PERFORMANCE ENHANCEMENT OF RPL ROUTING PROTOCOL IN THE IOT ERA

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Abstract. In the Internet of Things (IoT) concept, Low Power and Lossy Networks (LLNs) have a significant role, which can deal with restricted infrastructure (nodes and communication). Two objective functions (OF) were standardized for the IPv6 routing protocol for LLNs (RPL): objective function zero (OF0) and minimum rank with hysteresis objective function (MRHOF). The standard OF using only one metric, this makes the nodes select inefficient routes in the networks. In this paper, the author suggests an objective function with multiple metrics for overburdened nodes that balance the number of child nodes to optimize network lifetime. By designing a new objective function that takes three metrics instead of one into account to optimize routes, decrease the average hop count, decrease the average ETX, and increase network stability. The tool used in this study is the Contiki3/ Cooja simulator, which includes three network topologies (50, 55, and 60 nodes), and compares the results of the proposed objective function with the MRHOF, and the results showed that the proposed objective function succeeded in enhancing the RPL protocol in terms of packet delivery ratio (PDR), ETX, network routing stability, and the average number of hops. The best performance of the proposed protocol is shown in the network with 60 nodes.

Keywords: *internet of things, RPL, low power and lossy networks LLNs, objective function, MRHOF, ETX*

Introduction

Internets of Things (IoT) applications are wide, ranging from home automation to smart cities. Low power and lossy networks (LLNs) play a critical role in promoting IoT implementation infrastructure in this context. Therefore, the Internet Engineering Task Force (IETF) has standardized RPL protocol across several OSI layers to fulfill IoT requirements and evolve applications. Dealing with the lack of energy in LLNs is one of the key driving factors behind these standards. The IETF predicted this, thus establishing IPv6 over low power (Hui and Thubert, 2011; Atzori et al., 2010). “The IETF Routing over Low Power and Lossy Networks Working Group (ROLL) standardized a new routing protocol called IPv6 Routing Protocol for LLNs (RPL)” (Atzori et al., 2010). RPL is a proactive routing protocol for a distance-vector source that is specially built for LLNs. The structure is contained in a DODAG. It follows the topology of the tree and every node wishes to reach just one destination. The top of the tree is called a sink (root) node. The downward path leads away from the sink, and the upward path leads to the sink node. In a network, The RPL protocol generates several DODAGs, each of which is treated as an RPL instance. In this instance, a separate RPL instance ID or DODAG ID is stored. The sink node works as a border router, while the other nodes in the LLN serve as the children or host nodes. The host node provides the address from the prefixes of the sink ID. The whole network routing table is the root or sink node. The root node preserves the storage mode and provides some child node rights, which preserve the information of the routing in the network section. The node collects and then forwards the data to another node in the storage mode. In the non-storing mode, the only thing the node can do is forward data to some other node. Four control messages are available in the RPL protocol: DIS (DODAG Information Solicitation), DIO (DODAG Information Object), DAO (Destination Advertisement Object), and DAOACK (Destination Advertisement Object Acknowledgment) (Winter et al., 2011; Roman and Lopez, 2009).

