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DESIGN AND EVALUATION OF MULTI-SINK RPL ROUTING PROTOCOL FOR LOW POWER ENVIRONMENTS

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Abstract. With the introduction of the Internet of Things, the Routing Protocol for Low-Power and Lossy Networks (RPL) gained a lot of traction among academic researchers, owing to its versatility in dealing with various network topologies. The RPL has been designated as a standard for Low-Power and Lossy Networks (LLNs) by the Internet Engineering Task Force (IETF). The RPL protocol will use the Objective Function (OF) to build a Destination Oriented Directed Acyclic Graph (DODAG) based on routing metrics. After selecting and developing routes, the RPL's OFs assign network node ranks based on one routing metric. Minimum Rank with Hysteresis Objective Function (MRHOF) and OF0 are two kinds of RPL objective functions defined by the IETF. The MRHOF is based on the Expected Transmission Count (ETX) metric, while OF0 is based on the minimal hop count metric. Because of the single metric, both MRHOF and OF0 may experience long hops when choosing routes to the sink, and may choose inefficient pathways that include nodes with low residual energy, causing the node's energy to be consumed faster than that of other nodes. Another issue with RPL is that it is unbalanced parents chosen, resulting in bottleneck nodes that cause more network delay and a high packet loss ratio due to high congestion nodes, especially those near the sink node. Multiple sinks should improve the effectiveness of RPL routing protocol networks. In this paper we suggested an improvement RPL objective function that considers three metrics (load, Residual energy, and ETX metrics) instead of only one metric. The Cooja simulator was used in this analysis, we used three different scenarios with a different number of sinks (1, 2, 3) sink nodes, and we compared the performance of the MRHOF and proposed protocol. The results show that the proposed protocol increases the network lifetime by reducing node energy consumption, reducing latency, increasing efficiency, increasing PDR, decreasing packet loss ratio, and selecting optimal routes. The best performance was achieved with three network topologies (50, 60, and 70 nodes), with 3 sink nodes for the proposed protocol. The PDR is 95.01%, with 50 nodes, is 95.55% with 60 nodes, and is 93.573% with 70 nodes with 3 sink nodes.

Keywords: RPL, Low-power and Lossy Networks, OF0, Objective Function (OF), MRHOF, IoT, routing protocol.

AMS Subject Classification: 68M15.

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1 Introduction

A wireless sensor network is made up of wireless sensor nodes and a sink node (WSN). The nodes are wirelessly linked to one another and to the sink. These networks are referred to as low-power and lossy networks because nodes have limited power and operate in difficult conditions. Dealing with the lack of energy in Low-Power and Lossy Networks (LLNs) is one of the key driving factors behind these standards. The IETF predicted this, thus establishing IPv6 over low power (Atzori et al., 2010; Hui et al. 2011; Winter et al., 2012; Park et al., 2009). "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).

The RPL in LLNs networks routing protocol was created to handle resource-constrained equipment, routing in smart cities, manufacturing, smart homes, and many applications (Winter et al., 2012). When the resources in these devices are limited, poor quality paths can quickly deplete the limited resources. The routing protocols like OSPF, AODV, OLSR, and DSR can't overcome the LLNs networking's constraints like low data loss, low data rates, low power consumption, and network stability (Pister et al., 2009). 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 OF, 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. The RPL protocol is developed based on the physical layer and the IEEE 802.15.4 MAC layer. The RPL network contains two kinds of nodes. One is the sink node, which collects the data from all the network nodes. The other nodes are the source nodes, which gather separate data from various sensors. After the RPL node routing topology is created, all the common nodes in the network will periodically send their data to the sink node. To select a preferred parent for traffic forwarding, RPL relies on the OF operations. The OF considers a variety of parameters and constraints of nodes and networks to choose the best route. The IETF ROLL working group was fitted with two OFs, named OF zero (OF0), and Minimum Rank with Hysteresis Objective Function (MRHOF) (Thubert et al., 2012; Gnawali & Levis, 2012). In the RPL when constructing the DODAG and select parents, the RPL may suffer from select inefficient routes like paths contain nodes with small residual energy, which may cause consume the nod's energy faster than other nodes. The other problem of RPL is unbalanced chosen by parents that make bottleneck nodes that cause more network delay and high packet loss ratio because of the high congestion nodes, especially the nodes that locate near the sink node.

