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A Survey: Specific Aspect of the RPL Protocol and its Enhancements

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Abstract*:* Today, the era is of smart devices. Whenever smart devices come in the picture, Internet of Things (IoT) has to be a matter of discussion. Moreover, all devices becoming mobile nodes and are low power and lossy in nature which are used in Low Power and Lossy Networks. Many challenges are there in this area which leads the researchers to work upon routing, connections, transferring data, communications between nodes while all or few are mobile in nature, etc. In context with this, IETF group developed a routing protocol used in 'Low Power and Lossy Network – RPL' which is recommended for static network in the beginning and then many enhancements have been made on it. In this article Low Power Wireless Network (LPWN) with the detail model of RPL protocol has been introduced. The formation of DODAG and how the communication is done between various nodes in RPL through control messages has also been taken into consideration. The heart of RPL system is Objective Function. OF0 and MRHOF are primary objective functions but cannot work in current mobile network when broken connectivity is there. Here, authors have surveyed many enhancements of RPL protocols and discussed them in brief. The analysis of enhanced RPL reveals that many of the issues encountered by the RPL routing protocol when dealing with mobility, such as inefficient handling of control messages, recreation of DODAG, mechanisms for mobility tracking and selection of preferred parent, energy consumption of the node, and data loss, have been addressed.

Keywords: *Internet of Things, Low Power Wireless Network, Objective Function, RPL*

1. Introduction

Internet of Things (IoT) is taken into consideration the future of the next generation. The essential goal of IoT is to attach all heterogeneous devices on the Internet, which includes small and optimal devices as well. Because wi-fi nature and environmental context is used in IoT applications like smart cities, smart house, and healthcare monitoring, uses the devices which need low-power and having low-cost. In the IoT domain, there exist various issues related to routing of IP packets. To address this, the 6LoWPAN protocol was developed which allows for IPv6 communication over IEEE 802.15.4 links through an adaptation layer. RPL was then developed by IETF as a Routing Protocol for Low-power and Lossy Networks, which facilitates the connectivity of constrained devices to the internet. However, the standard RPL specification is quite complex and hence there is still scope for further research and enhancement in this area [3].

An IoT tool is mixture of various types of sensor devices and a wi-fi communication aspect. The sensor device is accountable for collecting data, at the same time the wireless module has exclusive radio range and transmission power based on the requirement of the IoT applications. The radio technologies utilized by IoT devices have characteristics like small broadcast range and less power utilization, because many IoT appliances may be operated by battery. The hop - by - hope model is used by IoT devices. In wireless network multihop communication led to delay in the grid because it uses a significant amount of energy, as well as packet loss. In today's network many IoT applications are working with both static and mobile devices in the network, asking for multi-hop communication. So frequent topology changes in this kind of environment, mobility of nodes and hop-by-hop communication require a robust routing protocol [4].

For LLN there is an essential need for efficient routing protocol which should rapidly detect mobility which may lead to less amount of packet loss because of movement of devices and decreases discontinuation outcomes. Initially the RPL protocol designed by IETF was used in static LLN network topologies only. Consequently, when it is used in mobile topologies it faces some issues like low Packet Delivery Rate (PDR). Many researchers have done enhancements in RPL, that's why it can be used in mobile scenarios too. Some of the RPL problems can be observed associated to lake of detection of mobility tools and effective way to select preferred parent in which mobility is taken into consideration [4].

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Within the domain of the Internet of Things (IoT), particularly in the context of LPWNs, the issue of mobility has posed a significant challenge and has been a bottleneck for the research community. Over the course of the past few decades, numerous varieties of standards and protocols to facilitate the adoption of LPWNs have been put forth. This paper aims to outline some of these standards and their associated mechanisms, as well as examine various works pertaining to multiple RPL Objective functions.

RPL is the primary protocol used for routing which is identical in solutioning in Low Power and Lossy Networks. Though, researchers have done much research in comparison with its performance. Henceforth, the valuation and thought of understanding the RPL's behavior in various situations and environments are critical to differentiate its necessity and constraint, that permits to make it even better [3].

2. Motivation

As already mentioned previously, in the beginning, RPL was originally evolved for static topology networks. But now a days, support of mobility is a necessity for many IoT utility application environments. It faces many performance issues because mobile nodes are present in the network topology. Mobility creates an issue related to loss of packets and recurrent discontinuations. However, RPL can be tailored for improved mobility support. Further, while managing node mobility we assess RPL boundaries, and the various enhancements to provide better mobility support in RPL in the upcoming literature.

3. Background

3.1. Low Power Wireless Sensor Network

As depicted in Figure 1, through the Internet the main router is connected to local server. To the main router the other sink routers which are Low Power Lossy Network (LLN) Border Routers are connected. LLN Border Routers are considered as gateway to the mobile network. Physical Access Points (APs) can be observed in the Low Power Wireless Lossy Networks (LPWN). Mobile nodes are also part of the LPWN which can connect to any of the AP using the connection metric used in particular protocol. The APs or Mobile nodes (MNs) can be different types of sensor nodes. These sensor nodes consist of embedded communication equipment like microprocessors, transceivers, and power sources. All the nodes are having capacity to sense, process and fetch the information from the network. Any IoT device available in the market can sense the parameters like high temperature, light, power line voltage signal, various body functions like heart beats, oxygen levels etc. These devices are light weight, small in size and low cost as well.