The DODAG includes a root node or sink node and other nodes are child nodes that collect and forward data. The participant node wants to enter the current DODAG and sends a DIS control message to the DODAG. DODAG multicasts the messages of the DIO control to all participating nodes. This contains the OF and rank definitions. Rank is determined using an OF. DODAG permitted the use of a trickle-timer. The DODAG waits for DAO messages to arrive at the participant node. Within the trickle time, the participant node sends DAO messages to the DODAG, accepts the participant's request, and sends DAO-ACK to the participant node. The OF offers the best choice for the best parent to be chosen and transmits the data to the sink node (Iova et al., 2016; Gadde and Chaudhari, 2015; Gaddour and Koubâa, 2012; Winter et al., 2011). To optimize the path selections toward the sink node, two main objective functions have already been standardized in the RPL. The construction of the Destination Oriented Directed Acyclic Graph (DODAG) is affected by the RPL objective function, which depends on one metric (OF0 depends on Hop count metric, MRHOF depends on ETX metric) to calculate the rank value to choose the preferred parent node. The parent node in the RPL, if selected as the preferred parent, may serve more than one child. Consequently, Since their resources are at risk of being depleted even faster than that of other nodes, the overburdened chosen parents would become vulnerable nodes, and after completing a thorough performance evaluation, the author found that the RPL original protocol leads to the construction of a topology that suffers from excessively unbalanced load traffic in congested nodes, particularly for the nodes near the sink. Subsequently, this issue has a critical effect on the lifetimes of nodes. The battery exhaustion of the crowded parent node could allow a part of the network to be disconnected and, thus, the DODAG to be rebuilt. This daunting problem is still unresolved to the best of our knowledge, as the current works provide sensor nodes with an insufficient lifetime. The author suggest a new objective feature to minimize the overuse of a bottleneck node to extend its battery life to solve this problem. The author used the Cooja simulator as a tool to apply the proposed objective function, compare the results with the MRHOF objective function and collect the results from the collecting view.

The remainder of this paper is organized as follows. First, in Section 2, the author review related work that attempts to improve the RPL objective function. Section 3 discusses the RPL protocol problem statement, and Section 4 defines the proposed objective function model to enhance the RPL protocol. In Section 5, the simulation results are evaluated with three network scenarios (50, 55, and 60 nodes) and show the results of the proposed protocol and compare it with the RPL MRHOF, in terms of PDR, average ETX, average parent switches, and the average number of hops. Finally, Section 6 concludes the paper.

Literature review

The efficiency of the network-forming phase was evaluated in Gaddour et al. (2012) and Accettura et al. (2011) using the Contiki Cooja simulator. The authors checked, among other metrics, how the objective functions (OF0 and MRHOF) affect the average hop count and the average energy of the nodes. In Karkazis et al. (2012), a composite metric that combines four metrics: hop count, residual energy, received signal strength indicator (RSSI), and ETX was proposed. The rank in this protocol is determined from the sum of these amounts based on the above metrics. In Liu et al. (2013), the authors proposed an enhancement of the OF to resolve the problem of network scalability, where large-scale networks may have a problem of long single hops by considering the path state and hop count of the possible routing route. A QoS-aware fuzzy-logic OF was proposed by the authors in Gaddour et al. (2014). The holistic objective function incorporates four different metrics that can effectively categorize the quality of the route using fuzzy logic strategies, namely, hop count, battery level, delay, and ETX.

In Iova et al. (2015a & 2015b), the authors highlighted the benefits of embedding multi-path forwarding schemes into the RPL protocol. Intuitively, it has been proven that the multi-path mechanisms have a wide spectrum of benefits such as improving fault tolerance, improving reliability, minimizing congestion, and improving QoS. The authors suggested an RPL based on a multi-path routing mechanism that allows the protocol to forward traffic for many parents of choice. The study notes that a routing metric must: (1) capture variations in the quality of the links; (2) use energy-efficient paths to optimize end-to-end reliability; and (3) reduce energy consumption for those nodes that use the most energy (the bottleneck nodes). A new metric is proposed in this regard, 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 (runs out of energy) the first node dies. The ELT of a particular node is determined by: (1) calculating the node's throughput based on its traffic and also the traffic of its children; (2) multiplying the average number of retransmissions by the traffic determined; (3) calculating the time ratio required for transmission based on the rate of transmission of the data; (4) calculating power consumption based on radio transmission power only; and, finally, (5) calculation the ELT as the ratio between the remaining energy of the node and the energy calculated in the preceding step. The bottleneck nodes are first identified and advertised along with the topology based on the value determined by the ELT, then a multi-parent, energy-balanced topology is constructed, in which traffic between parents is balanced with thoughtful consideration of bottleneck nodes. Since several parameters (retransmission count, data rate, transmission power, throughput, and residual energy) need to be exchanged to determine the rank, this method increases the size of DIO packets, raising the risk of fragmentation. This is an issue in LLNs when multipath routing is used as separate paths are taken by two fragments belonging to the same packet, raising 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. To an already confusing protocol, this added additional complexity.