The remainder of this paper is organized as follows. First, in Section 2 presented the related works, Section 3 defines the proposed OF model to enhance the RPL protocol, we suggested an improvement RPL OF that considers three metrics (load, Residual energy, and ETX metrics) instead of only one metric, using 3 sink node instead of only one sink node. In Section 4, the simulation results are evaluated using Cooja simulator with three network scenarios (50, 60, and 70 nodes), and compare the results of the proposed protocol and MRHOF protocol, with many numbers of sink nodes (1, 2, and 3), in terms of the PDR, average packet loss ratio, average power consumption, average hops, average churn, and average ETX. Finally, Section 5 concludes the paper.

2 Related Works

Many papers tried to improve the RPL performance by applying multi sinks instead of only one sink, in Isik et al. (2012) the authors suggested a new routing protocol to choose the right sink for data packets at a source node by using fuzzy formulas. The protocol is intended to achieve one or more of the following goals: Reduce energy demand thus increasing reliability. The input to the algorithms is a proper subset of the follows, depending on the needs of the implementation: the number of preferred one-hop nodes referring to a sink, residual power of the nodes, the total distance between nodes, and the sink. The simulations are run at nodes regularly, taking into account all sinks. The best sink is chosen based on the algorithms' performance. The disadvantage of the protocols is that they make choices locally, rather than considering the state of data forwarding routes from end to end.

The routing protocols described in Guo et al. (2014) and Mitton et al. (2012) are designed to improve reliability. The routing protocol in Guo et al. (2014) tries to find and keep two separate data forwarding routes to each root node. Since the paths' error rates are independent, sending the same data packet over both increases efficiency. In Mitton et al. (2012) constructs an energy-efficient minimum spanning tree against K sinks out of a total of M sinks in a network, with K < M. To increase reliability, a data packet is forwarded to K root nodes. Sending identical data packets over many routes consumes energy and can cause network congestion. The routing protocols described in Kim et al. (2014), Djenouri and Balasingham (2010) build and retain the best data forwarding route to all sink nodes. This is achieved under the assumption that the sink is chosen by the program, and that the sink node for a data packet is not chosen by the routing protocol. The shorter hop-count, geographical length, the residual power of one hop downstream node, downstream node mean buffer occupancy, maximum buffer occupancy at two-hop nodes, and end-to-end energy depletion rate are all used to create gradient fields against sinks. A node broadcasts the information needed to construct the gradient field regularly.

In Tang (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 OF of the two single-metric RPLs are vulnerable. The authors propose a multi-path routing protocol for congestion avoidance, called CA-RPL, whose primary objective is to allow the network to respond to sudden events quickly and reliably. In order 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. In order 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 with up to 50 %, the output by up to 34 %, the packet loss by up to 25 %. Compared to RPL, the average delay was 30 %. The protocol proposed is based on ContikiMac, which assumes that all nodes have identical wake-up intervals that may not be present in all LLNs scenarios. Moreover, the DIO message carries several additional fields, which raises the possibility of fragmentation.

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 OF 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 OF. The Propagation Delay (PD), Node Congestion (NC) and Link Congestion (LC) are the key parameters of the proposed OF. Energy considers a secondary parameter and is thus integrated into the OF in such a way as to exclude or consider it as desired. The weight values of such OF parameters were calculated using Particle Swarm optimization process. OMC-RPL is simulated with four different traffic groups and OF 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 term 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 term 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 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 are 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 in order 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 less conditions. The disadvantage is that the results didn't test the protocol performance with random deployment of the nodes, only the grid deployment is tested.

In the paper Saaidah et al. (2019), by integrating multiple metrics of fuzzy logic, an improved (OF), OFRRT-FUZZY, is proposed. The suggested OFRRT-FUZZY takes link and node metrics into consideration. Received Signal Strength Index (RSSI), Residual Power (RE), and Throughput (TH) are the parameters. The OFRRT protocol was developed with fuzzy logic to improve the efficiency of standard OFs and choose the most effective path to the sink node. The fuzzy inference process (FIP) is used in this proposed protocol, which is defined as "a process of mapping from a given input to an output using fuzzy set theory" Negnevitsky (2005). The suggested solution uses three input linguistic variables to calculate a single output linguistic variable: (RE), (TH), and (RSSI). It includes four stages in the process 1- crisp input fuzzification, 2-rule evaluation, 3-rule output aggregation, 4- defuzzification. The OFRRT-FUZZY protocol has the better performance in terms of energy consumption and PDR, but the performance of the protocol hasn't been tested in large scale networks that contain more than 50 nodes, and didn't test the protocol performance with random deployment of the nodes.

