Multi-Objective RPL to Support Heterogeneous Traffic for LLNs with Multiple Instances

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Abstract

RPL, an IPv6-based "Routing Protocol for Low Power and Lossy Network," addresses the popularisation of various real-time IoT (Internet of Things) applications designed to meet the varied requirements for sensor networks designed to support the unique characteristics of Low power and lossy Networks (LLNs). The hardest problems in the LLNs are considered to be data routing and traffic prioritisation. Numerous studies have demonstrated that Standard RPL performs very poorly to meet the Network Layer QoS requirements for the IoT network created by linking nodes that operate on a single instance's common objective function. It has a significant influence/effect on the claims of RPL in numerous scenarios for IoT applications, such as LLN with Multiple Instances for Supporting the Routing of Heterogeneous Data and traffic. To address this concern, we propose to build RPL with Multiple Instances within a single network which meets the demand for diverse data traffic and further enhances the performance of practical real-time applications. We built Multiple Instances (Traffic Classes) on the Contiki Operating System (OS), an open-source operating system for building the Internet of Things. To support the QoS differentiation at the network layer, the proposed Multi-Instance RPL defines three instances for three different types of data traffic classes. Each instance will demonstrate a different traffic class by adapting various Objective Functions, such as Objective Function 0 (OF0) and Minimum Rank with Hysteresis Objective Function (MRHOF), which select the appropriate routing metrics to choose the most suitable route for each RPL instance. Through simulations for three crucial routing performance indicators like Average Packet Delivery Ratio, Average delay and Average Energy Consumption, the effectiveness of the proposed mechanism is investigated. The obtained results outperform the standard RPL with an increased/ improved Packet delivery ratio and much lower latency for the priority traffic. Furthermore, we continue by stating that the results are much better if the NullRDC protocol is considered for Priority Traffic Class to meet the demands of High reliability and delay-constrained traffic.

Keywords

Internet of Things; RPL, Multiple Instances; Heterogeneous Traffic, LLNs, RDC and MAC Protocols.

1. Introduction

The development of IoT over the last few decades has spawned a variety of intriguing research areas focused on IoT communication. Bluetooth, Zigbee, and Low Power Wi-Fi are the most popular IoT communication protocols. 6LoWPANs are supplemented by the Low-Power and Lossy Networks (LLNs), including power, memory, and computational resource restrictions on embedded sensors. These connections are unstable, and prone to high packet loss and slow transmission speeds [1][2].

There are several challenges in evolving IoT and scaling it. One of the biggest challenges is routing because IoT operates in a wireless environment for which routing can be impacted/influenced by numerous elements i.e., energy, noise, etc.

The routing protocol to be developed for such networks needs to be highly dependable given the limited memory and energy constraints [3][4].

Routing over LLNs often makes use of RPL, which is an IPv6 Routing Protocol developed exclusively for LLNs and is the specification that has recently been implemented by the IETF. The difficulties associated with LLNs, incorporating constrained capabilities on various nodes with regard to memory, energy, and computation, unreliable connectivity paths, point-to-multipoint (P2MP) and multipoint to point (MP2P) data communication traffic types, and a huge count of nodes in terms of thousands , that may have constituted/been a member to this kind of networks, motivated the development of this protocol [5][6].

A lot of WSN’s protocols like LEACH, CTP, PEGASIS cannot support multiple applications while RPL on the other hand supports multiple applications. Thus, RPL is the chosen in the project.

2. About the Routing Protocol - RPL

The RPL-routing protocol represents the distance vector proactive routing approach for 6LoWPAN LLNs which separates the complete network topology

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into numerous intuitive graphical trees termed DODAGs (Destination Oriented Directed Acyclic Graph). Each DODAG is termed an RPL instance. Each RPL instance has a connected objective function which is needed to hone the network topology based on certain factors such as the smallest route and the goodness/ reliability of network linkages.[7][8]. The DODAG is centered at a node referred to as the root or sink node.

Since only the root node could communicate to the outside network, the root node in RPL, also known as the LBR (Border Router for LLN's), is responsible for communication between two networks. The LBR is a device that resides at the RPL network's edge and connects two networks. The LLN is connected to the outside world (most commonly, the IPv6 network or the Internet) via the DODAG root. In case a node cannot directly talk to the LBR, a multi hop mechanism is employed by using other nodes as parent nodes. To effectively transmit information between any sender node and LBR in the IoT network/ topology/ structure, the parent selection procedure is crucial in the network deployed through RPL.

Control messages typically are important management packets that help to create and update routing information within a network. The trickle timer algorithm along with these messages is used to maintain the network.

The following are the several categories of RPL control messages:

i. DODAG Information Object (DIO) –helps to establish/build, maintain, and find the DODAG.
ii. DODAG Information Solicitation (DIS) – sent from the new nodes requesting to connect and participate in the network
iii. DODAG Destination Advertisement Object (DAO) – optional packets and help to establish downward routes [8]

The RPL network arranges the nodes in such a manner that it has routes of all the nodes down to it. Routing in RPL can be done in two ways:

Routing Upwards-Routing the traffic upward by a node is done by directly sending the packet to its favoured parent which then continues to send it to its parent till the root is reached.