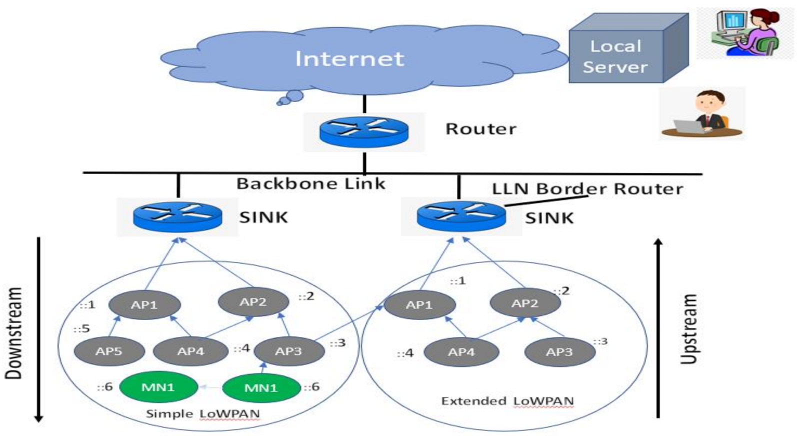

Fig. 1. Low Power Lossy Network

3.2 RPL - Routing Protocol for Low Power and Lossy Network

The IETF's 'Routing over Low power and Lossy network (ROLL)' team has devised the RPL, a Routing Protocol for LPWNs that operates on the IPv6 platform. RPL employs the concept of distance vector routing protocol and is executed on top of IEEE 802.15.4 Physical and Data Link layers. The nodes are arranged in a Destination-Oriented-Directed-Acyclic-Graph (DODAG) topology, where each router can identify a group of parents, typically a next-hop towards the DODAG root. The optimal parent is selected based on the metric used or any constraints among other contenders in the protocol. In Figure 2, the choice of a parent is determined by the lowest rank value, i.e., the shortest distance between the node and the root node. RPL can support various network traffic types such as point to point, point to multi-point, and multi-point-to-point communication. Each network comprises Low power and lossy network Border Router (LBR), routers, and hosts. RPL facilitates bidirectional links to enable traffic in both directions, upwards and downwards.

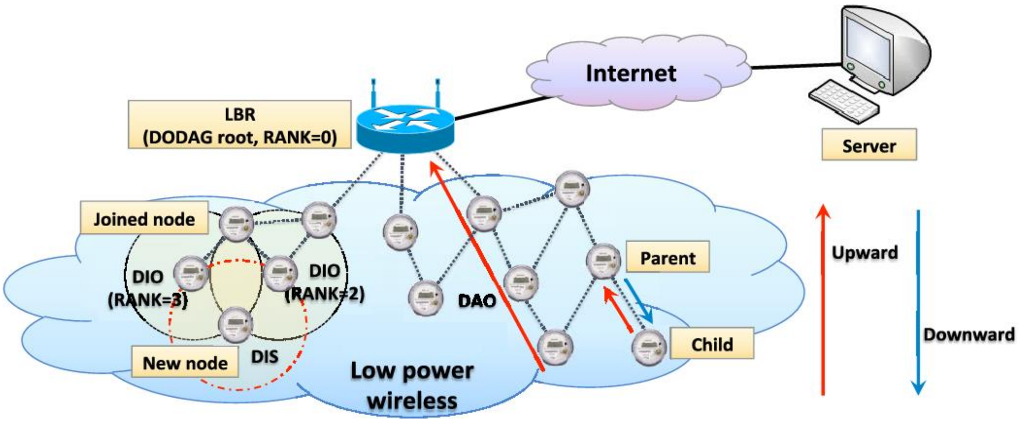

Fig. 2. RPL with a single DODAG [5]

During the network formation process, RPL creates a topology resembling a tree structure, with the border router (LBR) serving as the root node, and the host and other routers establishing links to enable bidirectional communication across the entire network. The rank is assigned to every node in the RPL network, which says its position from the LBR which has a rank of minimum as zero. In the tree topology the rank increases in the direction of the leaf nodes of the DODAG. The objective function is used to calculate a rank value. The OF is nothing but the routing metrics used to form the network. At the time of parent selection, the specific mechanism is used to reach the parent and control messages in the network. Neighbor Discovery (ND) algorithm is used to access the parent reachability and to propagate the control information, Trickle algorithm is used to build the routes in upward direction of DODAG using DIO. The following network parameters are a part of information carried by the DIO [1].

- RPL Instance ID - a distinctive identifier used to determine the networks which share the similar objective function as a metric.
- DODAG ID – A unique identifier is used to identify the DODAG root within the RPL Instance.
- DODAG Version Number – Whenever the DODAG is reconstructed, this is a sequential counter which is incremented.
- Rank of the Node - is an identifier of nodes' position from the root node based on the selection of the preferred parent within the network. It is not a path cost [1] but the value can be calculated by path metric. Its computation depends upon its own technique like Objective Function (OF) which is used to check the distance between a node from the root node. The rank of the root is considered as zero and it increases by one towards the leaf nodes in the tree topology to 256.

To maintain and construct the network, internet control messages (ICMPv6), are used to construct and preserve the information of logical network topology. This information can be related to neighbor parents, routing table, paths, etc. To confirm the stability and connectivity of nodes' these parameters can also be used to check the network links in the network.

To exchange the information and maintenance of the topology, RPL protocol uses four different kinds of control messages.

- DODAG Information Object (DIO)
  The node capable of becoming a root node or a parent node, multicasts DIO control message with the RPL instance in the downward direction. This permits other sensor nodes to receive the IPv6 address of the root node, existing RPL Instance, the existing rank of the node and allow them to join the network.
- Destination Advertisement Object (DAO)
  After receiving the DIO message from the root node or a parent node, DAO is the request from the leaf node to join in the DODAG as a child.
- DODAG Information Solicitation (DIS)
  When a leaf node can't hear any announcement from anyone, then it is able to send a request message called DIS. This is called Neighbor Discovery in which DIS allows for a request by leaf node to the DIO message to find out the neighbor.

Three types of nodes are there in the RPL topology or network.

- Root nodes: it is known as gateway node of the network which offer connectivity to the leaf nodes.
- Router: Other than root nodes these are the routers used to send the information related to the topology and routing tables to the neighbor nodes.
- Leaf (child) node: it is not capable of sending DIO message and can only join the DODAG after positive acknowledgement.