In the paper Lamaazi et al. (2019), Using the additive composition approach, the protocol proposes a new flexible OF dependent on Consumed power, ETX and Forwarding delay (OF-ECF). This method allows for the development of a new composite metric that nodes use to choose the right parent. Instead of many metric choices, it returns a single definitive point. The OF-ECF protocol has a good performance in terms of PDR, but the results show that this protocol consume more energy than OF0 and MRHOF protocols, while the FUZZY OF does further calculations when choosing the favored parent, it consumes large power. We can conclude that these two proposed protocols are not suitable for the Low Power and Lossy Network environments. The paper 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 OF combination called OFEC in their paper, "objective function based combined metric using 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.

3 The Proposed Protocol

In the RPL network, the OF decides how to build the DODAG and chooses the parents to improve the route. To maximize energy efficiency, we proposed a new OF that incorporates three metrics. This objective role focuses on issues such as multi-point 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 own energy much quicker than other favored parents. To address this issue, we suggest a load metric that provides the number of children they have to each preferred parent. Based on this, we consider 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 (RE) metric was used as a measure of network lifetime. 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 (Bhandari et al., 2020).

$$\begin{aligned} Econ(x) = P_{sleep}(x) \times T_{sleep}(x) + P_{Tx}(x) \times T_{Tx}(x) \\ + P_{cpu}(x) \times T_{cpu}(x) + P_{les}(x) \times T_{les}(x) \end{aligned} \tag{1}$$

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

While we can calculate the Residual Energy as the Eq. 2 (Bhandari et al., 2020).

$$RE(x) = EMax(x) - Econ(x) \tag{2}$$

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

Data traffic is the sum of the data transmitted over the network at a given time. We 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 Eqs. 3 and 4, (Qasem et al., 2016) as follows:

$$NT = \sum_{i=1}^{n} CN(i) \tag{3}$$

$$L(Px) = \sum_{N=1}^{n} NT(N) \tag{4}$$

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.

Table 1: Network Simulation Parameters

Parameter	Value
Network simulator	COOJA under Contiki OS
Simulation application	Cooja simulator
Simulation area	200 m × 200 m
Number of nodes	50, 60, 70 nodes
Number of sink nodes	1, 2, 3 sink nodes
Nodes type	Sky mote
Topology	Random
Radio medium (Wireless Channel)	Unit Disk Graph Medium (UDGM) with distance lose
TX Ratio	100%
RX Ratio	100%
Transmission Range	50 m
Interference Range	100 m
Simulation Times	600 sec

4 Simulation Results Analysis and Network Setup

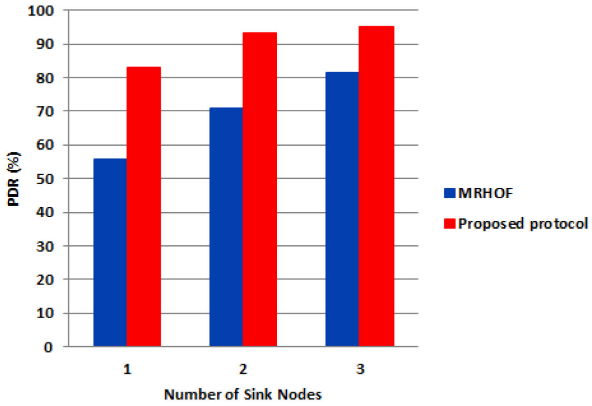
The simulation network parameters used in this study are presented in Table 1. The contiki3/ Cooja simulator was used to implement our networks, we test the results in terms of PDR, packet lost ratio, average power consumption, routing stability, average ETX, and average hop count to investigate the performance of the proposed OF. The application and the case study of this work is for a smart home, therefore, the number of nodes that are used 50, 60, and 70 nodes. We tested three scenarios (50, 60, 70 nodes), with the different number of sink nodes (1, 2, and 3 sinks). The transmission range of each node is 50 m, the interference range of each node is 100 m, and the simulation time is 600 sec.

4.1 Packet Delivery Ratio (PDR)

Figure 1 shows the packet delivery ratio (PDR) of the network with 50 nodes with the different number of sink nodes. The packet send is 10 packets per node in all networks. In the first topology the network with 50 nodes, when the number of sink node is only one, the results show that the PDR of the MRHOF protocol is 55.8%. In the second topology the network with 2 sink nodes, the results show that the PDR is 70.995%. In the third scenario the network with 3 sink nodes, the results show that the PDR is 81.49%. With the network of 60 nodes, when the number of sink nodes is only one, the results show that the PDR is 75.93%. The PDR increased to 84.855% when the number of sink nodes is 2, while it is 85.08% with 3 sink nodes. With the network of 70 nodes, when the number of sink nodes is only one, the results show that the PDR is 60.3%. The PDR increased to 79.45% when the number of sink nodes is 2, while it is 80.86% with 3 sink nodes.

