Energy-Aware Path Selection to Improve Packet Delivery Ratio and Throughput in RPL Networks

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Abstract: Internet of things (IoT) is a concept that motivates researchers to develop their ideas into an innovative application. RPL stands for Routing protocols for low power and lossy networks. RPL is the routing protocol, designed for constrained devices. IPv6 and Low power and Lossy network (LLN) techniques make this protocol more flexible with IoT. It is used to route the packets from the one node to another node. Various issues are observed during the routing. In RPL, Node failure, Mobility, energy consumption and congestion are few problems that are observed during the routing. The above problems lead to some issues like Packet loss, path loss, low packet delivery ratio, High energy consumption, and so on. Existing objective functions OF0 and OF1 are used in the RPL protocols to support static nodes in Destination-Oriented Directed Acyclic Graph (DODAG). In this paper, a solution is introduced to overcome node failure in RPL. The node failure in RPL is addressed by using the energy-aware routing approach in the network. The proposed technique has two mechanisms: finding the node with minimum lifetime and parent selection process. This proposed work is evaluated using COOJA simulator.

Keywords: Internet of Things, RPL, Node failure

1. Introduction

The concept of the Internet of Things is used to perform complex tasks. Devices connected to the physical environment are used to sense the data from the physical world. The data collected from the sensing layer are transferred from the Source node to the Destination node or from the Destination node to the Source node . The data are transferred with the help of the routing protocols. There are different types of protocols such as RPL, LOAD, LOADng, 6LOWPAN. In this article, the RPL protocol is considered.

RPL is specially designed for the IoT. The concept behind the RPL protocols is routing the information with low power and lossy network (Adewumi,2013). In RPL, routing begins after constructing the DODAG. DODAG is constructed based on the objective function. There are two types of objective functions: OF0 (ETX), OF1 (HOP). Each DODAG adopts a different rank calculation based on the objective function method.

Once the routing request is initiated at the Source node, the Source node broadcasts the control messages. DIO (DODAG information object), DAO (Destination Advertisement Object), DAO-ACK (Destination Advertisement object acknowledgement) and DIS (DODAG information solicitation) are used for the construction of DODAG in RPL. The Source node broadcasts the DIO message to the neighbour nodes. The broadcasting of DIO control message is continued until it reaches the Destination node. The position of the Destination node is not known to the Source node. The Source node will have the address of the Destination node. The node that receives the DIO message will reply with DAO message. The node selected to transfer the packet will receive the DAO-ACK from the Source node.

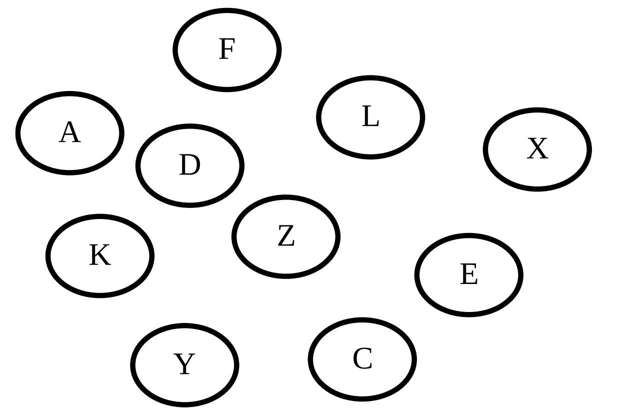

Figure1.1. Sample DODAG

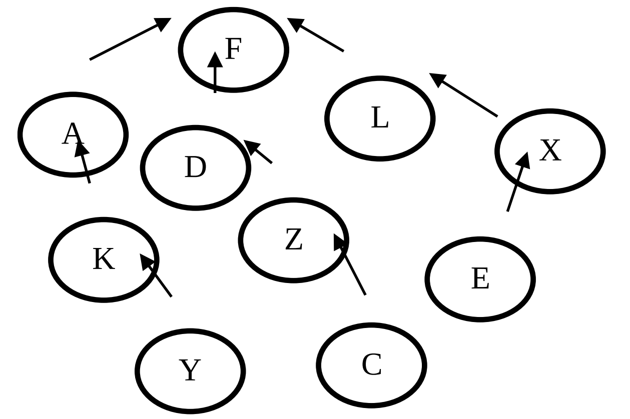

Figure1.1. Sample DODAG

Function used to construct the DODAG is OF0. Source node F sends the DIO messages to the neighbour node A, D and L. Node A, D and L send the DIO messages to their neighbour nodes. The nodes send back a DAO message from where they receive the DIO message. After transferring the DAO messages, DAO-ACK messages are generated and broadcasted to the neighbour node. After constructing the DODAG, routing process will begin from the Destination node to Source node. The above steps are followed by RPL protocols for constructing and transferring the packets in the network.