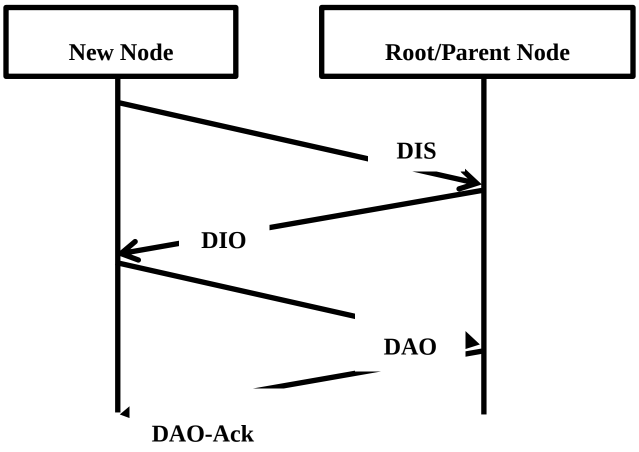

Fig. 3. Control messages for RPL protocol

Almost in all routing protocols it has been seen that the control messages are broadcasted at a specific interval which causes the energy depletion of the device when it is steady. Therefore, Trickle algorithm is used in RPL protocol to manage the transfer rate of DIO messages from the root node or a parent node. These control messages will be sent frequently in the situation where the topology changes more often [6].

RPL includes an Objective Function (OF) module that can be used by nodes as a metric to optimize or construct a network. In Contiki OS, RPL creates a Destination-Oriented Directed Acyclic Graph (DODAG) based on the OF, which includes the path metric, node policies, and rules to avoid loops that depend on the rank value. The OF determines the best parent node for each child node by using a metric suitable for the application. In RPL, each DODAG instance is associated with an OF, which nodes use to send information via the optimal path to its destination. An Objective Function that utilizes routing metrics is used by RPL to establish routes and identify the most appropriate parent for each child node. [1].

The RPL protocol, which is implemented in Contiki OS, has two objective functions: OF0 and MRHOF. OF0 uses the hop-count as a metric to assign ranks to nodes, while MRHOF uses a link quality measurement called ETX to determine ranks. Furthermore, various metrics have been developed in the past within RPL and other routing protocols, as listed in reference [1].

- remaining energy of a node,
- end to end delay,
- received signal strength indicator (RSSI), and
- Local traffic in the network topology.

To achieve reliable Objective Functions in the network, in the following part of paper some examples of RPL Objective Functions with their limitations are described.

3.2.1 OF0 Based on Hop Count

In Contiki OS, OF0 is utilized as the default objective function for achieving interoperability among networks. This objective function operates on the network layer and optimizes the network by selecting neighbors with the lowest rank value based on hop count. This method can be compared to the use of a shortest path protocol towards the destination, where the preferred parent is chosen based on the number of hops between a given node and the sink node, in comparison to other nodes in the network. The rank of the root node is set to zero and increases towards the leaf nodes.

OF0 is not a mechanism for assessing the features or burdens of the selected parent node. As a result, nodes that are nearer to the destination node may receive a higher volume of traffic, which can result in a reduction in the battery life of the nodes. Furthermore, in situations involving mobility, nodes with lower rank values may experience issues with link quality owing to environmental variables, resulting in packet loss. To guarantee network reliability in mobile settings, it is critical to use a metric like received signal strength (RSS) or ETX at the link layer.

3.2.2 Minimum Rank Hysteresis OF (MRHOF) Based on Expected Transmission Count (ETX)

To construct the DODAG in RPL another objective function which has been projected by ROLL working group is MRHOF. Which uses the concept of ETX and the node's remaining energy on additive link layer [7]. The ETX metric was introduced as a way to measure the effectiveness of wireless transmissions at the MAC layer, indicating the probability of a packet successfully reaching its destination. Its value ranges from 1 to infinity, with "1" representing 100% throughput and higher numbers indicating decreased throughput. The ETX value of a given route is determined by "calculating "the probability of successfully delivering data packets" and the "probability of receiving acknowledgement packets at the source". The formula for calculating link ETX is shown in the equation. (1).

$$\text{Link ETX} = 1 / (df * dr) \quad (1)$$

Where "*df* represents the forward delivery ratio" and "*dr* represents the reverse delivery ratio".

The calculation of ETX depends on the packet delivery ratio at a sender node to packet reception ratio at a destination node, which has a direct impact on the throughput. However, it does not consider the fact that routes with a larger number of hops may have lower throughput due to interference between different hops on the same path.

The benefit of ETX metric is minimum latency can be achieved in the network because it calculates the number of transmissions required for a packet to reach its destination successfully. Nevertheless, it does not guarantee minimum latency within a specific time frame for routing data. [7]. To put it differently, in a network with mobile nodes, routing tables may not be updated promptly, rendering the ETX metric unsuitable for timely and dependable information delivery. This is because the metric does not fully account for the received signal strength, which is a crucial factor in a mobile network and reflects whether a mobile node is within the transmission range of an access point.

3.2.3 OF-FL Based on Fuzzy Logic Model

In a study [7], an objective function utilizing fuzzy logic was proposed to enhance routing decisions towards the DODAG root by combining various metrics. The authors combined link quality, hop count, end-to-end delay, and node energy to identify the optimal node as the preferred parent to send data to the root. A fuzzy logic controller was used to evaluate the quality of neighboring nodes, utilizing the values derived from these metrics as inputs.

During the evaluation phase, the authors analyzed several performance metrics, including the average hop count, end-to-end delay, average number of parent changes, packet loss ratio, and average remaining energy of the node. The results revealed that in a dense network, the average hop count was similar across all three network scenarios. In a high-density network, OF-FL performed comparably to OF0. However, OF-FL had a slightly higher number of parent changes than MRHOF and OF0, which could affect network stability. By minimizing end-to-end delay and ensuring that most nodes had high remaining energy, OF-FL improved network lifetime. OF-FL had a similar packet loss ratio to ETX, but the packet loss ratio was much higher in OF0. As a result, OF-FL improves RPL packet loss ratio, end-to-end delay, and network lifetime. However, the study did not account for the main metric required to detect and analyze node mobility, which makes it unsuitable for mobile wireless networks.

4. Mobility Impact with RPL

RPL was previously designed for only static networks, so it is not able to deal with when mobility of nodes occurs in the topology. But it can be improved to deal with issues and changes. For example, when a node is disconnected from the existing DODAG it gives an outcome as loss of data packets before joining a new preferred parent either of the same DODAG or other nearby DODAG. This implicitly disturbs the performance of the network. The main purpose in this article is to discuss the various proposed protocols or methods which support micro-mobility to predict movement of the node or disconnections and recovering broken links quickly to generate new routes. Because of this it avoids data loss and allows continuous and efficient accessibility of the nodes.