The results show in Figure 1 the PDR increased in the proposed protocol, in the first topology the network with 50 nodes, and one sink node, the PDR of the proposed protocol is 83.2%. In the second topology, the network with 2 sink nodes, the results show that the PDR is 93.145%. In the third scenario, the network with 3 sink nodes, the results show that the PDR is 95.01%. With the network of 60 nodes, the number of sink nodes is one, the results show that the PDR is 86.17%. The PDR increased to 93.02% when the number of sink nodes is 2, while it is 95.55% with 3 sink nodes. With the network of 70 nodes, when the number of sink nodes is one, the results show that the PDR is 80.43%. The PDR increased to 90.24% when the number of sink nodes is 2, while it is 93.573% with 3 sink nodes.

PDR is an important network efficiency metric, high PDR means high network performance. The results show that the packet delivery ratio is highest when evaluating three sinks in the network, the PDR increased when the number of sink nodes increased, because the network is divided into many sub-networks, that means less hop count, less network congestion and higher PDR.



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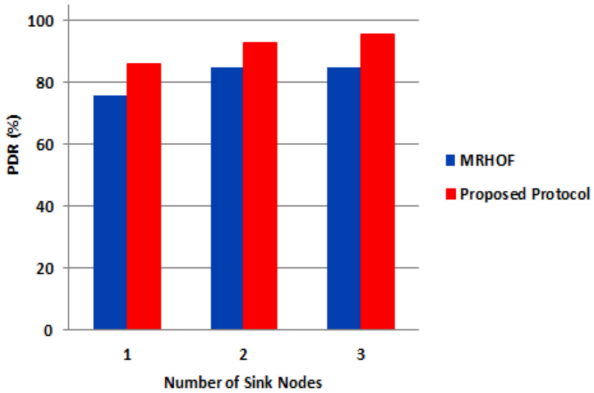

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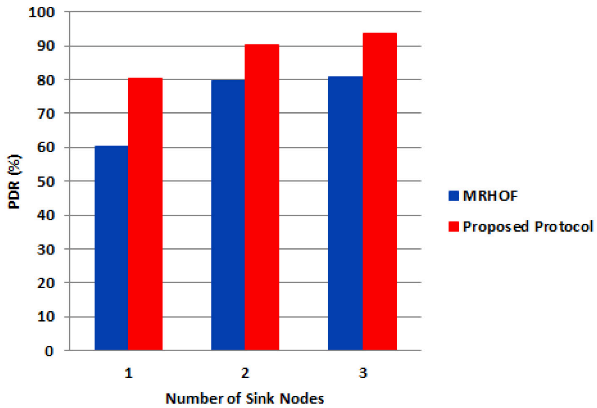
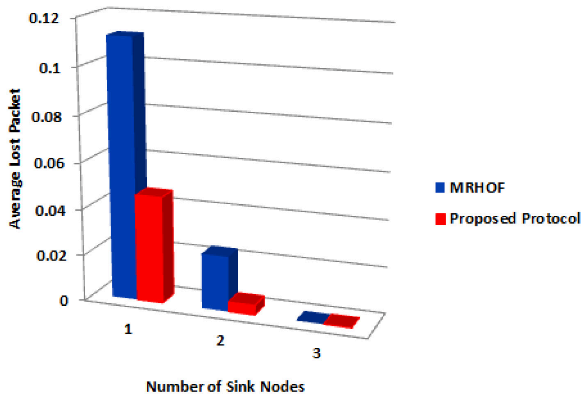


(c)

Figure 1: (a, b, c) Packet delivery ratio versus different number of sink nodes for (50,60,70 nodes). (a) 50 nodes . (b) 60 nodes. (c) 70 nodes.

4.2 Packet Loss Ratio (PLR)

Figure 2 shows the packet loss ratio (PLR) of the network for 50, 60, and 70 nodes with the different number of sink nodes. In the first topology the network with 50 nodes with one sink node, the results show that the PLR in the MRHOF protocol is 0.112. In the second topology, the network with 2 sink nodes, the results show that the PLR is 0.02375. In the third scenario, the network with 3 sink nodes, the results show that the PLR is 0.



