RPL-Based on Load Balancing Routing objective Functions for IoTs in Distributed Networks

Zibuyisile Magubane
Computer Science
University of Zululand
KwaDlangezwa 3886, South Africa
buyinkomose@gmail.com

Paul Tarwireyi
Computer Science
University of Zululand
KwaDlangezwa 3886, South Africa
p.tarwireyi@gmail.com

Adnan M. Abu-Mahfouz
Council for Scientific and Industrial Research (CSIR)
Pretoria 0184, South Africa
a.abumahfouz@ieee.org

Mathew .O Adigun
Computer Science
University of Zululand
KwaDlangezwa 3866, South Africa
adigunmo@gmail.com

***Abstract*—Internet of things (IoT) is a developing technology that enables the devices to communicate without human interaction. Routing is an important factor affecting the connectivity and the performance of information exchange. The performance of IoT devices is dependent on the implemented routing protocol in those devices. Routing protocol for low power and lossy networks (RPL) is rated as the best communication protocol for IoT devices. The protocol uses its default objective function and routing metrics to transmit packets from source node to destination. As the number of connected devices continues increasing, the child nodes forward the floods of packets to the nearest parents. Due to the default objective function and routing metrics of RPL that does not consider load balancing, leads to network congestion. This paper classifies the routing protocols and objective functions proposed to solve the load balancing problem that affecting RPL in Low power and Lossy Network (LLNs). Furthermore, it analyses the performance of RPL-based routing protocols and objective functions.**

Keywords—Internet of Things; RPL; Load balancing; Objective Functions; Routing Metrics;

I. Introduction

Internet of things (IoT) is an emerging paradigm that enables devices to be connected any time, anyhow and anywhere. It changes the life we live, work, and play. The IoT network depends on the routing protocols for communication because the responsibility of the routing protocol is to forward the traffic accordingly to its routing metrics and make route decisions. Routing is the crucial factor influencing the connectivity and the performance of information. The performance of IoT devices dependent on the implemented routing protocol [1].

Routing protocol for low power and Lossy Networks (RPL) is a trusted protocol for IoT devices communication and performance: packet delivery ratio, energy-efficient, etc. RPL was initially designed for light traffic network however IoT is coming with large data than LLNs [2]. In RPL for the node to transfer packets, it selects the path according to its objective function. RPL has the default objective function minimum rank with hysteresis objective function (MRHOF) and objective function zero (OF0) [3], that allow the decision making of the nodes and the routing metrics such as hop count and Expected Transmission count (ETX). The objective functions and routing metrics quantify the protocol to outperform while focusing on the shortest path, link quality and the minimum rank need to be taken by the node to transfer the packets. In large traffic, these routing algorithms provide non-uniform traffic distribution due to imbalanced load in RPL protocol and results in poor network performance. The RPL protocol needs to improve network performance by balancing the traffic load [4]. The routing metrics and objective functions dealing with traffic distribution and parent choosing required to be implemented in RPL. The scholars in the previous studies tried to solve the load balancing problem in RPL. Others proposed a new RPL-based routing protocol and others proposed a new routing metrics and objective functions that deal with load balancing issue.

This paper provides the state of the art of performance of RPL in IoT distributed networks. Understanding of the load balancing problem. Discuss the solutions proposed to approach the load balancing in RPL. Prepares the scholars to be able to come up with a stable solution for RPL load balancing in IoT distributed networks. The paper reviews the solutions proposed by the scholars to alleviate the load balancing problem in IoT.

The main contribution of this paper is to provide the scholars with the work that analyzes, discusses and review the research approaches made to address the Load balancing issue in RPL. This review provides additional insight into various load balancing solutions based on RPL protocol. The short summary of the contribution is as follows:

- The paper provides the state-of-the-art of RPL routing protocol in IoT distributed networks. Discuss the importance of balancing the load in RPL routing protocol
- Presenting the various approaches proposed by scholars to address load balancing problem in RPL protocol and the limitations of the present approaches.
- The paper also provides future research directions and open issues.