Routing Downwards-Routing is done through a routing table maintained at each node (storing mode) or root node (non-storing mode). Downward traffic is used for control, extraction and end-to-end messages [9].

Routing strategies in RPL are defined by users using objective functions (OFs). The OF can be used to define how a node selects its favored parent and how the computation of the node's rank is done. MRHOF and OF0 are the standard objective functions used for routing in RPL. The expected transmission count (ETX) measure is used by MRHOF by default. ETX considers the frequency of packet transmissions requires to arrive at its destination error-free. OF0 applies the 'step of rank' to determine how much to raise the rank alongside a certain connection using either considering Hop Count or ETX [10][11].

Because default OFs in RPL only take into account one metric, routing performance may suffer, especially for IoT applications that have various quality of service (QoS) needs in a single network. Additionally, because these OFs were primarily created for networks with little data flow, they have significant issues in large networks. Despite the idea that the RPL implementation allows for the use of several metrics to choose the favored parent, no predetermined criteria for a metric combination is specified [12].

a. DODAG Formation in RPL

The process of forming DODAGs begins with the LBR broadcasting DIO control packets to nearby nodes, which contain information such as rank and distance values of the current and other nodes, including the root. This information is used to construct the DODAG [12].

Upon receiving the DIO packet, neighboring nodes will assess their rank relative to the root, select the root as the next hop, and forward the packet to their neighboring nodes. In the same way, the receiving nodes will choose their next hop to the root based on the information in the packet they received. This process continues until the last node joins the DODAG [13].

The RPL protocol operates by exclusively generating pathways that direct traffic towards the root node. In order to enable downward traffic and allow for accessibility to the parent nodes, a node must initiate the transmission of a Destination Advertisement Object (DAO) to its parent, which contains information regarding the prefixes of nodes within its sub-DODAG. Once this message reaches the root, the prefixes are aggregated. Additionally, RPL nodes are capable of issuing DODAG Information Solicitation (DIS) messages to their neighboring nodes in order to request DIO messages. The process of creating a DODAG in RPL is illustrated in Figure 1.

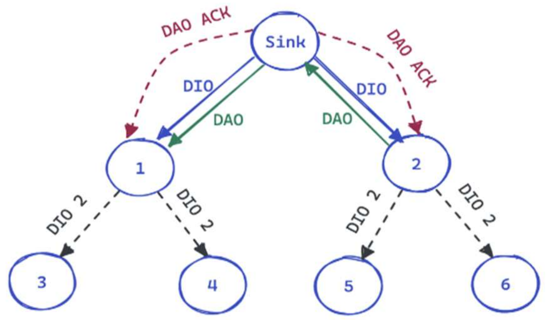

Fig. 1. DODAG formation in RPL.

b. Instances in RPL

An instance in RPL may be composed of one or more DODAGs. These instances are a logical grouping of DODAGs. Each DODAG may belong to a single RPL instance and all DODAGs belonging to a DODAG will have a unique RPLInstanceID. These DODAGs in an instance are identified by a unique DODAG ID. Which is used to validate the DODAG integrity. These parameters are exchanged through the IPv6 protocol in RPL [14].

An RPL node can join any DAG as long as each of these DAGs belong to different instances. Each RPL instance has a distinct OF that enables it to construct and classify various DODAGs inside the same physical topology.

c. RPL Multi-Instance

In actuality, varying applications may produce dissimilar kinds of network traffic, each with its own Quality of Service (QoS) prerequisites. In response to such traffic, the RPL protocol allows for the establishment of numerous instances, each with a distinctive objective function, within a single network. A single physical network can support a wide range of routing topologies and routing metrics. Each node in a multi-instance RPL network must maintain multiple routing tables for each objective function. Therefore, when a packet arrives, the leaf node is required to identify the particular instance it needs to join and subsequently look for the suitable entry in the routing table to direct the packet towards. [12][15].. Fig. 2 illustrates the typical architecture of a multi-hop LLN. The LLN border router, or LBR, serves as the connection between the 6LoWPAN-enabled network and the public network or Internet. While RPL does not inherently provide support for multiple instances. To handle multiple instances, we modify the default protocol and routing methods.

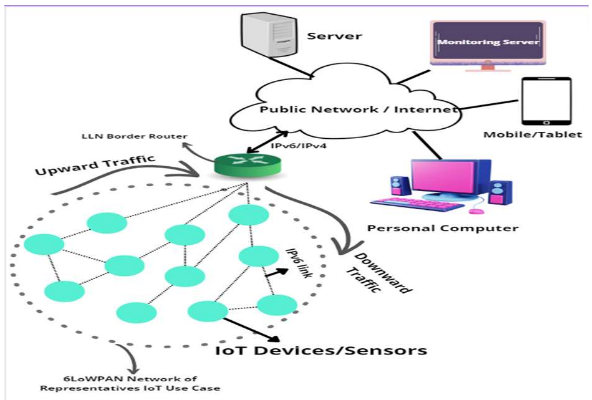

Fig. 2. An example of a multi-hop LLN architecture.