Whenever a node fails or moves, the network topology changes, leading to disconnection of the node from its parents and children, and resulting in loss of data transmission capability as per RPL Standard specifications. To overcome this issue, the node has to update its own knowledge about neighboring nodes and routing paths, which includes information such as list of parent nodes, preferred parent, and node rank. RPL addresses this problem through a self-healing strategy, where dynamically updated routing decisions are made, and nodes remain in constant communication with the network topology changes.

Before discussing ahead, let's see the main changes that take place because of the mobility of the node at the MN and its neighbors, which lead to a topology change as shown in Fig. 4.

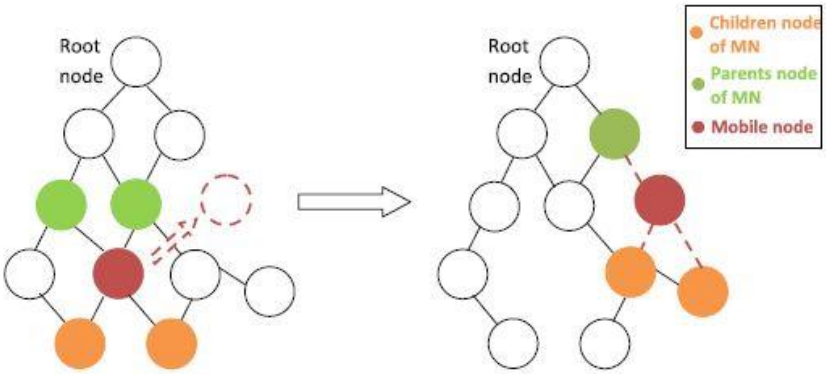

Fig. 4. Change in the route instigated by the mobility of the node [2]

4.1. The mobile node

If the mobile node (MN) moves beyond a certain range, it becomes disconnected from its parents and children in the DODAG, causing it to separate from the network. To address this issue, the MN attempts to connect to a new DODAG with the assistance of nearby nodes, which can be accomplished through two different procedures. The first approach is when the MN receives a DIO message from another router, in which case it modifies its parameters like parent list, preferred parent, rank, and routing table to establish an upward path, based on the information in the message. It can then send a DAO message to its children for the downward path and transmit the modified DIO message, which helps it to identify new children. The second approach is utilized when no DIO message is available. In this scenario, the MN sends out solicitation messages known as DIS to join the DODAG tree.

4.2. The neighbor nodes

To maintain the link between mobile nodes and their neighbors, it is a job of each node to broadcast DIO messages after a specific amount of time to its children based on the trickle timer and try to receive DAO messages. Therefore, when the node moves from its position it goes away from its neighbors results in data loss in turn breaking of the routing paths through the MN. To solve the problem, the node that is not able to receive any DAO or DIO messages from the MN assumes it being out of its range. Therefore, the routing table removes the corresponding entry for that MN and removes it from the list of parents and neighbors. After that, it is in a waiting state to receive the control messages from the remaining nodes to update its knowledge confirming the connectivity for both upward and downward paths [2].

4.3. Problems and limitations of mobility in to RPL

The RPL protocol is not adequate to cope with the mobility of the nodes in the topology and the dynamics of the network. Moreover, it is not able to provide suitable outcomes for time-restricted applications like some security applications or health related applications. Data losses and interruptions of MN are inevitable in RPL. In fact, it has a low approachability with the mobile nodes as it is considered fundamental for static networks.

Here, first it has to be considered that the applicable mobility detection technique relies on the acceptance or non-existence of DIO messages. However, this method suffers from delays in detection and long trickle intervals. Due to this delay, RPL is not able to quickly respond to improve the problem, which impacts the connectivity of MN and causes data loss. Ultimately, it can be said that this technique is not viable for real-time applications, which being a basic need in the network environment. Another option can be thought of is to reduce the trickle timer interval, but it will definitely increase the signaling overhead which ultimately leads to a greater number of collisions, high power utilization, and incremented data loss. For these reasons, it is required to suggest a different mechanism which helps resolve the mobility issue with the help of a smaller number of control messages.
Furthermore, if any reactive concept is used which supports mobility cannot avoid issues caused by the node mobility; the reaction to a disconnection is only clicked after receiving a new DIO message from another neighbor. This leads to a delay in the large handover and detachment time of the MN and a packet loss. So, there is a need for a new method which proposes a different

proactive approach based on the estimation of a new attachment.

At the end, the RPL protocol does not adequately address the need for reliable and stable paths, as the presence of MNs can lead to frequent disruptions in the routing path.

5. Related Work

The authors of [8] proposed a new protocol called Mobility Enhanced RPL (MERPL) that aims to support mobility in RPL. To increase route stability, the authors suggest that mobile nodes should not be selected as preferred parents (PPs). To prevent disconnection of mobile nodes, MERPL periodically sends DAG Information Solicitation (DIS) messages to request the sending of DAG Information Option (DIO) messages, which allow for rejoining in case of connection loss. However, the authors did not consider important parameters such as signaling cost, energy consumption, and handover delay, which are essential for evaluating the overall performance of the protocol.

The authors of [9] proposed a localization-based protocol called GI-RPL for Vehicular Area Networks. This protocol expands upon RPL and addresses frequently changing network topologies. The node's localization is determined by its distance from the sink node, which is dependent on the vehicle's direction. Instead of the trickle timer, an adaptive DIO period is used, leading to improved packet delay and delivery ratio. However, the protocol does not take into account energy constraints as they are not considered significant in the context of VANETs.

A study by [10] evaluated the effectiveness of RPL in the context of Vehicular Ad hoc Networks (VANETs) and proposed some revisions. The authors recommended disabling the DIO trickle timer as it was not suitable for the frequent topology changes in VANETs. They also suggested improving the reactivity of RPL by promptly measuring link quality and updating the routing graph. Additionally, they advised including the parent's ID in the DIO message to avoid issues related to loops. However, the study did not propose any mechanism for tracking the varying speeds of vehicles in VANETs.