The findings obtained is that the approaches proposed to address the load balancing problem in RPL were conditional to the situation. The RPL protocol still needs the unconditional and stable load balancing algorithm to be implemented for IoT distributed network. After this review, we hope scholars will have an idea to come up with a solid approach to solve the imbalance load in RPL.

The paper is organized as follows; Section II depicts the RPL overview. In Section III provides RPL-based routing protocols and its performance in IoT. Section IV depicts the objective functions proposed to overcome the load balancing problem in RPL and the last section V concludes the paper.

II. RPL OVERVIEW

IPv6 Routing Protocol for Low power and Lossy networks (RPL) was designed by the Internet Engineering Task Force (IETF) group for resource-constrained devices. RPL has the objective to meet the Low power and Lossy Network (LLN) requirements and optimize the route and parent selection. It falls under proactive distance vector routing protocols category; it sends the packets through the best routes based on distance (hop count) and link quality (ETX). The protocol has the control messages that its use to send, receive and approve the packets. Figure.1 depicts the original RPL tree formed when the child nodes send the packets to the nearest parent node. The tree topology is a result of the shortest path algorithm that does not check the availability of the parent node. The nodes choose the nearest hop with the best link quality and unable to consider the density and the queue of existing traffic in the chosen parent node.

In RPL the nodes organize themselves by forming a Destination Oriented Acyclic Graph (DODAG) routed towards the sink where each link is oriented to avoid cycles formed between the nodes, however the links in the paths oriented towards the root node either away from root node [5], [6]. The protocol uses its default Objective function to guide the DODAG construction, for better path creation towards the root. The nodes compare their neighbors before selects one with the best path to the root according to the OF. RPL routing based on the Destination Oriented Directed Acyclic Graphs (DODAG). RPL has different types of control messages.

- DODAG Information Object (DIO) it advertises the routing constraints and metrics of a node it contains the information about DAG instance. It maintains the DODAG and selects a DODAG parent set.
- DODAG Information Solicitation (DIS): the new nodes use this message type to join the network and probing neighbor nodes. The DIS control message is used to solicit the DIO message from router nodes in RPL.

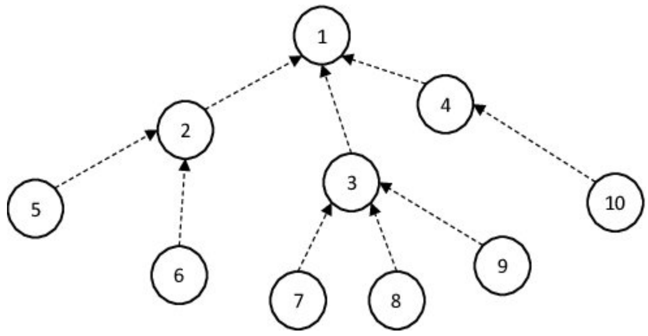

Fig. 1. RPL network tree-topology [7]

- Destination Advertisement Object (DAO): the message is used specifically to send information based on the path from all nodes toward the root. It is used to propagate destination from upward along DODAG.
- Destination Advertisement Object Acknowledgement (DAO-ACK): the node requests the DAO-ACK message to guarantees the delivery of the DAO message.

RPL protocol has objective functions (OF) that define the routing mechanism that needs to be used by RPL child node to select the parent nodes and route optimization within an RPL instance. It also enables the node to select the parents. The protocol has two default objective functions.

- OF0: Objective Function Zero
- MRHOF: Minimum Rank with Hysteresis OF.

OF0 allows the node to select a preferred parent, find the nearest grounded root. The upward traffic is routed via preferred parent without attempting to perform any load balancing.

MRHOF it enables the nodes to select routes that minimize a metric while using hysteresis to reduce churn in response to small metric changes. MRHOF works with additive metrics along a route, and the metrics it uses are determined by the metrics that DIO messages advertise. It finds the path that cost less and enables the node to support at least one of the routing metrics among hop count, ETX and latency.