In Lodhi et al. (2015), the authors pointed out the problem of RPL being a single path 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 that will allow the protocol to react effectively to congestion. The authors suggest an extension named a multi-path RPL (M-RPL) that offers many temporary ways of congestion. In M-RPL, the forwarding nodes detect congestion using the packet delivery ratio (PDR). If a forwarding node on a routing path detects that the PDR has decreased below a given threshold, the node sends a warning to its children, informing them of congestion, using DIO messages. By splitting its forwarding rate in half, the child node that hears the message about congestion advertisements begins multipath routing. Only a second packet is subsequently sent to its original congested parent, while the others are forwarded to every other parent from its parent list. In terms of throughput, latency, and energy consumption, the proposed protocol is evaluated using Cooja and compared with RPL with MRHOF. Because of its splitting mechanism, their simulation results show that M-RPL has higher performance and lower energy consumption per bit than RPL. The findings have shown that while the M-RPL delay is initially compared with the RPL, this changes when congestion starts. Initially, with the introduction of multiple paths, M-RPL experiences greater latency, but in terms of latency when the network stabilizes. The issue is that DAO messages are costly in terms of energy use and overhead because they are sent end-to-end. A load balance objective function in IoT routing was proposed by the authors in Qasem et al. (2016). The proposed protocol was compared with two objective functions, namely, (MRHOF) and objective function zero (OF0). However, the data traffic throughout the network nodes is managed using this objective function. The child node wants to pick a preferred node depending on the number of child counts that are present around the path. The changed DIO message format was implemented, which decreased the overhead control between networks.

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 volume creates congestion, resulting in substantial delay and packet loss, the objective functions of the two 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 respond to sudden events quickly and reliably. To minimize the average delay towards the DODAG root, known as DELAY ROOT, they have built a composite routing metric built in the ContikiMac duty cycle protocol. A node saves time just by learning the wake-up stage of its candidate parents under this metric and then sending 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, packet loss ratio, latency, and packet reception number (PRN) per unit time. The experimental results show that the proposed protocol decreases network congestion and increases the PRN by up to 50 percent, the output by up to 34 percent and the packet loss by up to 25 percent. Compared to RPL, the average delay was 30 percent. The protocol proposed is based on ContikiMac, which assumes that all nodes have identical wake-up intervals that may not be present in all LLN scenarios. Moreover, the DIO message carries several additional fields, including the ETX, REC, RANK value, cycle time CT, wake-up phase, its DELAY ROOT value, and other fields, a long control message is undesirable in IoT 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). The study asserts that when providing QoS, standard RPL faces two important problems. The first is the lack of an objective role that is holistic and detailed.

For example, an objective function may increase the delay, but at the cost of higher energy consumption, because with the minimal delay, all packets overuse the same paths. The second issue is that RPL does not accept a data classification process, which is crucial in ensuring the QoS. Therefore, a comprehensive, objective feature is required that supports multiple data classes. The OMCRPL steps are as follows: the first one, the nodes send the information needed to construct its virtual DODAG to the SDN controller using one-hop communication; and so, the SDN controller determines the node ranges in the network by each traffic class using a specific weighted-metric objective function. 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 objective function 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 different traffic groups and Objective Function Parameter weight values were found using the Particle Swarm Optimization (PSO) algorithm compared to the regular ETX-RPL in terms of end-to-end latency, packet loss, network lifetime, 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 PDR for the traffic class that needs reliability. It is also found that because it can use a backup parent to replace a failed one, OMCRPL responds better to network failures. In terms of network life, OMC-RPL outperforms RPL by up to 41 percent and displays stronger energy delivery fairness by about 18 percent. The study also states that the combination of the SDN controller with OMC-RPL decreases the amount of control packets exchanged by approximately 62 percent compared to both OMC-RPL and standard RPL and minimizes energy consumption by more than 50 percent compared to standard RPL. The reporting interval to the SDN is not quoted for SDN-based OMC-RPL, although it may have a major impact on the overhead control plane.

