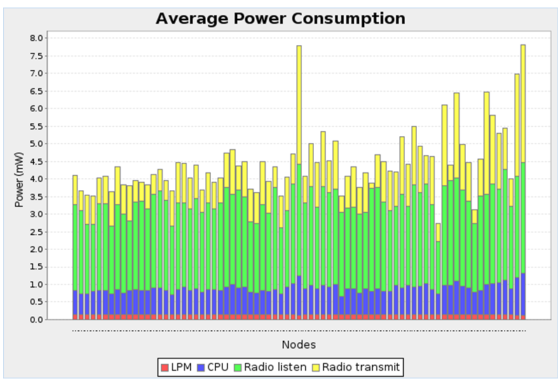

Figure 7: Network Power Consumption for the MRHOF with 100 Nodes

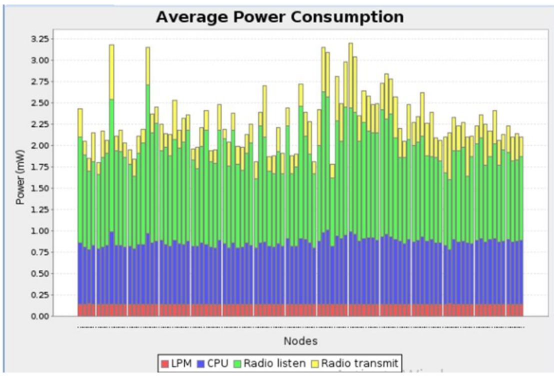

Figure 8: Network Power Consumption for the Proposed Protocol with 100 Nodes

6 Conclusion

By changing the method of calculating the OF, when constructing DODAG and selecting parents, we proposed development on the Minimum Rank with Hysteresis Objective Function (MRHOF). Thus, we proposed a way of considering three metrics instead of only one metric. In crowded networks, the MRHOF Protocol suffers from high congestion and high delay, but the proposed Protocol maintains a high performance. To evaluate our three topology networks, we generated an environment with randomly distributed nodes in a $100m \times 100m$ region using Cooja simulator/Contiki3. We implemented three topologies 50, 70, and 100 nodes with one sink node on the top of the network, because of the long hops, bottleneck problems, and high flocking phenomena, the network with MRHOF protocol will suffer from high congestion, low PDR, high PLR, high retransmission, high delay, and high network power consumption especially in the networks with 70, 100 nodes. Because of the highest efficient route selection in the new proposed protocol, the protocol succeeded in solving these problems and maintain high performance in all networks. With the network of 100 nodes PDR, the power consumption for the proposed Protocol is 88.73%, 226.512 mW; while the PDR is 31.408%, the power consumption is 349.362 mW for the RPL MRHOF Protocol. Therefore, we conclude that the objective function that takes only one metric is not sufficient and the objective function that takes more than one metric into account is more accurate and efficient. Load balancing is very important in the RPL networks to avoid congestion and delay. For future work the following points are suggested: Proposing an efficient trickle time algorithm that provides trickle DIO time to increase efficiency more. It would be fascinating to research the RPL behavior with mobility models. Designing an efficient RPL protocol in large-scale environments such as smart cities, where the nodes are combining static and mobile nodes.

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