MRHOF also have the mechanism for detecting the loop and repairing a DODAG. This mechanism repairs the broken links between the nodes and sends the DIO message to notify the change of subDAG. The objective function performs better with its routing metrics, ETX and hop count. It has a high packet delivery ratio in the normal network but in heavy traffic, it delivers fewer packets because it has unbalanced traffic. The nodes choose the parents with the good link quality but unchecking the load in the parent nodes choose and the links are chosen. The RPL default objective functions are limited to link quality and the shortest path [3].

RPL protocol performs poor in heavy traffic due to an unbalanced load. The scholars are concerned about solving the load imbalance issues in RPL protocol to improve network performance. They proposed different routing algorithms that work differently with the purpose of balancing the traffic load. The objective of balancing the load is to minimize network congestion, improve network performance and network reliability [8]. In[9] they proposed a Directed Acyclic Graph-based Multipath routing algorithm (DAGMR) to minimize congestion in Machine to Machine (M2M) networks. The routing algorithm disperses the data flow to multiple paths to minimize congestion. The routing algorithm balances the load, protect the route failure by distributing traffic among a set of disjoint paths. DAGRM provides fault tolerance and higher aggregate with bandwidth, furthermore, it ignores the RPL objective functions and routing metrics. Load balancing introduced in acyclic graphs to avoid loop between the sender node and the routed or sink node.

III. RPL-Based Routing Protocols

The routing protocol for IoT devices RPL does not consider load balancing. The authors proposed different solutions to address load balancing in RPL protocol to enable the protocol to maintain packet loss, network lifetime and decrease the delay of packets. The existing RPL-base load balancing solutions can be categorized below.

Load Balanced Routing Protocol (LB-RPL) an RPL load balancing protocol proposed by scholars in [10] for 6LoWPAN network to balance the load in heavy traffic. The protocol considers the network load differences and distributing data traffic among different parent nodes. It modifies the RPL control message construction procedure DODAG to avoid the node to send a new DIO packet immediately instead the node starts a timer, which is proportional to its workload and transmits the DIO packet after the timer expires. They defined the buffer utilization counter parameter to express the workload. The parameter defined as the average number of new packets pushed into the buffer. In LB-RPL protocol, the source node chooses the top k parents from its parent table to distribute and forwards its traffic load.

The LB-RPL was implemented through simulation over a large network of 250 nodes using Contiki Cooja network simulator for 3 hours. The results ensure that the LB-RPL routing protocol performs better when it compared to RPL in terms of packet delivery ratio with 90% confident and network throughput. The LB-RPL enables the packets to reach to destination through alternate routes although they are longer. RPL provides better average end-to-end delay than LB-RPL. The BL-RPL distributes data traffic through the network and performs better than RPL in balanced workload distribution to prevent congestion in the nodes, end-to-end delay, and packet delivery ratio. LB-RPL manages the traffic distribution better than RPL although it delivers fewer packets at an interval of five minutes, that would be an issue in large scale network. It also ignored the use of routing metrics and objective functions to balance the traffic.

The prevention of network congestion is relying on the load balancing if the network is balanced congestion does not occur in the network. Since RPL lacks on load balancing the scholars in[11] proposed the RPL backup protocol Context-Aware and Load balancing RPL (CLRPL). The protocol is proposed to deal with the packet loss and energy depletion affecting RPL protocol in heavy traffic. The routing protocol works with its new objective function Context-aware objective function (CAOF) and routing metric Context-aware routing metric (CARF). CAOF computes the rank, prevents the thundering herd issue in the network. CARF considers the Queue Utilization, balance the power of the network and balance the load in routes. the protocol is proposed with the aim of increasing the lifetime of the network and increase packet delivery ratio. CLRPL was implemented in Contiki OS and evaluated in Cooja network simulator for different scenarios. The protocol balanced the traffic better compared to standard RPL; it lessens the queue ratio in the network.