In the paper by 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 focused on node energy and link quality that seeks to simplify the routing mechanism to satisfy the needs of applications that demand 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, 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. The paper by Lamaazi and Benamar (2019) 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 introduced a new RPL objective function combination called OFEC in their paper, “objective function based combined metric using the fuzzy logic method”. They used the hop count to route nodes to the root after combining two key metrics: power consumption and ETX. The method is divided 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. *Table 1* shows the summary of the RPL protocols.

Table 1. *Simulation network parameters.*

Parameter	Value
Operating system	Ubuntu 14.04, Instant Contiki 3
Simulator	Cooja simulator
Simulation area	100 m X 100 m
Transmission range	50 m
Interference range	100 m
Radio model	Unit Disk Graph Medium (UDGM)
Packet format	IPv6
Number of nodes	50 nodes, 55 nodes and 60 nodes
Types of nodes	1 sink node, and 49, 54 as well as 59 sender nodes
Packet size	127-byte payload
Transmit and received ratio	TX=100%, RX=100%
Data packet rate	1 packet/min
Microcontroller	MSP430
Transport	UDP/IPv6
MAC layer reliability	Enabled
Node type	Tmote (Sky mote)
Data link layer	CSMA-CA
MAC	Standard IEEE 802.15.4 MAC
Physical	Standard IEEE 802.15.4 PHY

The problem statement

RPL has many powerful features, such as a loop-free topology, fast configuration, and self-healing. However, this protocol has a major weakness such as the flocking phenomenon that causes weakness in the network because of the continuous parent switches that make an unstable network, increase delay and decrease the quality of service of the network. Besides, load imbalance is a weakness of RPL networks. More precisely, in addition to the uniform node distribution, RPL deals with non-uniform distribution in large LLNs, as a result, traffic data is unequal. Additionally, the resources of the overloaded nodes are exhausted much quicker than the other nodes (Lamaazi et al., 2019). However, if the crowded node is a bottleneck node, this issue has more harmful consequences, such as a sub-network being disconnected if the bottleneck node dies. Specifically, because of the parent selection process, this extreme issue appears in the RPL. The node selects the sender as the chosen parent when it receives the first DIO message (Saaidah et al., 2019). Becoming a parent for more children causes more problems that need to be solved. The ETX metric is insufficient for consider the traffic load. Therefore, it is important to develop a new objective function and parent-selection technique to resolve this issue.

The objective function

In the RPL network, the objective function (OF) decides how to build the DODAG and chooses the parents to improve the route. To maximize energy efficiency, the author proposed a new objective function that incorporates three metrics. This objective role focuses on issues such as multipoint-to-point communication data flow, where the bottle-neck grows rapidly near the sink node. More children, being a chosen parents, have unbalanced loads, more packet loss, more overhead, and high congestion, thereby losing their energy much quicker than other favored parents. To address this issue, the author suggest a load metric that provides the number of children they have to each preferred parent. Based on this, the author considers three metrics (ETX, residual energy, and load metric) into consideration for rank calculation. Each node should choose the node with the maximum node residual energy, minimum ETX, and minimum load metric (max RE+ min ETX+min Load) when determining the parent and building the DODAG from the preferred parent nodes. The residual energy metric was used as a measure of network lifetime (RE). Therefore, each node must not choose a parent with low residual energy when constructing the DODAG and selecting a parent to avoid selecting lower-energy nodes. The current consumption of energy consumption can be estimated using Eq. (1) (Lamaazi et al., 2019):

$$Econ(x)=Psleep\times Tsleep+Pcpu\times Tcpu+Ptx\times Ttx+Ples\times Tles \qquad \text{Eq. (1)}$$