During routing in RPL, some of the issues are observed. They are network congestion, node failure, energy, path loss, load balancing and so on. In this paper, node failure due to minimum lifetime of a node is considered as the focus areas to enhance the performance of RPL protocols.

In general, RPL supports the static nodes in the network. In the network, due to the presence of node with minimum lifetime in the network, the impacts are observed. Some of the impacts are delay in execution, high packet loss, and decrease in packet delivery ratio, path loss and so on.

In this paper, to overcome node failure in RPL, a work is proposed to detect and monitor the nodes in the network. If the execution is stopped due to node failure or once the node with minimum energy is detected in the network, a parent selection process is initiated. While selecting the alternative path, distance and energy of the node is considered for the parent selection. Through this proposed work, the trustworthiness of the node is increased by a proactive approach.

2. Review of literature

RPL is a protocol, which is designed for the IoT. Routing of packet will begins after constructing the DODAG. The objective function used to construct DODAG will support the static nodes. In a network, the node with minimum lifetime is identified while the error occurs and an alternative path selection method is introduced to reconstruct the path.

Sheeraz et al , developed a route maintenance and recovery mechanism (RMR) to enhance the performance of the RPL protocol. RMR was developed to minimize reconnection time and to reconstruct the reliable path. This proposed work was compared with the existing RPL protocol. Contiki Cooja simulator was used to simulate this proposed work.

Sebastian et al, proposed a work to overcome the issue of node failure in the network using the RPL protocol. The author introduced this technique to reduce the energy consumption during the routing. This work was simulated using the OMNeT++ simulator.

Ahmed Al-Dubai et al (Bhasha, A. C,2019), introduced an enhanced RPL to address the issue of node failure (lack of memory) during routing. This work was introduced to increase the reliability of alternative paths. This issue was mitigated by adding storage limitation of the node’s preferred parent. This work is compared with existing RPL protocol using Contiki Cooja simulator.

Habib Yousef et al (Brachman, Agnieszka. RPL objective function impact on LLNs topology and performance. In Internet of things, smart spaces, and next generation networking), designed and implemented a proactive scheme to predict and mitigate node failures. This work evolved in terms of packet loss and energy consumption. This mechanism was evaluated using Contiki Cooja simulator.

Sheikh Tahir Bakhsh (Ezhilarasi T.P,2020), proposed an energy-efficient distributed relay selection (EDRS) technique. This proposed work reduces energy consumption and increases the network life time. EDRS technique was compared with existing Random Relay mode (RRM) and direct mode (DM) techniques. Contiki Cooja simulator was used for the simulation.

Sankar et al, proposed a fuzzy logic-based energy-aware routing protocol. Routing metrics like load, residual energy and ETX are considered for selecting alternative routes. The author used the Contiki Cooja simulator to evaluate the proposed work. This work was compared with RPL, MRHOF-(Minimum Rank with Hysteresis Objective Function) and FL-RPL (Fuzzy Logic- RPL). The metrics considered for the evaluation are packet delivery ratio (PDR) and network lifetime.

Martin Hope et al(Kim, Hyung-Sin,2017), introduced a new objective function is introduced to construct a path, which discards disadvantages and to enhance the QoS in Internet of Things. Packet delivery ratio and Delay are considered for evolving the proposed work. The performance of Objective function was simulated in Contiki COOJA simulator.

Celestine Iwendi et al (Gaddour, Olfa,2012), designed an energy-efficient routing algorithm (EERA) to select the shortest reliable and efficient path for transmitting the packets. Concept of ant-colony optimization and key-management technology are used to select the optimal path for sending packets. EERA algorithm was compared with long-hop first-scheduling algorithm (LHFSA) and Energy-efficient secured-routing (EESR) protocol.

According Zahra et al (Kim,2017), the default objective function used in the RPL protocol is ETX. The result implies that the calculation used in ETX to compute the rank value is not enough for constructing the path. In order to overcome this issue, the authors have introduced a new ETX computation method for constructing the DODAG with better rank computation for selecting the routes. Throughput, end-to-end delay, packet delivery ratio and number of retransmission were considered for the evaluations.