RPL performs poor in heavy traffic, its losses many packets due to the network congestion occurs. The authors in [12] proposed Que-Utilization method based RPL (QU-RPL). The protocol uses QU-Utilization factor for parent selection to satisfy the traffic load balancing. When the node experiences a certain number of consecutive buffer overflows, it broadcast a DIO message contains the congestion information. The node changes its parents on experiencing congestion with one that has less buffer occupancy and lower hop distance to the LLN border router. However, without congestion, the node chooses its best parent base on the default parent selection for RPL.

The protocol implemented in the real testbed and tested in Tiny OS. QU-RPL improves packet delivery ratio, lowering the queue losses using the hop distance and QU. The protocol's implementation is cheap. QU-RPL outperforms RPL.

RPL performs poorly when the network is congested; avoiding network congestion can increase the performance of RPL in IoT distributed networks. The authors in [13] proposed the routing protocol base that deals with congestion in RPL. The protocol named as Congestion Avoidance multipath Routing Protocol (CA-RPL). The protocol is proposed to achieve the goal of sending packets fast to the sink node. The protocol works with the metric based on RPL to minimize the packets delay towards the DAG root. The protocol considers load balancing, time factor and the reliability of the link. The protocol balances the load in LLN through the ease of congestion and time delay reduction. CARPL was implemented in Contiki 2.6 OS and simulated in Cooja network simulator along with MSPsim emulator [14].

To summarize the work has been done to balance the load in RPL protocol. LB-RPL solve the problem by calculating the load imbalance factor for each level of the routing. It maintains the tree balanced during the network lifetime. The protocol increases the packet delivery ratio.

CLRPL improves the network lifetime and increases packet delivery ratio. Balances the power in the network and balance the routes. CLRPL uses its own objective functions and routing metric such as Context-Aware routing metric CARF that helps in creating a balanced network. Network congestion occurs when multiple nodes send packets concurrently at a high rate of data [15]. QU-RPL is lowering queue loss to avoid network congestion, increase the packet delivered per node. The performance evaluation of CA-RPL compared to RPL base on throughput, packet loss rate, and the average delay. The packet loss indicates the link quality situation and the congestion of the network. CA-RPL performs better on delivering the packet compared to RPL; it has low packet loss ratio affected by a time delay to transmit packets. CA-RPL is an energy-efficient routing protocol than RPL protocol. Increasing the packet delivery ratio and improved the performance of LLNs. CA-RPL avoids congestion by introducing the metric that deals with poor link quality and large data traffic.

The authors in[16] proposed the Energy and Aware RPL(EL-RPL) to enhance RPL. The protocol balances the load and energy among the network nodes, avoids the bottleneck near the intermediate node and the sink node. The protocol enables the participant node to choose the greatest parent among the preferred parent based on DODAG rank. The rank calculates from objective function and rank increase. This routing algorithm improves the network lifetime through Battery Depletion Index (BDI) and ETX metrics to mitigate the load on the node and the link.

The RPL-based routing protocols provide different approaches to solving load balancing and network congestion in LLN. The better approach must consider the best packet delivery ratio in high data traffic, energy-efficient, and low average time delay. RPL being energy efficient and balancing the load to master heavy traffic brought by the Internet of Things. Parent selection can be added, but its need to be overlooked on how it affects the energy consumption of nodes and time delay while the child node searching for the parent node with fewer packets. Table I summaries the discussed load balancing protocols.

TABLE I. RPL-BASED ON LOAD BALANCING ROUTING PROTOCOLS

References	*Routing Protocol*	*Operating System*	*Performance metrics*
[9]	LB-RPL	NS2	- Energy consumption - Packet Delivery Ratio - End-to-End delay
[10]	CLRPL	Contiki OS	- Packet delivery ratio. - Energy consumption - Queue loss
[11]	QU-RPL	Tiny OS	- Packet delivery ratio
[12]	CA-RPL	Contiki OS	- Energy conservation - Packet loss ratio - Average delay
[15]	EL-RPL	Contiki OS	- Packet delivery ratio - Throughput

IV. RPL-BASED OBJECTIVE FUNCTIONS

The objective function specifies the procedure that is used by nodes to choose routes in RPL, they work together with routing metrics such as ETX, Hop count, Buffer occupancy and Parent count. The default objective functions calculate the rank based on the routing metrics such as energy, packet delivery ratio, delay, etc. the protocol uses the default objective functions, Minimum Rank with Hysteresis OF (MRHOF) and Objective Function Zero (OF0) that does not consider the parent selection, load balancing and checking of the traffic overload in the nodes.