3. Related Works

As QoS differentiation is not allowed by the primary OF and associated metric of RPL, it is unoptimized for Smart Grids, making RPL unoptimized for Smart Grids, even though standards recommend using RPL for command distribution over smart grids. Nassar et al., 2017 [16], in their paper “Towards Multi-instances QoS Efficient RPL for Smart Grids.” Propose OFQS. OFQS is an objective function that adapts automatically to the different traffic classes and based on the various smart grid requirements, provides a QoS differentiation. The multi-objective metric used by OFQS takes into account the battery nodes' available energy as well as delay and network quality. With a longer network lifetime, this proposal offers a higher packet delivery ratio and a low latency

Mardini et al., 2021 [18] created multiple RPL instances and grouped data based on the traffic class. The first instance dealt with only critical data, while the second dealt with low-priority and periodic data. Multi-instance RPL outperformed single instance in average PDR of all RX values. Their approach also showed marked improvement for critical data traffic over single instance RPL. The average latency is also significantly improved.

Bhandari et al., 2020 [19] propose different OFs. This is to guarantee that network-level QoS differentiation takes place. Virtually, the actual network is divided into several RPL instances, and various types of traffic can be included into each instance using different OFs. They also suggested a new framework for selecting parents based on a multi-attribute approach to decision-making. Their parent selection framework considers different metrics' benefit and cost criteria to respond to the flocking effect. Their method significantly reduces packet loss, delays, and reliability issues with QoS provision. In comparison to default RPL, it also ensures minimum overhead and network stability.

In their 2019 paper "Using of Multiple RPL Instances for Enhancing the Performance of IoT-based Systems," Al-Abdi et al. [15] present the benefits of supporting multiple RPL instances. Through simulations using the Cooja simulator, they establish a baseline of improved performance in terms of Packet Delivery Ratio across all RX values and traffic types when multiple RPL instances are used. Their study highlights the unsuitability of a single RPL instance for critical data traffic.

Bouzebiba and Lehsani propose a new objective function, named FreeBW, in their 2020 paper "FreeBW-RPL: A New RPL Protocol Objective Function for Internet of Multimedia Things," to enhance the RPL protocol. The FreeBW function uses FreeBW computation at the network layer to select a routing path based on the bandwidth required for QoS routing. A distributed method is used to measure the FreeBW value, which determines the available free bandwidth. The proposed FreeBW-RPL function improves multimedia applications by delivering better performance in terms of Packet Delivery Ratio, end-to-end delay, throughput, and energy consumption compared to RPL. This improvement is achieved by dynamically selecting the optimal forwarding candidate based on available free bandwidth information provided by the ascending nodes. This approach reduces congestion by switching to the least congested paths.

In his 2019 paper, Brandon Foubert [22] proposes a technique to provide redundancy for border routers using a virtual Destination-Oriented Directed Acyclic Graph (DODAG). This enables multiple border routers to participate in a single DODAG, with their DODAG parameters synchronised. This permits a congested border router to divert traffic to a neighbouring one, which offers better results than using the RPL protocol alone. This method enhances the overall end-to-end and Media Access Control (MAC) delivery ratio by reducing the number of link layer errors.

4. Proposed Approach

Our proposal involves the introduction of three distinct instances, which we have named M-Instance-1, M-Instance-2, and M-Instance-3, each designed to handle specific types of traffic, i.e., critical, non-critical, and periodic. We then compared Instances-1 and 2 to a standard RPL protocol running two separate instances, one using the MRHOF objective function to support the ETX metrics for critical and non-critical traffic and the other using the OF0 objective function to support the HC metrics for periodic traffic, as implemented in Instance 3.

a. Experimental Setup

As Contiki OS does not inherently support multiple RPL instances, we developed an implementation that does support multiple instances and improved upon it. Our focus was on upward traffic, and we ignored downward traffic. We used NullRDCMAC to augment ContikiMAC for critical data traffic in the multiple instance setup, while MRHOF and OF0 served as the objective functions for critical and non-critical traffic and periodic traffic, respectively. Figs. 4 and 5. depict the experimental setups used for single and multiple instances, respectively. In scenario 1, we used the default settings of Contiki OS for the MAC and RDC protocols, such as CSMA and ContikiMAC, respectively. In scenario 2, we used multiple instances for critical traffic and adapted the NullRDC protocol. Fig. 3. shows the proposed traffic classes and protocol stack for single-instance RPL, while Fig. 4. shows the proposed traffic classes and protocol stack for multiple RPL instances.