In RPL, the node selects the parent through an objective function. Tomas Lagos Jenschke et al, proposed a new objective function called packet replication and elimination method (PRE). The objective function was introduced to enhance the reliability and minimize jitter. Contiki COOJA simulator was used to evaluate the performance of the proposed objective function.

Adeeb saaidah et al (Iwendi,2018), argued that Open Shortest Path First (OSPF) was inefficient to satisfy the LLNs. Objective function used in the RPL considers single metric. This approach is unable to accommodate the application need. Through this article, the authors have introduced new objective OFRRT-FUZZY by using node and link metrics. New objective function is compared with the existing objective OF0 and MHROF. Simulator used for simulating is Contiki Cooja. Received signal strength indicator (RSSI), Remaining Energy (RE) and Throughput (TH) are considered for developing new objective function.

Loganathan et al (Jenschke,2019;Kulau,2017;Khelifi,2015), compared the performance of the objective function HOP, MRHOF-ETX and MRHOF- Energy. OF0 (HOP) and OF1 (ETX) are the existing objective functions used in the construction of the shortest path in RPL protocol. After comparing, the author develops a new objective function to enhance the lifetime and to reduce the power consumption.

Sathya Lakshmi Preethi et al, proposed an energy-efficient routing protocol for low power and lossy network. The authors introduced a new path-selection technique by combining the ACO (Ant Colony optimization) and dynamic trickle algorithm for energy-efficient DODAG. ACO technique considers three factors such as compute rank value and energy of the node to identify the nearest node. Dynamic trickle timer algorithm is used to select the energy-efficient node. Energy and packet delivery ratio are considered for the evaluation. This proposed work is evaluated in Contiki Cooja simulator (Ranjeeth,2020;Satanasaowapak,2018;Suganya P,2020).

From the above review, it is clear that the performance degradation seem to occur due to energy issues. In this paper, a new technique is proposed to overcome the node failure. The main idea of this paper is to detect the nodes with minimum energy in a dedicated path and Energy-Aware routing in RPL.

3. Proposed Work

In RPL, the problem of node failure is addressed by proposing a new mechanism. The new mechanism used to find the node with minimum lifetime in the network. New proactive parent-selection scheme is introduced to select the alternative parent. Identifying the node with minimum lifetime is a big challenging task in the network, the reason being that RPL protocols are reactive protocols. Once the issues occur, then the solutions are identified during the routing. The existing objective function used in the RPL reduces the reliability and performance of the protocols. The proposed work has two mechanisms. Through this proposed work, the node with minimum lifetime is identified before it gets disconnected from the network. After identifying the node with the minimum lifetime, the packets are re-routed by choosing the alternate path to the Source node.

3.1 Identifying a node with a minimum lifetime

The DIO messages are broadcasted to the neighbour node to find the nearest node. The neighbour nodes reply with the DAO-ACK message. RPL protocol finds the alternative parent from the routing table. Neighbour node information is stored routing table. Based on the information, routing paths are constructed. In the existing work, the concept of RSSI is used to find the node's communication range in the network m-RPLv1 , ImRPLv2 and LNR-PP . Once the path is constructed, based on the energy, life time of the parent nodes are calculated. The energy level of the node is stored in the table, and they are maintained until the routing completes. The stored information of neighbour node energy values are monitored periodically. If the energy value is greater than the threshold value, then the routing will proceed in the same path. If the energy value of the node is less than the threshold value, then the parent-selection process is initialized. Threshold value is fixed as 25%.

3.2 Path Construction in RPL

1. Routing Request is initiated in the Source node.
2. The Source node starts sending the DIO control messages.
3. Neighbour node replies with DAO messages.
4. Based on the rank value, paths are constructed.

3.3 Working procedure of the proposed work (Node with minimum lifetime)

4. After constructing the path, lifetime of the nodes are calculated using the formula 2 and 3.
5. The energy values are calculated periodically until the routing completes.
6. If the energy value is greater than the threshold value (25%), then the routing will proceed in the same path.
7. If the energy value of the node is less than the threshold value (25%), then the parent -selection process is initialized.

3.4 Parent-selection procedure

In this proposed work, the concepts of RSSI and energy are used to address node failure and energy-aware routing in the network. Once a node with minimum lifetime is identified, then the child node initiates the parent-selection process. The parent node identifies the neighbour node information from the routing information table. The routing information tables contain the information of the nodes that are selected as a parent, nodes' ranks, neighbour of the child node and information of the child node. The above information is stored until the routing is completed. Here, the path is constructed by using the concept of RSSI and energy to select the alternative path construction to complete the routing.