The authors in [17] proposed a load balancing optimization for RPL based emergency response using Q-learning (LBO_QL). The routing algorithm proposed to improve network performance than standard objective functions. BLO-QL balances the load at DODAG level through RPL construction and applies a Q-learning technique to optimize load balancing for emergency scenarios. Q-learning algorithm, the node needs to know the intermediate parent node then the traffic overhead of the entire network is avoided. LBO-QL was implemented as an objective function in RPL routing protocol using Contiki OS and simulated in Cooja simulator. Network performance measured with Convergence time control, Packet delivery ratio and energy consumption. LBO-QL provide efficient packet delivery ratio, improve the network performance, and network lifetime. The objective performs better than the ordinary RPL objective functions although it does not consider the link quality and not cover all the aspects of RPL design routing process.

The authors in [18] proposed the Congestion aware objective function. The objective function to work properly it combines two routing metrics, ETX and Buffer Occupancy (BO). The BO routing metric enables the child node to forward the packets through less congested nodes.

ETX metric is chosen because it lowers the data rate and BO is considering the congestion occurrence during the parent selection process. The CA-OF is aware of congestion and reflects also how much the nodes and links are congested. CA-OF has better network throughput, better packet delivery ratio, and less energy consumption. CA-OF is also able to indicate how much the nodes are congested using the buffer occupancy metric. The new proposed routing objective function in RPL has been implemented and tested Contiki 2.7, it improves the network performance based on throughput, packet delivery ratio, and energy consumption.

The scholars in [4] studied RPL routing protocol's performance and they conclude that the protocol lacks on the load balancing that leads to high packet loss. They proposed LBSR as the new load balancing objective function for RPL. The new objective function enables the node to select the best parent to send the packets, it has a goal to build a balanced topology. The OF combines the default RPL metrics with the parent selection for best results. The OF introduce the parent selection and optimization primitive. The performance of proposed OF has been carried out in terms of energy consumption, load distribution and packet delivery ratio. The OF was implemented and tested in Contiki OS. The proposed OF improved the packet delivery ratio compared to original RPL, the OF is limited to less energy consumption and load distribution.

Scholars in [8] proposed the new routing metric based on RPL to approach the load balancing issue. They named the routing metric as lbRPL. The Load Balancing Index (LBI) introduced to work together with ETX, parent count (Pc), and Remaining Parent Energy (Pe). The routing metric calculates the parent before choosing the parent to send packets. LBI depicts the load balancing characteristics of RPL to enable the child nodes to select balanced parents and routes. The performance of routing metrics in RPL was implemented in

Contiki OS and simulated in Cooja network simulator. The simulation of the algorithm was based on network performance and network stability. The performance of lbRPL improved network stability by allowing the nodes to choose a balanced parent.

The authors in [19] proposed the powerful objective function that deals with load balancing in RPL protocol known as A LoAd BaLancing Model (ALABAMO). The OF is based on MRHOF and it uses ETX for link quality to approach the imbalance problem in RPL. The routing algorithm considers the traffic profile to avoid overloading the nodes with high link quality. The objective function has been implemented to provide traffic awareness in RPL and balance routing. It was implemented in a real operating system and evaluated in the testbed. The result shows that it balances the load by providing the tree with an equal number of nodes and a minimum hop count. The ALABAMO reduces the energy consumption in RPL but when it compared to the default objective function of RPL MRHOF. ALABAMO enables the nodes to consume more energy than MRHOF. It also reduces the packet delivery ratio but makes a better tree than MRHOF.