Where, Econ(x): Energy consumed by node x; P_{mode}, power consumption modes (P_{les}, P_{Tx}, P_{cpu}, P_{sleep}); and T_{mode}, time spent in each mode (T_{les}, T_{Tx}, T_{cpu}, T_{sleep}). While the author can calculate the Residual Energy as the Eq. (2) (Bhandari et al., 2020):

$$RE(x)=Emax(x)-Econ(x) \qquad \text{Eq. (2)}$$

Where, RE(x): residual energy of node x; and EMax(x): maximum energy of a node x. Data traffic is the sum of the data transmitted over the network at a given time. The author perform load balancing by taking the load metric, which can be used to manage network data traffic. The load metric was computed based on the number of children in the parent node. The DODAG calculates a rank based on the total number of children present in the relation. Based on the load metric, the participant node chooses the parent from the preferred parent list. The load metric was computed using Eq. (3) and Eq. (4) (Sankar and Srinivasan, 2017), as follows:

$$NT = \sum_{i=2}^{n} CN(i) \qquad \text{Eq. (3)}$$

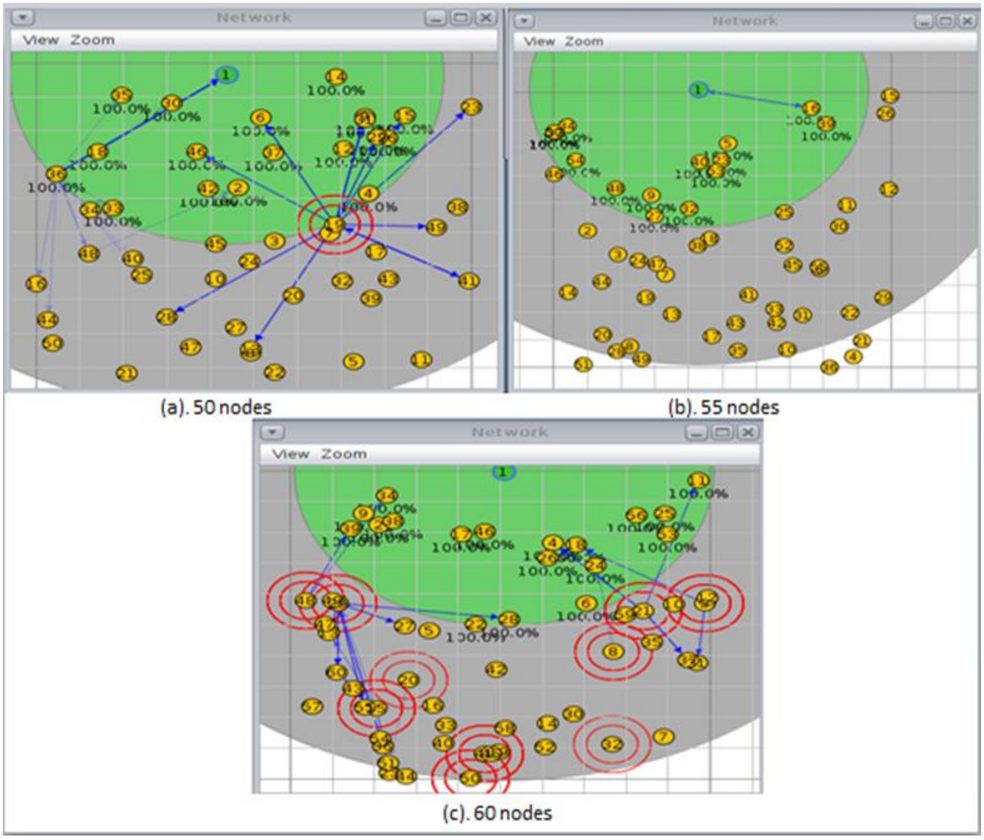
$$L(Px) \sum_{N=1}^{n} NT(N) \qquad \text{Eq. (4)}$$

Where, NT represents the node traffic, CN represents the number of children, and L(Px) represents the load on parent x. Calculation of node traffic based on the child count that communicating with a node.