In [11], the new protocol is proposed named as MoMoRo which supports mobility in the standard RPL protocol. MoMoRo uses a distinct approach to detect mobility, which relies on the count of retransmissions. It collects information from neighbors and processes them when nodes move. It uses a fuzzy estimator to assess link quality and identify a stable path for new MNs to attach. However, this protocol is reactive, leading to increased handover delay and signaling costs.

In their paper [12], the authors presented a new protocol named Co-RPL and introduced a new Objective Function called OF-FL (Objective Function based on Fuzzy Logic). The previous OFs had limitations that were addressed by this new OF. Moreover, Co-RPL is an advanced version of RPL that employs a corona mechanism to improve mobility and address the problem of slow responsiveness to topology changes, providing better performance in dynamic networks. Evaluation of the protocol's performance revealed that both OF-FL and Co-RPL demonstrated improved packet loss ratio and average network latency.

In [13], authors projected a protocol named as PL-Probe. In this protocol they have proposed link quality monitoring for detection of mobility of the node. It measures link quality with minimum overhead and waste of energy. PL-Probe uses synchronous and asynchronous monitoring mechanisms and checks the recent information on link quality, and it reacts immediately when any unexpected changes occur in the topology. Here authors used reinforcement learning model to monitor the process to reduce the overhead caused due to active probing operations. This protocol improves the signaling cost and packet delivery rate. But the handover delay is not considered here.

The authors of [14] suggested a protocol which considers the traffic which goes from the gateway towards mobile nodes in dynamic network topology. Based on this they have come up with a mechanism to improve downward route updating. Though, the idea of this explanation comprises in assessment the traffic directed from the root to the mobile node, not as usual protocols in the survey. This resolution contributes to provide constant connectivity with the mobile node, which decreases the signaling cost and packet loss rate. The problem occurs with the packet loss can be there when the existing parent is not able to reach to the mobile node, but the DAO message has not cancelled the existing route yet.

In [15], they talked about MRPL protocols to work with mobility. In which they used proactive process. In this process the RSSI value is calculated periodically for all received signal messages by the mobile node. Because of this the mobile node itself detects the mobility and prompt to manage the disconnection. Even though this proposal provides feasible contribution and enhanced the performance, some of the improvements are still in need because they have not considered energy consumption. Here the MN provides mobility support and because of that its energy-draining speedily. Also, the control messages are sent periodically so it has high energy consumption and signaling overhead. This results in the loss of data and still there is a disconnection time problem because the MN is not allowed to send packets during the handover process if it was a detached node.

Anand and Tahiliani in [16] represent an enhancement to their RPL protocol, [15] to solve their RPL drawbacks. In mRPL, the selection of a parent node by mobile nodes is solely based on the RSSI value, without considering any other objective functions. This approach may result in the selection of a non-optimal route. To fix this problem, [16] considers the concept of smarter-HOP concept with the average of the ranks of the parent nodes who are candidate plus RSSI value. The problem with this protocol is that they haven't evaluated the performance with the different types of topologies and mobility models.

The authors of paper [17] proposed a dynamic RPL (D-RPL) protocol that incorporates an inverse-Trickle timer based on the RSSI value to adapt to the mobility of nodes. In this protocol, each node keeps track of the RSSI value from the last two packets received from its neighbor nodes, which can be either control messages or data packets. When a node receives a new packet from the same neighbor, it measures the RSSI value and compares it with the previous value. If the new RSSI value plus a redundancy constant KRSSI is lower than the previous RSSI value, the inverse-Trickle timer is triggered, and the node sends a local multicast DIS message to all its neighbors. Otherwise, the default Trickle timer is executed. The evaluation results show that D-RPL has a higher Packet Delivery Ratio, reasonable energy consumption, and slightly lower end-to-end delay compared to existing RPL protocols.

In reference [18] EKF-MRPL has been proposed by authors, which follows a proactive process to conserve the connectivity of the mobile node and to avoid data loss. In this process the MN attached to the new PP before ditching from the current PP. EKF_MRPL uses the concept of Extended Kalman Filter in MN position prediction. The advantage of this protocol is it minimizes the signaling cost as well as collision of packets. It also provides a continuous connectivity between Mn and PP. But they haven't considered the end-to-end delay for selecting a new Preferred Parent.

In article [4] mobility support in the RPL protocol is discussed. MARPL introduces two distinct procedures: mobility detection and adjustment of control packet transmission. To support mobility detection, MARPL utilizes information from both the data link and network layers. In MARPL, they have proposed that the neighbors have to maintain adaptability metric to update the parent node and to select the new routes created by nodes. These routes are static in nature. In the result analysis the MARPL gives better output related to the overhead, PDD, DODAG disconnection prevention and Packet Delivery Ratio (PDR). It also provides good results in terms of the number of disconnections.

In reference [2], a routing protocol named EMA-RPL was proposed for supporting micro-mobility on the Internet of Mobile Things, with a particular focus on real-time applications. EMA-RPL ensures stable connectivity and ensures that mobile nodes remain reachable whatever the location is. Proactive protocol concept is used in EMA-RPL in which before any disconnection it is possible to predict new attachments. The prediction process works based on the RSSI and modification in ICMPv6 messages. To check the performance authors combined EMA-RPL and MRPL in Contiki. The experimental result shows that EMA-RPL provides better performance in mobility in terms of connectivity, minimum signaling cost which saves energy and because of that greater number of packets can be delivered successfully. In EMA-RPL less participation of MN is required which saves their energy and distributes the signaling overhead to the different adjusted nodes. The problem in the protocol is the prediction process to be enhanced. Different methodologies can be used to replace RSSI as it is not efficient in an indoor environment as well as in the presence of hurdles in the mobile network.