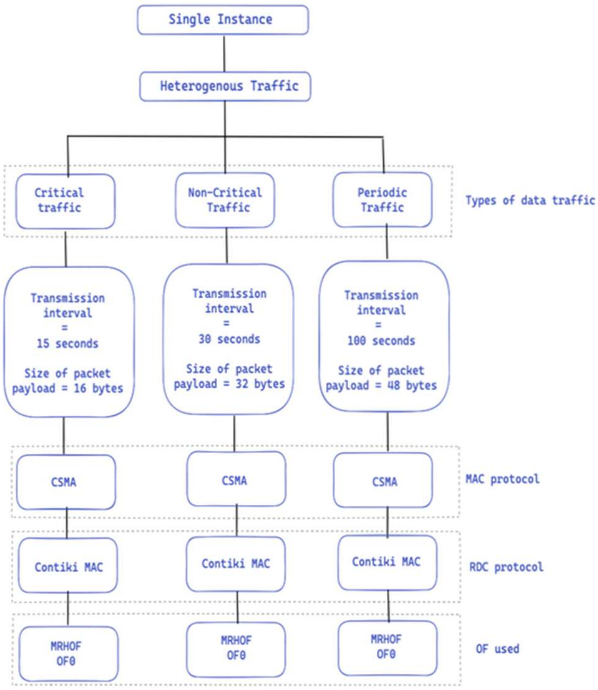

Fig. 3. Experimental setup for single instance traffic

b. Simulation methods and Experiments

To evaluate and analyze the proposed strategy, A group of simulation experiments were run on the Cooja simulator hosted on a machine with Contiki 3.0 OS. An emulation was made of a network consisting of 38 Zolertia motes, with a single DODAG root located at the Centre. The motes were distributed in a specific pattern over an area of 200m by 200m. fig.5. shows the network topology created for experimentation. The network grouping is constituted of 38 client nodes, all of which are positioned systematically around the central server. The client nodes transmit UDP packets following the sending intervals for various instances as described in Table 1. The radio transmission and the interference ranges were mapped at 50 and 100 meters, respectively. The reception success ratio varies between the range of 20% to 100%, while the transmission success ratio is kept constant at 100%.

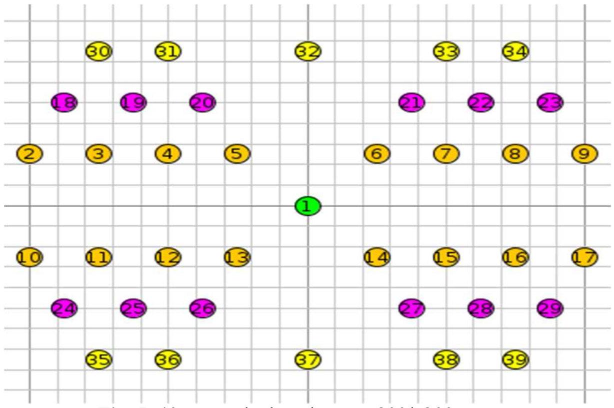

Fig. 5. 40 motes deployed over a 200* 200 metres area.

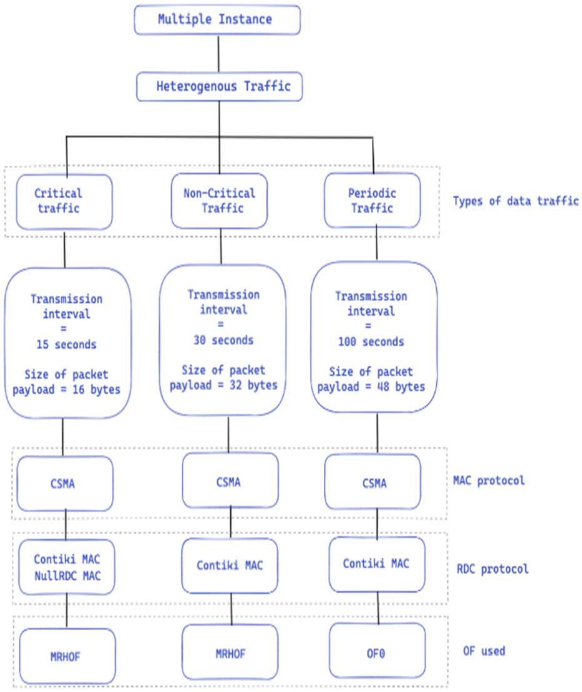

Fig. 4. Experimental setup for multiple traffic instances

TABLE 1: VALUES SUGGESTED FOR TRANSMISSION INTERVALS AND PROPOSED PACKET PAYLOAD SIZE.

RPL Instances	Motes Count	Type of Data Traffic	Transmission Interval	Size of a Packet Payload	Objective Function
Instance 1	16	Critical	15 Seconds	16 Bytes	MHROF (ETX)
Instance 2	12	Non-Critical	30 Seconds	32 Bytes	MHROF (ETX)
Instance 3	10	Periodic	180 Seconds	48 Bytes	OF0 (HC)

Table 2 illustrates the simulation parameters. The simulation was run for 45 minutes, and the final results were averaged over quite a few random runs

TABLE 2: NETWORK SIMULATION ENVIRONMENT AND THEIR VALUES

Simulation Environment	
Simulation Parameter	**Values**
Type of Operating System	Contiki 3.0 / Ubuntu 21.04
Mote Device Model	Z1 Zolertia
Objective Function (OF)	MHROF – ETX, OF0 – Hop Count
Wireless Channel	Loss of Distance in the Unit Disk Graph Medium (UDGM)
Deployment Coverage Area	200 X 200 m
Simulation duration	2700 Seconds
Transmission Range for every Instance	50 m
Interference range for every Instance	100 m
Transmission Ratio	Fixed at 100 %
Reception Ratio	Varying from 30%, 50%, 70%, 85%, and 100%
Number of Sender Nodes	38
Number of Sink Node	2
Network Layer	IPv6, ContikiRPL
Adaption Layer	6LoWPAN
MAC Layer	CSMA with Collision Avoidance
Radio-Duty Cycle	NullMAC and ContikiMAC
Physical Layer	IEEE 802.15.4 (Channel 26), CC2420 2.4 GHz