3.5 RSSI

The concept of RSSI is used to find the distance between two nodes. The range of RSSI value is between -10dBm to 92dBm. Based on the range value, the parent node identifies the child node in the network. The concept of the RSSI is used for finding the nearest node in the network. If the RSSI value is low, then the node is considered as the nearest node to the parent. If the RSSI value is high, then the node is far away from the parent node. The RSSI Minimum value is -10dBm for Low rate wireless personal area network (LRWPAN).

1. The RSSI value of the node is calculated by using the formula (17)
2. RSSI = -10*n*log (d) +A
3. A-Received signal power
4. n- Path loss index
5. d- Distance

If the energy value is low, then the parent node initiates the path-selection process. The RSSI values are calculated from the parent node to the neighbour node. Figure 3.1 explains that A is a Source node, L is a Destination node, and D is the node with minimum lifetime. Now, node D left from the position; then, node G initiates the parent-selection process. The neighbours of node G are H, E and B. The RSSI value of node H, E and B are calculated from node G. The node with the minimum RSSI value will have the highest priority.

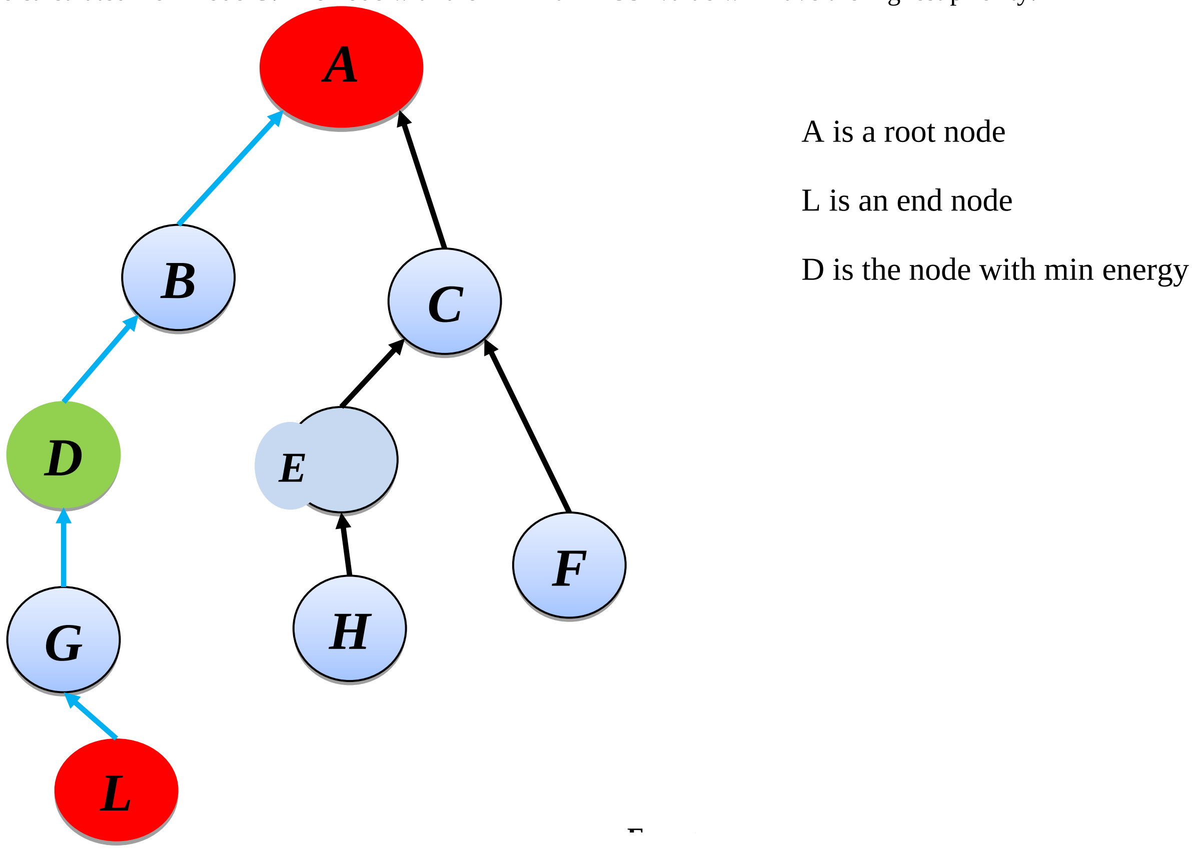

Figure 3.1. RPL scenario

While reconstructing the path, energy plays a vital role and is therefore considered so that the path may not be disconnected. This issue may occur if a node with low energy is selected as the parent node. It may leave during execution or before starting the execution. This may lead to an increase in execution time. Once parent selection request is initiated at the parent node, it starts calculating the energy of the neighbour node. Here, in this work, energy is considered to avoid selecting the node with minimum life time. Based on fig 3.1, node G initiates to calculate the energy of the neighbour node. Energy of the node H, E and B are calculated by using the formula