An interesting study on energy-efficient parent selection and dynamic trickle algorithm for mobility in RPL is proposed in [21]. Which shows that parent selection algorithm using various metrics like ELT, ETX, RSSI, and dij between parent and mobile nodes can help select the most suitable parent for a mobile node, while the Dynamic Trickle algorithm can dynamically adjust the timer based on a random set of mobile node neighbors under mobility. It's great to hear that the proposed algorithms perform well in terms of packet delivery ratio and energy consumption, while also ensuring network stability during node movement by establishing a stable path to the destination with significantly lower end-to-end delay. Overall, this could potentially enhance the performance of RPL in mobile networks.

In article [22] the authors proposed an enhanced routing protocol for mobility support in wireless sensor networks, referred to as EM-RPL. EM-RPL is designed to increase network efficiency and reliability by selecting a more stable route and reducing the frequency of route discovery. The protocol incorporates TTL and Freshness Timers to allow nodes to select a Preferred Parent Node (PPN) that is outside the communication range and to choose a candidate parent that will remain available for a longer duration, minimizing the variability of the PPN. Additionally, a Fixed Router Node (FRN) is introduced to minimize the frequency of the discovery process by broadcasting DIO messages based on the DIO timer when a mobile node is within communication range. Simulation results show that EM-RPL significantly improves packet delivery ratio and reduces power consumption compared to other protocols. However, EM-RPL requires a fixed node before deployment, and the end-to-end delay is high.

Reference [23] proposes a framework for mobility management called mRPL+, which uses appropriate topology management techniques to achieve interoperability between fixed and mobile nodes. The framework combines two models, hard hand-off and soft hand-off, to enable a mobile node to find a new link before disconnecting from the present node. Simulation results indicate that mRPL+ significantly improves packet delivery ratio in networks with mobile nodes, while the performance of standard RPL is comparatively poor. The disconnection period during hand-off is also reduced to a few milliseconds in mRPL+. The authors found that re-transmission of dropped packets is more effective in increasing hand-off efficiency than exchanging more control packets during hand-offs. mRPL+ includes features such as backward compatibility with RPL, extra timers to detect mobility and manage hand-off timing, collision evasion, and a freshness parameter to ensure updated link and network information is used when selecting a parent node.

Reference [24] introduces a novel energy-efficient mobility-aware routing protocol called EC-MRPL for Low Power and Lossy Networks. The protocol utilizes a proactive approach to predict the attachment of mobile nodes before disconnection by utilizing cross-layer information such as RSSI and ICMPv6 messages with predefined flags from the RPL standard. EC-MRPL combines an enhanced mobility detection mechanism and a unique strategy for point of attachment estimation and replacement, which is aware of the resource constraints. The protocol aims to improve energy conservation and ensure continuous connectivity of mobile nodes, while minimizing their involvement and distributing resource consumption among different access nodes. The protocol also focuses on reducing control message exchange to avoid overloading and enabling efficient data packet transmission. The results of the protocol implementation in Contiki RPL demonstrate its superiority over the standard RPL protocol in supporting micro-mobility of nodes and outperforming other protocols such as MRPL in terms of unified connectivity, reduced signaling cost, and energy consumption of mobile nodes.

In article [25] the authors have introduced a novel mechanism called Enhanced Routing Protocol for Low Power Lossy Networks (ERPL) that aims to update the Preferred Parent (PP) of a Mobile Node (MN) as soon as possible when the MN moves away from its current PP. They have proposed a new objective function for Fixed Router Nodes (FRNs) to select a PP based on the mobility of the node and its quality, availability, and power consumption. The performance of ERPL was evaluated under different traffic and system parameters in different topologies to simulate real-life scenarios. Results showed that ERPL significantly reduced power consumption, packet overhead, and latency while improving the packet delivery ratio when compared to existing protocols. One important requirement of ERPL is that the MN needs to be within the range of at least one FRN since it cannot be a PP or send DIO messages.

In Wireless Sensor Network mobility is still an open challenge. In [26] authors have stated that standard RPL protocol is inefficient in mobility and high signaling cost to keep up-to-date routing. So, they have introduced a new mechanism called Kalman positioning RPL (KP-RPL). KP-RPL aims to achieve efficient and reliable routing by considering the real-life challenges of positioning inaccuracies and node disconnections. For communication among static nodes the original RPL is used and position-based routing for mobile nodes, utilizing a unique RPL metric that incorporates Kalman positioning and blacklisting.

KP-RPL avoids constructing links among mobile nodes. This protocol tackles the routing problem in two distinct sub-problems: one is anchored to anchor and another is mobile to anchor routing. While constructing anchor-to-anchor links, standard RPL protocol is used. However, for end-to-end ETX estimates, mobile-to-anchor links are calculated using the positions estimated by the Kalman filter, which is combined with blacklisting. To define its own confidence region, the mobile node uses RSSI measurements from anchor nodes. Routing decisions of mobile nodes are improved by Kalman filtering by enhancing their position estimation, while blacklisting provides robustness against inevitable positioning errors due to flaws in RSSI measurements and estimation of velocity.

According to [26], the experimental findings indicate that KP-RPL is a reliable routing approach that can effectively deal with diverse channel situations. The authors assessed the average ETX (Expected Transmission Count) of KP-RPL in different mobile node trajectories and network environments and discovered that it enhances network reliability compared to geographical routing. The study revealed that blacklisting enhances network reliability but increases the average ETX of the network. The authors suggest that this trade-off can be addressed by adjusting the size of the confidence regions, where reducing the size of the regions improves the ETX and increasing their size improves the PDR (Packet Delivery Ratio).

The 6LoWPAN protocol and IPv6 Routing Protocol for Low Power and Lossy Networks (RPL) have been widely used in IoT for Wireless Sensor Networks. However, the RPL protocol is not efficient in handling network overhead and packet loss caused by the mobility of nodes. To address this issue, the authors of reference [27] proposed a new cost metric that combines the number of hops, RSSI value, and delay summation to enhance RPL mobility. They also introduced a mobile detection method to activate parent selection and enable the mobile node to maintain its connectivity while transmitting data. The proposed protocol, imRPLv2, detects node mobility when the mobile node moves away from its original parent and uses a notification message to initiate and select a new parent node. Simulation results demonstrate that imRPLv2 achieves a high packet delivery ratio (PDR) with minimal end-to-end delay. Additionally, the mobile detection method enables the mobile node to select its new parent node before losing its current connection, resulting in continuous data forwarding and reduced packet loss.