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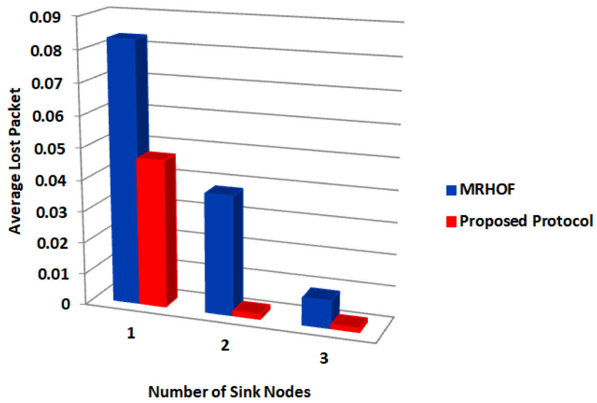

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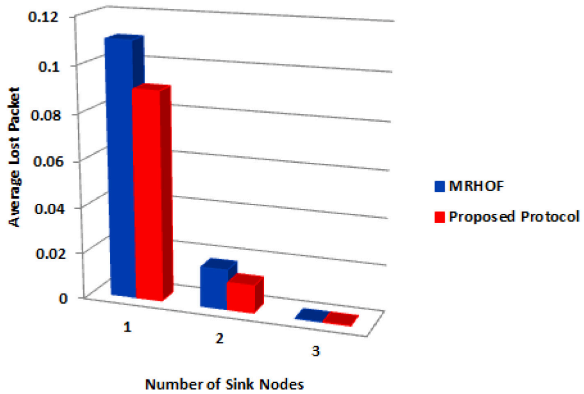

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Figure 2: (a, b, c) Packet lost ratio versus different number of sink nodes for (50,60,70 nodes). (a) 50 nodes . (b) 60 nodes. (c) 70 nodes.

With the network of 60 nodes, when the number of sink nodes is one, the results show that the PLR is 0.0831. The PLR decreased to 0.03785 when the number of sink nodes is 2, while it is 0.00863 with 3 sink nodes. With the network of 70 nodes, when the number of sink nodes is one, the results show that the PLR is 0.11. The PLR decreased to 0.01715 when the number of sink nodes is 2, while it is 0 with 3 sink nodes. The average PLR decreased with the proposed protocol, when the number of sink nodes is one for the network of 50 nodes, the results show that the PLR is 0.046. In the second topology, the network with 2 sink nodes, the results show that the PLR is 0.0042. In the third scenario, the network with 3 sink nodes, the results show that the PLR is 0. With the network of 60 nodes, when the number of sink nodes is one, the results show that the PLR is 0.0467. The PLR decreased to 0.00145 when the number of sink nodes is 2, while it is 0.0012 with 3 sink nodes.

With the network of 70 nodes, when the number of sink nodes is one, the results show that the PLR is 0.09. The PLR decreased to 0.0118 when the number of sink nodes is 2, while it is 0 with 3 sink nodes. When the number of sink nodes increase, the network performance increase, low congestion and low packet loss ratio, because the network is divided into two sub-networks, that means less network congestion and less PLR.

4.3 Total Power Consumption

Figure 3 shows the total power consumption with the number of nodes with the different number of sink nodes. In the proposed protocol, the total power consumption is decreased when the number of sink nodes increased, as we explained, the network divided into many sub-networks, that's mean less power consumption.

4.4 Average ETX

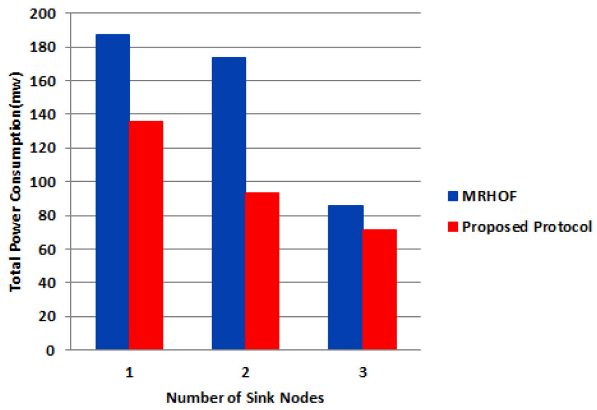
"The Expected Transmission Count (ETX) metric is an advanced routing metric for finding high-throughput paths in multi-hop wireless network, it can be defined as the expected number of transmissions which are required to send a packet over the communication link successfully. The path ETX is the sum of the ETX of all the links along the path. When ETX is applied, the nodes must select the parent that has the lowest ETX value". Each node calculates the path to the root node using ETX and chooses the parent with the lowest overall ETX to the root node. The following formula (5) can be used to measure ETX over a link.