SCENARIO 1: RPL INSTANCES SET UP WITH CONVENTIONAL MAC AND RDC PROTOCOL

RPL Instances	**Type of Data Traffic**	**Objective Function**	**MAC Protocol**	**RDC Protocol**
Instance 1	Critical	MHROF (ETX)	CSMA	ContikiMAC
Instance 2	Non-Critical	MHROF (ETX)	CSMA	ContikiMAC
Instance 3	Periodic	OF0 (HC)	CSMA	ContikiMAC

SCENARIO 2: RPL INSTANCES CONFIGURED WITH VARIOUS RDC AND MAC PROTOCOL

RPL Instances	**Type of Data Traffic**	**Objective Function**	**MAC Protocol**	**RDC Protocol**
Instance 1	Critical	MHROF (ETX)	CSMA	NullMAC
Instance 2	Non-Critical	MHROF (ETX)	CSMA	ContikiMAC
Instance 3	Periodic	OF0 (HC)	CSMA	ContikiMAC

TABLE 3: PROPOSED APPROACH TO SUPPORT MULTIPLE RPL INSTANCES

Instance Classification	**Type of Data Traffic**	**Maximum allowed Delay**	**Reliability**
Instance 1	Critical	5 seconds	90% to 100%
Instance 2	Non-Critical	5 seconds	No strict reliability constraints
Instance 3	Periodic	1 to 5 minutes	90% to 100%

5. Experimentation Results and Interpretation

In this research, we evaluate the effectiveness of the Routing Protocol for Low-power and lossy networks (RPL) across various radio link quality conditions, both for a single instance and multiple instances. We assess the effectiveness of RPL using default Objective Functions (OFs) with a single instance and our proposed multiple-instance RPL with diverse OFs. To evaluate the routing performance, we use various metrics such as packet delivery ratio (PDR), average end-to-end latency, and throughput. Furthermore, we also compare the performance of heterogeneous data traffic for the multiple-instance RPL.

Packet delivery ratio (PDR) measures the percentage of packets that are successfully received by the intended receiver in comparison to the total number of packets sent by all network nodes. We use Equation 1 to compute the PDR, which serves as an indicator of network quality [9].

$$PDR = \frac{Total\ Packets\ recieved}{Total\ Packets\ sent} \times 100$$

Equation 1. Calculation of PDR

End-to-end latency is the amount of time taken from the moment packets are sent by the source node to when they are received by the sink node. Meanwhile, the average latency is a measure used to evaluate the overall latency of the network. [9].

Energy consumption of a node is defined as the amount of energy a node consumes/ spends when communicating with other nodes (for data transfer or control message transfer). It is an important aspect to be measured as these nodes are constrained in nature [25].

a. PDR

Our analysis indicates that the Packet Delivery Ratio (PDR) of the instance supporting Multi-Parent Routing Objective Function (MRHOF) exhibits superior performance when compared to the instance supporting Objective Function 0 (OF0). Furthermore, we conducted experiments with varying packet reception ratios of 30%, 50%, 70%, and 100% on both MRHOF and OF0 objective functions. Our results demonstrate that MRHOF outperforms OF0 in both scenarios. Fig. 8 presents a comparative analysis of the PDRs achieved by MRHOF and OF0. The Multi-Parent Routing Objective Function (MRHOF) is a routing mechanism that enables multiple-parent nodes to contribute to the transmission of packets towards the destination node, thereby enhancing the network's routing efficiency. Conversely, Objective Function 0 (OF0) is a standard routing mechanism that uses a single-parent node to transmit packets to the destination node. Our research illustrates that MRHOF's superior performance can be attributed to its ability to leverage the collective intelligence of multiple-parent nodes in routing packets, resulting in enhanced PDRs.

Furthermore, we conducted experiments with varying packet reception ratios to evaluate the robustness of MRHOF and OF0 in diverse network conditions. Our findings reveal that MRHOF performs consistently well across different packet reception ratios, indicating its suitability for deployment in networks with varying link quality. In contrast, OF0 exhibits inconsistent performance across different packet reception ratios, resulting in a lower PDR. The comparison between MRHOF and OF0 with respect to PDR is presented in Fig. 8.

Scenario 1: RPL instances set up with default conventional MAC and RDC Protocol

By default, RPL instances are set up with conventional MAC and RDC protocols. The conventional MAC protocols, such as CSMA and TDMA, are utilized to regulate communication among different devices in a network. In the case of a wireless network, CSMA/CA (Collision Avoidance) protocol is typically used to reduce collisions when multiple devices try to access the shared wireless medium.

The RDC protocol, on the other hand, determines when a device should be in a sleep mode or active mode to conserve energy. The conventional RDC protocol follows a simple duty cycling scheme, where a device periodically wakes up to listen for incoming messages, and then goes back to sleep mode to conserve energy.

When setting up RPL instances with default conventional MAC and RDC protocols, the protocol parameters are typically set to default values. These parameters determine the behavior of the protocol and the communication between different devices in the network. The default settings are usually selected depending on the wireless network's needs and anticipated amount of data traffic.

Overall, setting up RPL instances with default conventional MAC and RDC protocols provides a basic setup for LLNs. Nevertheless, in certain situations, it may be necessary to develop tailor-made MAC and RDC protocols to enhance network performance and satisfy the specific demands of the application.