Materials and Methods

Simulation and network setup

The simulation network parameters used in this study are presented in *Table 1*. The contiki3/Cooja simulator was used to implement our networks, test the results and compare it with the performance of the original RPL objective function (MRHOF) in terms of routing stability, optimized ETX, and minimize hop count. The application and the case study for this work is for a smart home, therefore, the number of nodes that are used 50, 55, and 60 nodes. *Figure 1* shows the random dissemination for the three scenarios. The transmission range for each node is 50 m, because the area of simulation is 100 m2, the interference range for each node is 100 m, and the simulation time is 1200 sec. Three metrics are calculated that include, routing stability, average hop count, and average ETX to investigate the performance of the proposed objective function.



(a). 50 nodes

(b). 55 nodes

(c). 60 nodes

Figure 1. *The randomly dissemination of (a) 50; (b) 55; and (c) 60 Nodes in 100m × 100m.*

Results and Discussion

Packet Delivery Ratio (PDR)

Figure 2 shows the packet delivery ratio with the number of nodes. The packet send ratio in both the original RPL and proposed protocol is about 20 packets per node in all scenarios. In the first scenario (the network with 50 nodes), the author found that the PDR in the MRHOF RPL is 0.901, but in the proposed objective function the PDR is 0.97145. In the second scenario (network with 55 nodes), the author found that the PDR in MRHOF RPL is 0.6898, but in the proposed objective function the PDR is 0.95185. In the third scenario (network with 60 nodes), the author found that the PDR in the MRHOF RPL is 0.53985, but in the proposed objective function the PDR is 0.94575. Because the original objective function selected inefficient paths, collision and packet loss rise as the number of nodes increases. The problems have been significantly reduced by the new idea. This indicates that the proposed objective function has succeeded in increasing the PDR in all scenarios.

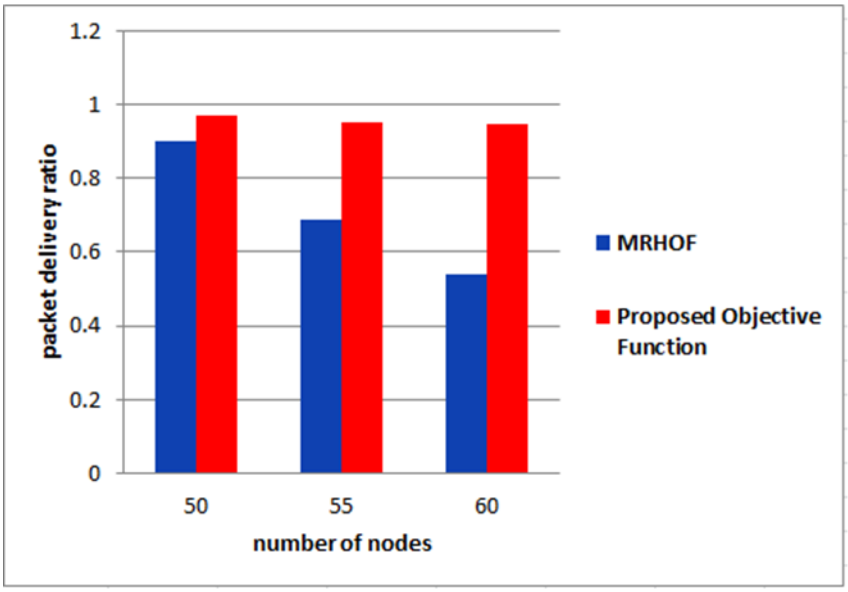


Figure 2. *Packet delivery ratio versus number of nodes.*

Network routing stability

The average parent switches are making flocking phenomena, and a flocking effect can result in the parent selection method in RPL, which refers to the phenomenon of attracting nodes and continuously moving from one parent to another. Consequently, this flocking phenomenon would have a large negative effect on QoS and cause more power consumption, an unstable network, more packet delay, and more packet loss. *Figure 3* shows the behavior of the networks by measuring the average parent switching (churn) while implementing the topologies of 50, 55, and 60 nodes. In the first topology (50 nodes), for the MRHOF objective function, the average parent switching is 1.49, but for the proposed objective function, the average parent switching is 0.918. In the second topology (55 nodes), for the MRHOF objective function, the average parent switching is 2.056, but for the proposed objective function, the average parent switching is 1.111. In the third topology (60 nodes), for the MRHOF objective function, the average parent switching is 2.407, but for the proposed objective function, the average parent switching is 1.136. This means that the author succeeded in increasing the network routing stability and load balancing.