$$ETX = \frac{1}{DF \times DR} \tag{5}$$

where DF represents the probability of receiving a packet from the neighbor node, and DR the probability of receiving an acknowledgment successfully. A smaller ETX means a high throughput path and a lower energy consumption, which indicates a better quality of the routes to the sink node. Figure 4 shows the average ETX for three network topologies (50, 60, and 70) nodes, with different sink nodes. The result shows that the networks with 3 sink have little ETX, which means better performance. The average ETX was decreased when the number of sink nodes was increased because the network divided into 3 sub-networks, that means that the nodes are closer to the sink, less hops, smaller ETX to reach the sink node.

4.5 Average Churn

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 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. Low churn means low parent switching. Figure 5 shows the behavior of the networks by measuring the average parent switching (churn) while implementing the topologies of 50, 60, and 70 nodes with the different numbers of sink nodes. The results show that the average churn is decreased when the number of sink increased because the network divided into many sub-networks, each sub-network has fewer number of nodes which means less number of hops, that make less churn to reach the sink node.



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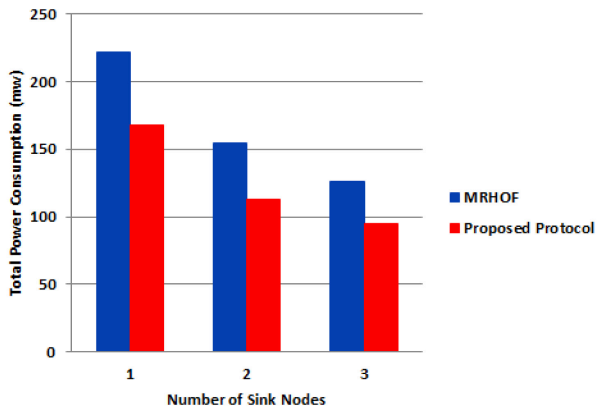

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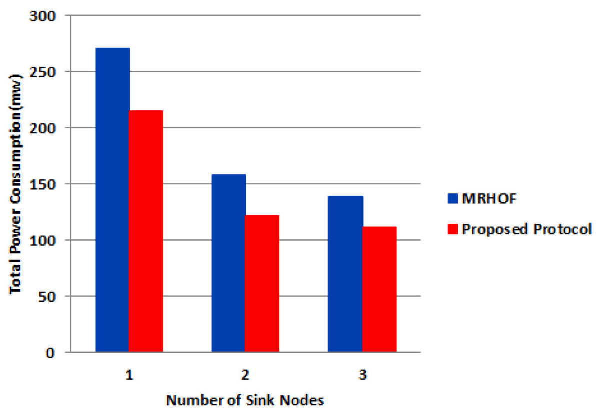
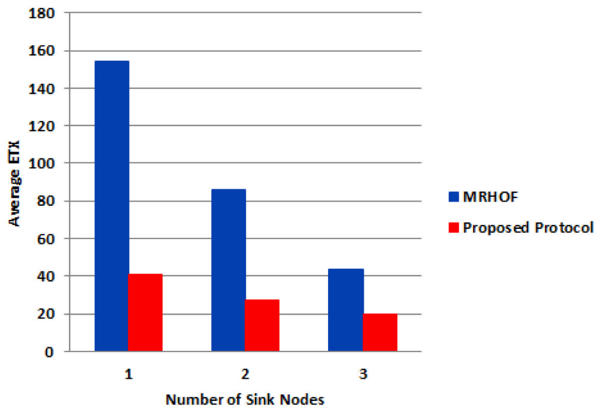


(c)

Figure 3: (a, b, c) Average power consumption versus different number of sink nodes for (50,60,70 nodes). (a) 50 nodes . (b) 60 nodes. (c) 70 nodes.