During the experiments, it was observed that when using a single RPL instance and the reception ratio (RX) was less than 70%, the overall packet delivery ratio (PDR) decreased significantly due to poor link quality. Specifically, for Critical and Non-critical traffic, the obtained PDR was below 50%. However, when using the proposed RPL with Multiple Instances, the PDR for Critical and Non-critical traffic remained consistently above 90%, even at lower RX ratios.

When the Hop Count metric (OF0) was chosen for Periodic traffic type in the Multiple instance approach, the PDR values were high even at lower RX ratios. Fig. 9 illustrates the average PDR for different data traffic classes, including Critical, Non-critical, and Periodic traffic within a single instance network and a Multiple Instance network. It was observed that the PDR for Critical and Periodic traffic with Multiple Instances was higher than that of Single-Instance.

Overall, the proposed Multiple Instance approach demonstrated better PDR performance for Critical and Non-critical traffic compared to the Single-Instance approach, especially at lower RX ratios. Furthermore, the use of the Hop Count metric in the Multiple Instance approach showed higher PDR values for Periodic traffic type, even at lower RX ratios. These findings suggest that the proposed Multiple Instance approach with the appropriate objective function selection can improve the reliability and efficiency of data transmission in LLNs.

Scenario 2: RPL Instances configured with NullRDC and MAC Protocol

In addition to the default conventional MAC and RDC protocol, RPL instances can also be set up with NullRDC and MAC protocol. NullRDC is a protocol for radio duty cycling that enables nodes to switch off their radio during periods of inactivity, thereby reducing energy consumption. The MAC protocol manages the wireless medium by regulating the way nodes access it, ensuring that nodes do not interfere with each other and avoiding collisions. The combination of NullRDC and the MAC protocol reduces energy consumption and improves network efficiency in LLNs.

When RPL instances are configured with NullRDC and the MAC protocol, the performance of the network can be evaluated in terms of various metrics such as packet delivery ratio (PDR), average end-to-end latency, and throughput. These metrics provide a measure of the effectiveness of the protocol in delivering data packets with minimal delay and maximum reliability.

In general, the utilization of NullRDC and MAC protocol in RPL instances presents a hopeful resolution for achieving effective and dependable communication in LLNs. Such a strategy delivers noteworthy benefits regarding the consumption of energy, longevity of network performance, and the successful delivery of data packets.

In scenario 2, the Multiple Instances for Critical Traffic have been set up with the NullRDC protocol. This means that the radio is always turned on for the transmission of Critical Traffic, without considering the fact that it may lead to higher energy consumption. The results of this configuration have been presented in Fig. 10, which shows a comparison between the PDR of the Single Instance and the Proposed Multiple Instances with NullMAC. It should be emphasized that the Packet Delivery Ratio (PDR) is a crucial measure that indicates the proportion of packets received by the intended node compared to the overall number of packets sent by the initiating node.

The analysis reveals that in the case of a single instance with a Reception Ratio (RX) lower than 70%, the overall PDR decreases significantly due to the poor link quality. As a result, the obtained PDR is below 50% for Critical and Non-critical traffic types. The implementation of the proposed RPL protocol with Multiple Instances configured with NullRDC has proven to be significantly effective in maintaining a higher Packet Delivery Ratio (PDR) for both Critical and Non-critical traffic types, even at lower Reception Ratios (RX). This outcome signifies that the Multiple Instances approach offers better performance in terms of PDR compared to the Single Instance approach. It is worth mentioning that within the proposed Multiple Instances approach, the NullRDC protocol is used, which keeps the radio always on for the transmission of Critical Traffic. Although this approach leads to higher energy consumption, it ensures that the Critical Traffic is delivered with higher reliability. Additionally, it should be noted that the proposed Multiple Instances approach can be extended to other types of traffic and protocols, This could potentially generate varying outcomes based on the state of the network and the precise prerequisites of the given application.

The performance comparison between scenarios 1 and 2 regarding PDR is exemplified in Fig. 11. The figure shows that the proposed Multiple Instances with NullRDC protocol significantly outperforms the conventional Single Instance approach, with consistently higher PDR values for all traffic types at various Reception Ratios (RX).

The findings suggest that the proposed Multiple Instances approach with NullRDC protocol is a better choice for routing Critical Traffic, as it ensures a higher PDR and thereby reduces the likelihood of packet loss and end-to-end delay. However, it is important to note that using the NullRDC protocol can lead to increased energy consumption, as it keeps the radio module continuously active for transmitting Critical Traffic.

Overall, the PDR results suggest that the proposed approach can effectively mitigate the negative effects of poor link quality on network performance. The findings further support the notion that selecting an appropriate MAC and RDC protocol can significantly impact the reliability and efficiency of the routing protocol, particularly for critical traffic.

b. Average Latency

During our performance evaluation of the proposed multiple instances approach for all types of traffic, including critical, non-critical, and periodic, and with reception ratios ranging from 30% to 100%, we found that the proposed method outperformed the single-instance RPL. We also compared the average latency of the objective functions MRHOF and OF0 for single-instance traffic and observed that MRHOF significantly outperformed OF0.

The proposed multiple instances approach demonstrates an average latency of approximately 0.1% of the latency of the single-instance RPL. This indicates that the proposed technique significantly reduces the latency in comparison to the existing approach. Table 4 presents a comparison of the average latency results between the proposed and existing approaches.