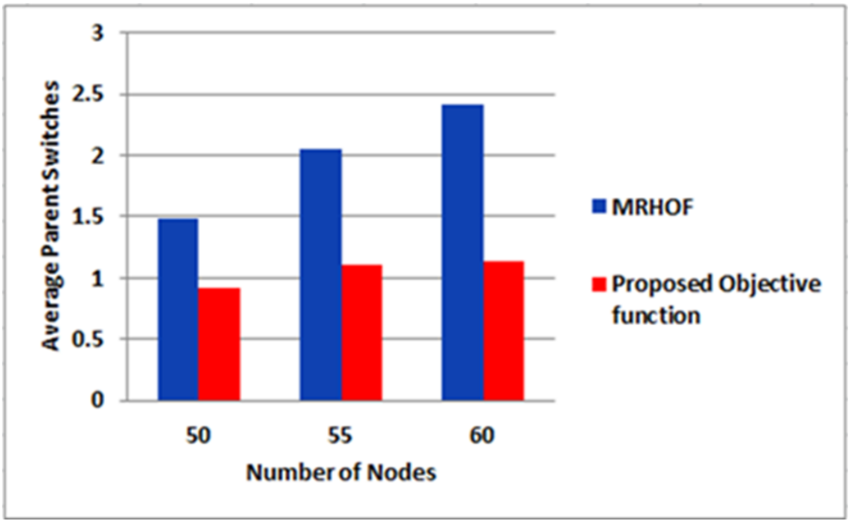


Figure 3. *Average parent switches versus number of nodes.*

Network average expected transmission count

Figure 4 shows the average expected transmission count (ETX) to the next hop while implementing the MRHOF and the proposed objective function with three topologies of 50, 55, and 60 nodes. The author observes that in the first topology (50 nodes), the average ETX is 35 in the MRHOF objective function, but in the proposed objective function, the average ETX is 23. In the second topology (55 nodes), the average ETX is 48 in the MRHOF objective function, but in the proposed objective function, the average ETX is 24. In the third topology (60 nodes), the average ETX is 53 in the MRHOF objective function, but in the proposed objective function, the average ETX is 27. The average ETX was the lowest in the proposed objective function and increased with MRHOF. A smaller ETX means a lower energy consumption, which indicates a better quality of the routes to the sink node.