4.6 Average Hop Count

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. Figure 6 shows the average hop count for three network topologies (50, 60, and 70) nodes for the MRHOF and proposed protocol, with different number of sink nodes. The results show that the average hop count is decreased when the number of



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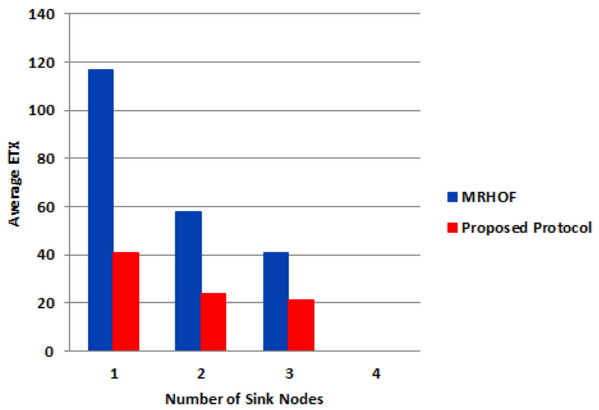

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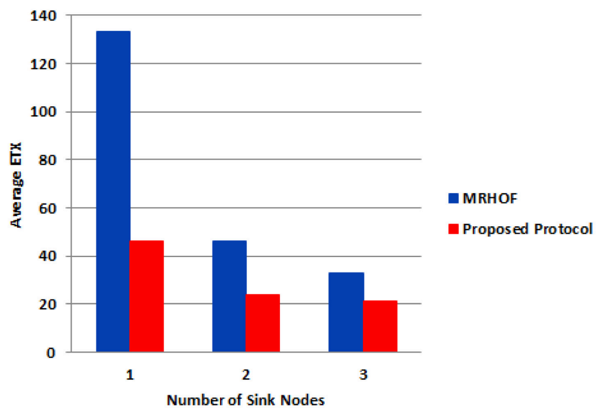
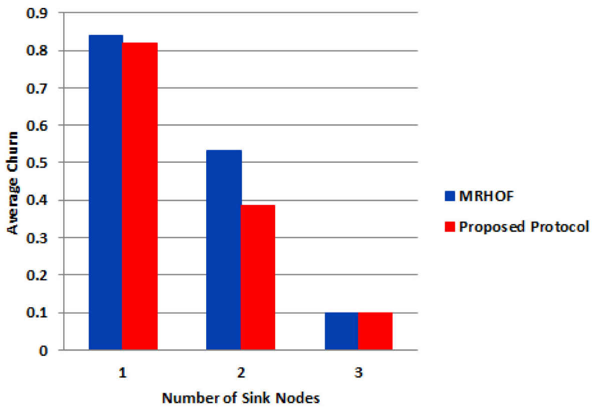


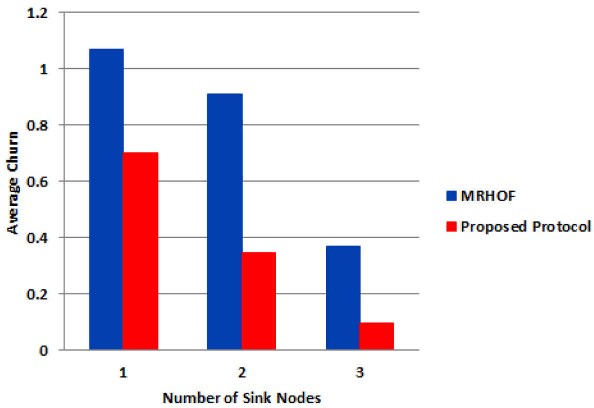
(c)

Figure 4: (a, b, c) The average ETX versus different number of sink nodes for (50,60,70 nodes). (a) 50 nodes . (b) 60 nodes. (c) 70 nodes.

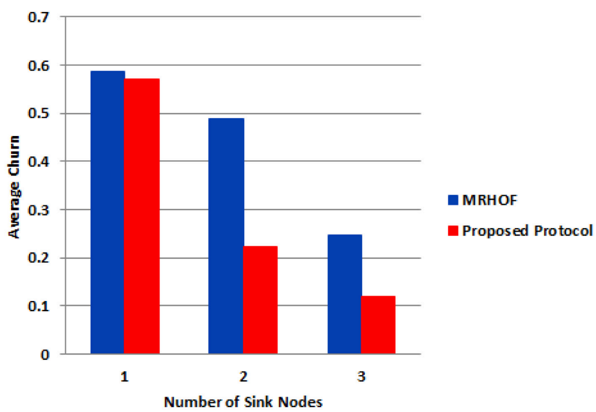
sink increased because the network divided into many sub-networks, each sub-network has fewer number of nodes which means less hop count to reach the sink node.