It is worth noting that reducing latency can be beneficial in various applications, such as time-sensitive applications like remote surgery or industrial automation. The proposed technique offers a significant advantage in reducing the end-to-end delay and improving the overall performance of the system. The reduced latency results from the effective routing of packets through the network using the MRHOF objective function, which considers the reliability of links in addition to hop count.

Furthermore, the proposed multiple instances approach provides a scalable solution for handling different types of traffic and network conditions, this attribute renders it appropriate for IoT networks on a large scale. The approach also allows for the customization of the routing protocols for specific traffic types, allowing for efficient utilization of network resources.

In summary, the proposed multiple instances approach outperforms the single-instance RPL approach in terms of average latency and packet delivery ratio for all types of traffic, making it a promising solution for improving the performance of IoT networks.

c. Average Energy Consumption

The results obtained from the experiments are presented in Figs. 12, 13, and 14. These figures clearly indicate that the single instance approach with MRHOF performs Superior with regards to energy consumption than the single instance approach with OF0. Moreover, it is observed that the multiple-instance approach for both scenarios 1 and 2 ensures significantly lesser average energy consumption values than the single-instance approach at all reception ratios.

The reason behind this improved energy efficiency can be attributed to the fact that MRHOF considers the quality of communication links, which is ignored by OF0. As a result, MRHOF can establish better and more reliable communication paths that require fewer retransmissions, especially at lower reception ratios. This ultimately leads to a significant reduction in energy consumption. This finding is in line with previous studies that have reported the effectiveness of MRHOF in improving energy efficiency in low-power wireless networks [29]. It is worth noting that the multiple-instance approach further enhances the energy efficiency of the network as it provides multiple parallel paths for data transmission, thereby reducing the burden on any single path. This, in turn, ensures that the network can operate with a higher degree of reliability and fault tolerance, which is crucial for mission-critical applications. In summary, the results presented in Figs. 12, 13, and 14 demonstrate that the proposed multiple-instance approach with MRHOF outperforms the existing single-instance approach with OF0 in terms of energy efficiency, especially in scenarios with lower reception ratios.

TABLE 4: COMPARISON OF AVERAGE LATENCY

Successful Reception Ratio	**Type of Data Traffic**	**Single Instance**		**Proposed Multiple Instances**
		OFO	MRHOF	
100%	Overall Traffic	33.6	30.4	0.0273
85%	Overall Traffic	37.1	32.7	0.0281
70%	Overall Traffic	39.8	34.5	0.0314
50%	Overall Traffic	41.5	37.8	0.0348
30%	Overall Traffic	43.1	40.1	0.0375

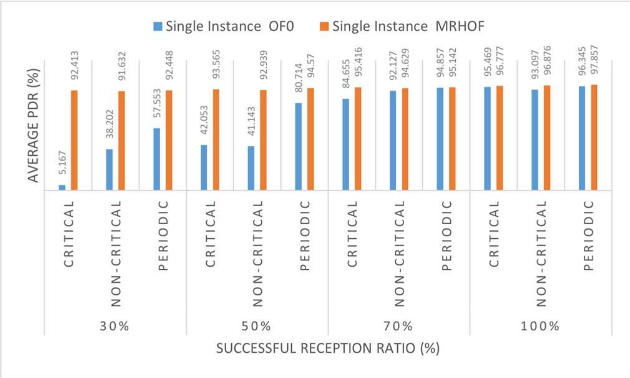

Fig. 8. PDR for Single Instance for different Objective Function like OF0 & MRHOF.