EC = iE- rE --2

Ne=Max E-Ec --3
Ec = Energy consumed
iE=Energy at initial stage.
rE = Residual energy of the node
Ne = Node energy
Max E= Maximum energy (100)

Table 3.1 RSSI value of neighbour node G

S.No	Node	RSSI
1	B	-64
2	E	-45
3	H	-41

Table 3.2 Energy of neighbour node G

S.No	Node	Energy
1	H	80
2	E	87
3	B	88

Parent selection process is carried using the above two formulas (RSSI and Energy). Calculated values of RSSI and the energy of the each neighbour node are stored in the table. Tables 3.1 and 3.2 show the energy and RSSI value of the neighbour node G. The RSSI values are sorted in ascending order and energy is stored in descending order. This sorting technique is used to choose the node with minimum RSSI value, and the node with high energy will be selected as a parent.

3.6 New parent selection process

1.The Child node broadcasts the control message to the neighbour node.
2.Identify the neighbour node position by using the RSSI value and store it in the table
3.Calculate the energy of the neighbour node
4.Select the alternative parent
5.Re-route the packet via the new path

4. Scenarios and Discussion

4.1 Scenario - 1

As observed in Fig 3.1, Node E has energy 87, Node H has energy 88, the RSSI value of Node H is -41, the RSSI value Node E is -45, Node H has minimum RSSI value when compared to the Node E, and the energy of Node H is greater than that of Node E. Table 3.3 contains the energy value and condition. If the energy values are above 80, then the node strength is good to route the packet. If the energy value is above 30 to 80 then consider as medium strength to route the packet. If the energy value is below 30 then the node is not fit to transfer the packet.

Table-3.3 Categorization of energy

S.No	Energy value	Condition
1	>=80	Good
2	30<=80	Medium
3	<30	Bad

Table3.4 Comparison 1

S.No	Node	RSSI	Energy
1	E	-45	87
2	H	-41	88

Table 3.4 contains the information like RSSI and energy of the node E and Node H. In this case, the priority-based parent selection is set. The energy of the nodes are evolved to select alternative node. The Signal strength of the nodes is categorized into three aspects: Nodes with high energy, medium energy and low energy. If the energy level is greater than 80, then the priority level is good.

If the energy level is greater than 30, then the priority level is medium. Energy levels less than 30 priority level are poor. Depending on the priority level, the node selects the parent. If the priority level is poor, then the node selects the alternative node from the table. Now, from the table, the node with high priority and node with minimum RSSI value is selected as the alternative parent. Here, in this case, the node sends packets in the direction of G-H-E-B-A.

Table3.5 Priority

S.No	Node	RSSI	Energy	Priority
1	E	-45	87	1
2	H	-41	88	1

4.2 Scenario - 2

As observed in Fig3.1, Node E has energy 87, Node H has energy 88, the RSSI value of Node H is -41, the RSSI value Node E is -45, Node H has minimum RSSI value when compared to the Node E, and the energy of Node H is greater than that of Node E. In this case, Node G chooses Node E as alternative parent. Now, the routing will proceed in the direction G-E-B-A.

5.Conclusion

Energy-aware path selection process is introduced to overcome the node failure in RPL. In this proposed work, two approaches are introduced for identifying node with minimum energy and Parent-selection process. The node with minimum energy present in the dedicated path are identified. If the energy of the node greater than the threshold value then the routing will proceed in the existing path. If the energy value is less than threshold value then the parent selection process initialized to select alternate parent. In Parent-selection phase, the concept of RSSI and energy are used to select the alternative parent among the neighbours. The concept of RSSI is used to find the nearest node in the network. The node energy is considered to avoid selecting the node with low energy. Packets are transferred continuously without disconnecting from the network by continuously monitoring the energy value of a node. This increases the packet delivery ratio and decreases packet loss. This work can be enhanced by considering the delay in the parent-selection process.

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