(a)

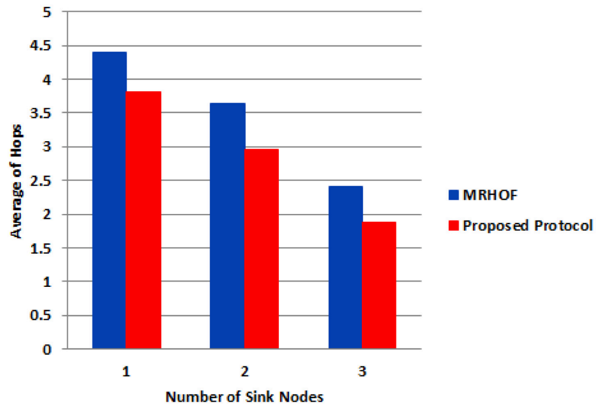


(b)

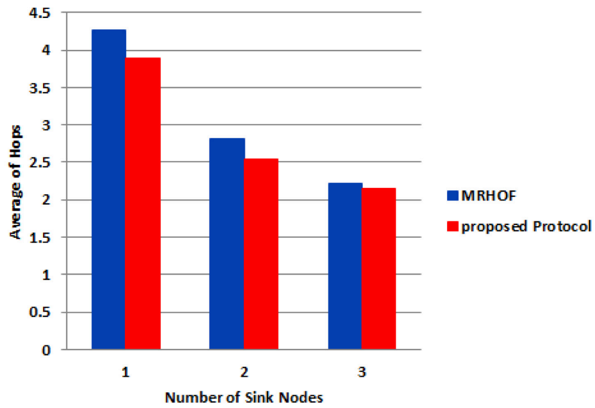


(c)

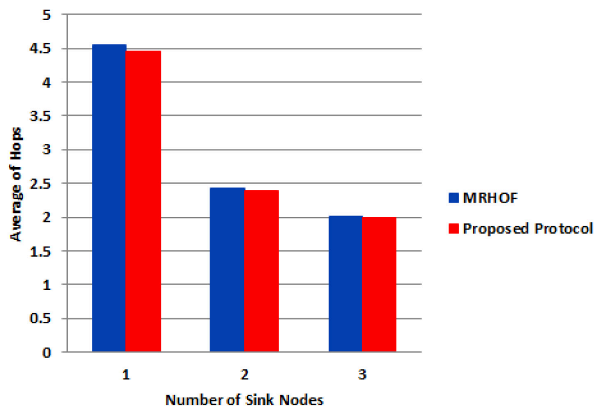
Figure 5: (a, b, c) Average Churn versus different number of sink nodes for (50,60,70 nodes). (a) 50 nodes . (b) 60 nodes. (c) 70 nodes.



(a)



(b)



(c)

Figure 6: (a, b, c) Average Hop Count versus different number of sink nodes for (50,60,70 nodes). (a) 50 nodes . (b) 60 nodes. (c) 70 nodes.

5 Conclusions

In this paper, an improvement of the MRHOF in the existing RPL protocol is proposed. A configuration based on a combination of three metrics (load, residual energy, ETX) is carried out. Contiki 3/ Cooja simulation program was used. The results indicate that in all network scenarios (50, 60, and 70 nodes), with the various number of sink nodes (1, 2, and 3), the proposed protocol effectively select a better routing path with 3 sink nodes instead of one sink node, and achieve the goal of lower packet loss ratios, higher packet delivery ratios, lower average ETX, and lower power consumption. In the network with 50 nodes, with different sink nodes (1, 2, and 3), the average PDR is 83.2%, 93.145%, and 95.01%, the total power consumption is 136.1 mW, 93.625 mW, and 71.45 mW, the average lost packet is 0.046, 0.0042, 0. In the network with 60 nodes, with different sink nodes (1, 2, and 3), the average PDR is 86.17%, 93.02%, and 95.55%, the total power consumption is 167.46 mW, 112.8 mW, and 94.8 mW, the average lost packet is 0.0467, 0.00145, 0.0012. In the network with 70 nodes, with different sink nodes (1, 2, and 3), the average PDR is 80.43%, 90.24%, and 93.573%, the average power consumption is 215.18 mW, 121.73 mW, and 112 mW, the average lost packet is 0.09, 0.0118, 0. For future work the following points are suggested: 1- Proposing an efficient trickle time algorithm that provides trickle DIO time to increase efficiency more. 2- It would be fascinating to research the RPL behavior with mobility models. 3- Designing an efficient RPL protocol in large-scale environments such as smart cities, where the nodes are combining static and mobile nodes.

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