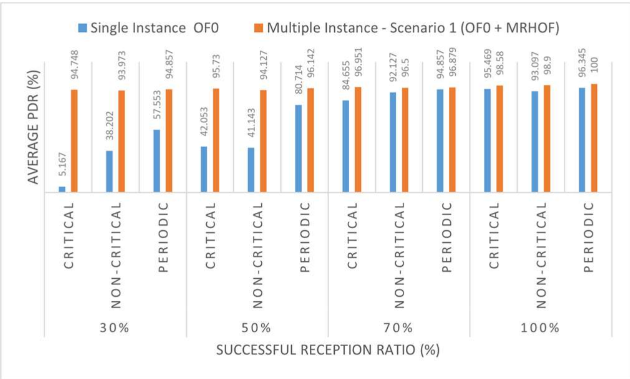

Fig. 9. PDR for Single Instance and Proposed Multiple Instance Scenario 1

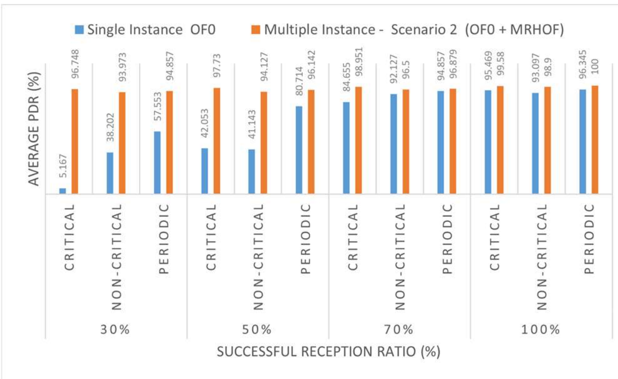

Fig. 10. PDR for Single Instance and Proposed Multiple Instances with NullMAC

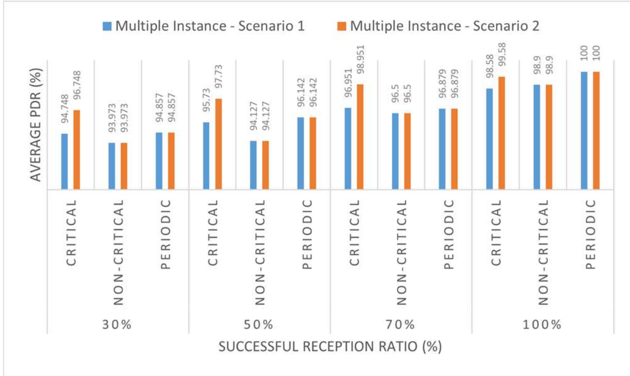

Fig. 11 PDR for Proposed Multi Instance – Scenario 1 & 2

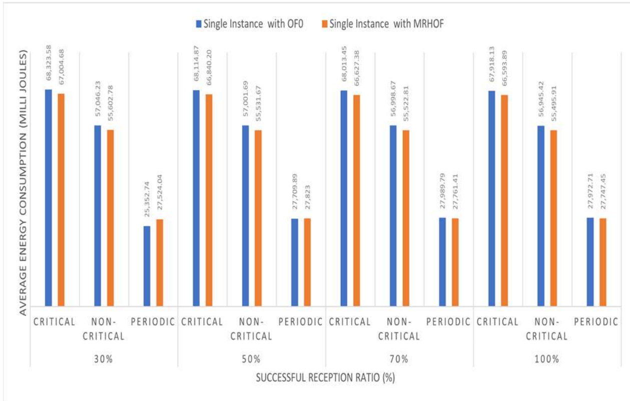

Fig. 12. Average Energy consumption for Single Instance for different Objective Function like OF0 & MRHOF

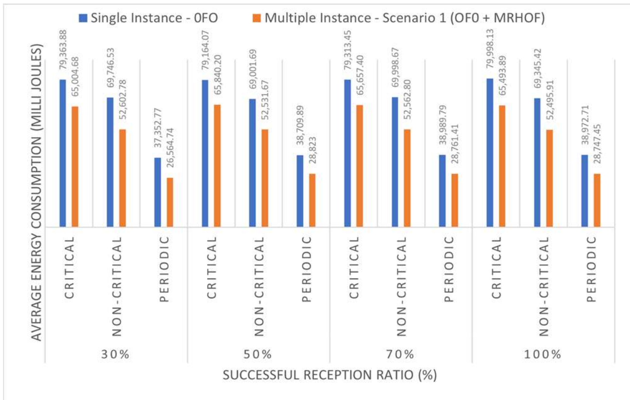

Fig. 13. Average Energy consumption for Single Instance and Proposed Multiple Instance – Scenario 1

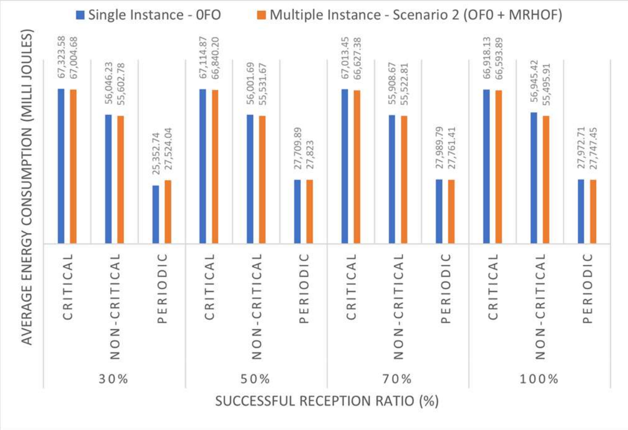

Fig. 14. Average Energy consumption for Single Instance and Proposed Multiple Instance – Scenario 2

6. Conclusion

In this study, we present a novel approach to efficiently handle heterogeneous traffic in Multiple Instances of LLNs. The problem of multiple traffic types generated by different applications is identified, and a new routing approach is proposed by modifying the existing RPL protocol designed for a single type of data traffic to support multiple instances.

To evaluate the proposed approach, we investigate the performance of two different objective functions, MRHOF and OF0. Our findings suggest that MRHOF outperforms OF0 in most cases, indicating the importance of considering the quality of communication links in routing.

We also examine the impact of using NullRDC MAC instead of Contiki MAC for critical data traffic. Our results show that NullRDC MAC provides superior results in terms of parameters such as latency, throughput, and PDR, although it leads to relatively higher energy consumption.

Overall, our approach builds on the single instance RPL by using two different OFs for different traffic classes. Specifically, we suggest the use of MRHOF as the OF for critical and non-critical traffic and OF0 as the OF for periodic data traffic. Additionally, we propose the use of the NULLRDC MAC protocol in combination with Contiki MAC in the MAC layer for critical data traffic.

In conclusion, our proposed technique provides an efficient data dissemination method for handling multiple traffic types in Low Power and Lossy networks. The use of multiple instances, different OFs, and NullRDC MAC protocol contributes to a significant improvement in the network's performance, particularly for critical and non-critical traffic.

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