In article [28], the authors have come up with a new enhancement of existing RPL protocol which is called as FDTM-RPL. In which the concept of FDTM-IoT has been embedded as an OF. FDTM-IoT is a fuzzy, dynamic, and hierarchical trust model which calculates trustworthiness in three dimensions. They have considered the dimensions as quality of service (QoS), contextual information (CI) and quality of P2P communication (QPC). Then this trust model has been used as an OF in FDTM-RPL. They have conducted simulation in Cooja simulator which improves network performance as well as results in notable enhancements concerning the average number of parent changes, end-to-end and packet loss ratio delay when compared to conventional protocols. FDTM-RPL remains unaffected by prominent IoT attacks, such as RANK, SYBIL and BLACKHOLE. However, it is imperative to evaluate the efficacy and resilience of FDTM-RPL against other types of attacks as well.

As already discussed in the article that RPL is not sufficient for mobile nodes in the WSN. So many researchers have proposed different types of OFs or methodologies. In the article [29], authors have proposed different OFs and used the combinations of it to enhance the performance of RPL which can be used in various smart IoT applications. Three metrics, namely Content, ETX and Energy are utilized to improve the design of the protocol. These metrics are used individually as well as in combination with each other, along with an enhanced triggering technique for better results. The combination of Energy and Content (EC) along with aggregation and an enhanced timer (EC_En_Timer) design yields better Packet Delivery Ratio (PDR) and Latency Delay (LD) outcomes than the default OF. The combination of Residual Energy (RE) and ETX (EE) with an Enhanced timer (EE_En_Timer) design has been proposed to achieve better results in terms of energy consumption. The proposal has minimal overhead, which reduces conversion time by 50% in the En_Timer design. The EC and EC_En_Timer designs exhibit a high PDR and low delay, which can be useful in health monitoring applications where reliability is crucial. Similarly, the RE, EE, and EE_En_Timer designs result in low energy consumption, which is beneficial for forest monitoring applications where energy is a critical factor. However, the authors noted that there is a need for enhanced objective functions (OFs) based on the specific application requirements, as different IoT applications have different needs. It is difficult to use only one OF for all applications. It should be noted that this proposed methodology has some limitations. The authors did not consider various topologies, different mobility patterns, flexible data rates, different node locations, numbers of nodes, periods of activity, environmental conditions, and different data types.

The proposed algorithms for RPL enhancement only discussed how to select a new parent or an objective function. But they have not talked about how to establish a long-lasting reliable path. To overcome this problem paper [30] talked about ARMOR. ARMOR is a new proposed routing protocol on the top of RPL. In this, a new routing matrix called Time-To-Ride (TTR) and different parent replacement policy has been advised. As people are aware about the mobile nodes are moveable in the specified range, TTR provides an approximate time period that for how long time the node will be there in the transmission range. Because of this mechanism it allows the proposed algorithm to select the nodes, which is able to provide higher reliability of longer connection period. In ARMOR the TTR matric is integrated in the structure and thus it is the main criterion. Here, the DIO message structure is modified to achieve this. The parent which is selected here is aware of mobility in the structure. To increase the PDR in the topology and to have a smaller number of broken connections in the existing DODAG, ARMOR the higher TTR neighbors ae spotted. The preferred parent is selected based on selecting the most reliable path from nodes to sink by choosing the maximum amount of TTR. In ARMOR the power consumption is kept constant and improvement in PDR is 2.5 times more. It also improves reliability by 4.2 times compared to the original protocol. The packet overhead is more but it provides less amount of packet drop and more reliability. Because of this there is less retransmission and less amount of power consumption compared to MA-RPL.

The RPL protocol is primarily used for LLNs, and its Objective Function is responsible for selecting preferred parents for routing packets to the root node of the topology. However, this approach may not fulfill all the routing requirements of the network. To address this issue, the authors of article [31] proposed a hybrid Objective Function with empirical stability awareness (HOFESA) that has been implemented at the network layer in CONTIKI. HOFESA utilizes a combination of three metrics, namely RSSI, hop count, and energy consumption of the node. While the combination of metrics may result in frequent preferred parent changes, the proposed algorithm relies on static and empirical thresholds to mitigate this problem. The authors compared their algorithm with standard RPL and EC_OF and observed an improvement in PDR, reduced convergence time, lower power consumption, and a smaller number of DIO control messages. However, the authors did not consider metrics such as ETX, traffic management, node buffers, and delay.

In [32], authors have talked about a new mechanism called DDSLA-RPL in which a list is created members of optimal parents based on hop count, quality of the link and SNR (Signal to Noise Ratio) rate and energy consumption (ETX). The child nodes have to be informed about connection link to accessible parents. Based on the learning automata, the decision system approach is used which has proposed a dynamically determined and updated weight of significant parameters. In DDSLA-RPL, battery depletion index node queuing, connection delay and throughput is used as effective parameters in routing. Many researchers have used the concept called fuzzy logic, K-Means algorithm but they haven't had success. Because of this the distributed automata are used here. Based on the feedback received from the network at a specific time, it updates the parameters in the system and leads to an increase in the lifetime of nodes which provides the higher quality of the network. The result shows good performance as lifetime, index of energy fairness latency, graph consistency and PDR in the topology.

The below analysis of literature work indicates that the RPL routing protocol encounters several challenges while handling mobility, including the lack of effective methodology for transmitting DIO and DIS control messages which detect DODAG disconnection, the need for a methodology to monitor mobility in the topology, and the requirement for selecting a preferred parent that considers node mobility.