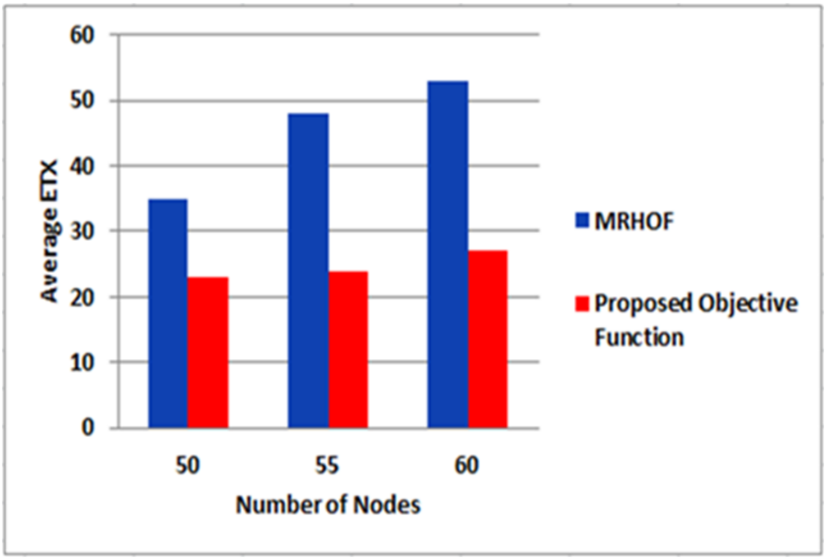


Figure 4. *Average Expect Transmission Count (ETX).*

Average network hops

For a network specifically with event-driven and QoS-centered communication requirements, maintaining low hops may help minimize the risk of connection loss and data drop; however, multiple hops can occur in the network. The average hop count was examined for the various network topologies (50, 55, and 60 nodes). The average hop count in the MRHOF objective function was 1.968 in the first topology (50 nodes), but it was 1.891 in the proposed objective function. In the second topology (55 nodes), the average hop count is 2.365 in the MRHOF objective function, while in the proposed objective function, the average hop count is 2.027. The average hop count in the third topology (60 nodes) in the MRHOF objective function is 2.365, while it is 2.169 in the proposed objective function. This means that, as compared to MRHOF, the proposed protocol was successful in decreasing the average hop count, which indicates the lowest probability of connection loss. The average hop count of the proposed objective function and the MRHOF objective function are compared in *Figure 5*.

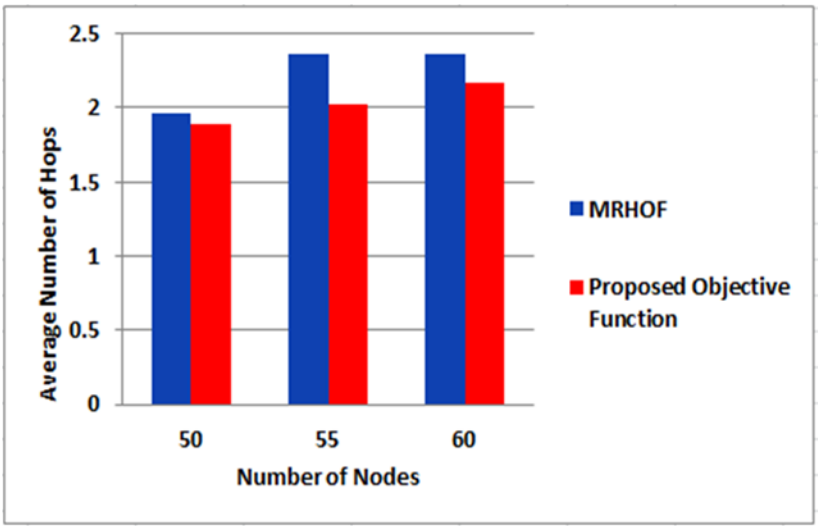


Table 5. *Average Networks Hops.*

Conclusion

In this paper, the author proposed a new objective function that improves the RPL protocol by taking into account three metrics rather than just one when measuring the rank using the objective function. To evaluate our three topology networks, the author generated an environment with randomly distributed nodes in a 100 × 100 m^2 region using Cooja simulator/Contiki3. The author concentrated on the issue of unbalanced traffic, which causes several of the problems; include early bottleneck node deaths due to low node energy. The author also considered the issue of the flocking phenomena, which means that a large number of parents switch in the network decreases the QoS of the network. A new metric called the load metric is proposed to avoid unbalanced traffic and consider the ETX and residual energy when building the DODAG and selecting the parent. The author built a medium-density network for the smart home environment. In all networks topologies (50, 55, and 60 nodes), the author found that in terms of average PDR, the PDR improved by 0.07045, 0.26205, and 0.4059 respectively, in terms of average ETX, the average ETX decreased by 12, 24, and 26 respectively. In terms of the average parent switching, the proposed protocol succeeded in reducing the average parent switches by 0.572, 0.945, and 1.271. In terms of average hop counts, the proposed protocol succeeded in reducing the average hop counts by 0.077, 0.338, and 0.196, in all scenarios respectively. As a consequence, the author concludes that an objective function with only one metric is insufficient and that an objective function with multiple metrics is more accurate and effective. 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.

Acknowledgement

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Conflict of interest

The authors declare that there is no conflict of interest involve in this research study.

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