Traffic-Aware Objective Function (TAOF) is an objective function that levels the traffic load assigned on each node through the routing metric, it proposed Packet Transmission Rate (PTR) [5]. The routing metric represents the number of packets each node forwarded during the certain period. It can trace the load in each node. The routing metric for it to function properly it needs to amend the DIO message format and introduce the packet transmission rate into DAG metric container. The objective function tested in Cooja simulator under the RPL routing protocol. The performance of the objective function TAOF is better in balancing the network topology, achieves the stability better than default RPL objective functions. It also decreases the packet overload in the nodes.

Load balancing is a critical issue affecting the network connectivity in IoT distributed network. Unbalance load lead to network congestion that may cause fewer packets delivered successfully, delay the network lifetime and nodes consume more energy to transmit packets. Many scholars are concerned about unbalanced load in RPL protocol, others proposed new objective functions to upgrade RPL. This paper is discussing solutions proposed for load balancing. Providing the preferences according to the author's view. The knowledge from authors lbRPL performs better than the default ETX and Hop count. It is very fast when reconstructing DODAG; however, it can be used to upgrade RPL although it does not include parent count when the node sends packets. ALABAMO objective function performs better on the distribution of nodes to create a uniformly balanced sub-tree. It lacks on packed delivery ratio because the node selects the path with poor link quality. It is energy efficient objective function. CA-OF has high packet delivery ratio compared to OF0, high throughput, energy-efficient objective function. TAOF balances the network topology, decrease the overload in the nodes. Creates a stable network that enables the nodes to deliver high packets compared to MRHOF.

TABLE II. LOAD BALANCING OBJECTIVE FUNCTION.

References	*Objective Functions*	*Routing metrics*	*Performance metrics*
[5]	TAOF	Packet Transmission Rate (PTR), Expected Transmission count (ETX	- Energy consumption - Packet Deliver Ratio
[14]	CA-OF	Buffer Occupancy (BO), Expected Transmission count (ETX)	- Packet delivery ratio. - Energy consumption - Throughput
[16]	LBO-QL		- Convergence time - Packet delivery ratio - Energy Consumption Control Traffic Overhead
[18]	MRHOF	Load balancing metric-based routing for RPL (lbRPL), Expected Transmission count (ETX) and Hop count	- -Packet delivery ratio - Network lifetime through Node Participation - Control Traffic Overhead
[19]	ALABAMO	Expected Transmission Count (ETX)	- Network delivery ratio - Energy Consumption - Network lifetime

V. CONCLUSION

Load balancing in RPL is a problem that needs to be solved. There are several solutions proposed to address the RPL load balancing problem. Unfortunately, the solutions are conditional and have some limitations. RPL is still unable to manage traffic better in large scale network, the load balancing solutions proposed are suitable for different network scenarios and different performance parameters. This paper categorized the solutions according to its features. Discussed the RPL-based routing protocol, its performance metrics, and the limitations. The RPL-based routing protocols perform according to the performance metrics used on it. Most of the discussed routing protocols are limited to packet delivery ratio and parent selection. Not all of them includes energy consumption, while for RPL to perform better in IoT, it needs to be energy-aware routing protocol to extend the network lifetime.

Balance the tree topology to reduce network congestion, packet loss, and packet delay. The routing metrics that guide the performance of the protocol in RPL considers the link quality and hops. Load balancing objective functions based on RPL are discussed. ALABAMO performs better in energy consumption compared to OF0 but delivers fewer packets due to delay. However, implementing ALABAMO in RPL will be the last option due to its poor performance. TAOF can work better for RPL in IoT distributed networks, it balances the topology, considers energy-efficient and packet delivery ratio. CA-OF has high packet delivery ratio compared to OF0, high throughput, energy-efficient objective function.

The existing methods of approaching load balancing in RPL provide partial load balancing. Reviewing the approaches proposed for load balancing in RPL helps to understand the important aspects of Routing protocols in IoT. The design process rules of the protocol and the drawbacks of the objective functions and protocols.

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