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Table 1 Enhanced RPL for Mobility Management

Ref. No.	***Protocol Name***	***Contribution***	***Network***	***Results***
[2]	EMA-RPL	Proactive protocol, Connectivity, Signaling Cost	WSN	Low packet loss, Low energy, Low signaling overhead but inefficient because of RSSI technique
[4]	MARPL	mobility detection, control packet transmission adjustment	WSN	High packet loss, Low signaling overhead but more reconnection delay
[8]	MERPL	modification of DIO messages	WSN	Low packet loss but didn't consider signaling overhead and energy consumption
[9]	GI-RPL	Objective Function using geographical information	VANET-WSN	Low packet loss, Low signaling overhead didn't consider dynamic scenario
[10]	VANET RPL	Neighbor Connectivity using ETX and no use of Trickle timer	VANET	High overhead, low packet loss but no use of any specific adaptive timer
[11]	MoMoRo	Sending probes when disconnected using Adaptive flood messages [20]	VANET	High Overhead, Low energy
[12]	Co-RPL	Objective function with new matric strategy and new method for DODAG creation	WSN	Low packet loss, Low delay and high energy but limited mobility management
[13]	RL-Probe	link quality estimation strategy using machine learning	WSN	Low packet loss and low delay but high packet overhead as well as works only on symmetric links
[14]	Enhanced RPL	downwards route maintenance	WSN	Low signaling overhead, low delay but didn't consider energy consumption

[15]	mRPL	Link Monitoring using RSSI and more Timers	WSN	Low Overhead, Low energy, High responsive
[16]	MRPL++	Extension to mRPL with new objective function	WSN	Low Overhead, Low energy, High responsive
[17]	D-RPL	Adaptive DODAG Information Solicitation (DIS) and adaptive timer [20]	WSN	Improves Packet Delivery Ratio (PDR), energy efficiency and delay and Low overhead but very less enhancement in low mobility environment
[18]	EKF-MRPL	Proactive protocol, Connectivity, Signaling Cost	WSN	seamless continuous connectivity, Reducing the signaling cost, High delay
[21]	Mobility-Aware Energy-Efficient Parent Selection Algorithm	Efficient Parent Selection and Dynamic Trickle algorithm	WSN	Less energy consumption, Improves Packet Delivery Ratio but high end-to-end delay
[22]	EM-RPL	Selection of a route that is more stable and reduces the frequency of the route discovery process	WSN	Improves the Packet Delivery Ratio and minimizes power consumption but medium packet overhead and high responsiveness
[23]	mRPL+	Immediate beaconing (Control Messages) with hard and soft handoff	WSN	Improves Packet Delivery Ratio but High packet overhead and responsiveness
[24]	EC-MRPL	Proactive mobility prediction using control messages	WSN	seamless connectivity, reducing signaling cost and high data packets transmission but inefficient because of RSSI as OF
[25]	ERPL	Multiple OFs for MN as well as fixed nodes	WSN	Medium Power consumption, high packet overhead, bit improvement in PDR
[26]	KP-RPL	Geographical routing approach which predicts the movement of MN	WSN	High PDR, High packet overhead and medium responsiveness as well as average energy consumption
[27]	imRPLv2	mobility detection and selection of parent using new cost matric mRank	WSN	high PDR and a less end-to-end delay but didn't consider energy consumption
[28]	FDTM-RPL	FDTM-IoT has been used as OF in FDTM-RPL with dynamic, fuzzy and hierarchical trust model	WSN	Improves network performance and substantial enhancement in the form of packet loss ratio, number of parent changes and end-to-end delay. Not much affected in attacks as SYBIL, RANK, and BLACKHOLE occurs in IoT so, it is required to check the effectiveness and strength under other attacks

[29]	Three metrics Energy, Content (EC) and ETX with enhanced triggering technique	Three metrics named as Energy, Content and ETX, individual and grouping with each other for different IoT applications	WSN	Energy + Content - EC aggregation including Enhanced timer (EC_En_Timer) provides improved outcomes for PDR and Latency Delay than the default OF. (Residual Energy (RE) + ETX (EE)) aggregation and Enhanced timer (EE_En_Timer) model gives better results in the form of energy consumption. It can also be seen that the overhead is very low in ETX and RE design. There is nearly 50% reduction in Conversion time in an En_Timer design. Disadvantage is it can be used for a specific application only
[30]	ARMOR	mobility aware routing matrix named as Time-To-Ride (TTR) and a new parent replacement policy.	WSN	Improves the PDR in the network by up to 2.5 times, improves the consistency by up to 4.2 times. The overhead control packet of the anchor nodes in ARMOR is higher but ARMOR provides better reliability in terms of lower packet drops. As an outcome it lowers the re-transmissions of packets, no noticeable difference in the power consumption of the ARMOR in comparison with MA-RPL
[31]	HOFESA	hybrid objective function as combination of hop count, RSSI and energy consumption of nodes	WSN	In comparison with original RPL and EC-OF protocols, HOFESA shows an improvement in PDR, less power consumption, less convergence time as well as a lesser number of DIO control messages. It also ensures network stability. It has not considered the matric ETX, nor any matric for traffic management, buffer of nodes and delay to get improved outcomes
[32]	DDSLA-RPL	hop, SNR rate, link quality, and ETX energy consumption with distributed learning automata	WSN	Performance is good in average lifetime, latency delay, energy consumption and PDR in the network topology

6. Conclusion

As discussed in the paper, mobility is a new standard where devices are naturally mobile nodes in the Internet of Things (IoT). Mobility remains an interesting topic because it causes broken connectivity and disconnection between nodes, that effects critically on the network performance and efficiency. Additionally, conserving energy of the nodes can be challenging for networks that have limited resources. The existing routing protocol RPL is not efficient to provide responsiveness to mobility of the nodes in the network as it has been proposed for static systems by IETF. With this aim, many researchers have proposed and designed an enhanced version of RPL protocol for Low power and Lossy Networks which overcomes the limitations of the traditional RPL. The enhanced protocols enable better experience of connectivity of mobile nodes and preserving energy. Integrating an improved mobility detection method through constant monitoring of the distance between each mobile node and its parent node. The study shows that still many of the problems the RPL routing protocol faces when it deals with mobility like absence of efficient methodology to minimize the control messages, recreation of DODAG, methodology for mobility monitoring and selection of preferred parent, energy consumption of the node and data loss which further leads to have mobility into consideration with different fundamental.

Author contributions

Ditixa Vyas: Conceptualization, Methodology, Field study, Data curation, Writing-Original draft preparation, Validation **Ritesh Patel:** Reviewing.

Conflicts of interest

The authors declare no conflicts of interest.

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