Low Power and Lossy Networks Routing Improvement in IoT Applications

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Abstract :

IoT has recently attracted the interest of engineering, educators, and governmental units from various enterprises. IoT poses additional risks, including flexibility, big data analytics, security, availability, connectivity, performance, and mobility. This study will concentrate on providing the most optimal routing amongst various network environments, including wired, wireless, and IoT sensors. The main challenges involved in designing a routing protocol, as well as the difficulties involved in the design of a routing protocol, are described in this book. The many classifications of routing protocols are also reviewed. The constraints of dynamic topology, node mobility, scalability, and restrictive bandwidth are the most frequent difficulties faced by the Internet of Things. The review covers a variety of routing protocols, including reactive, multipath, location-aware, hybrid multicast, Geo-cast, and power-aware protocols. The most popular routing protocols have been carefully studied, and discussions of routing techniques and analyses of the strengths and weaknesses of the existing research field are included. The analysis of current routing protocols is conducted based on the shortest path for the least transmission time. Finally, the research community and academic community examine the difficulties in routing that need to be addressed.

Keywords: Terms- routing, Internet of Things, WSN, low power and lossy networks (RPL).

تحسين توجيه الشبكات ذات الطاقة المنخفضة والخسارة في تطبيقات إنترنت الأشياء

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الخلاصة :

في الفترة الاخيرة كان إنترنت الأشياء محط اهتمام المهندسين والمعلمين والوحدات الحكومية و مجاميع متنوعة من الشركات. يشكل إنترنت الأشياء بعض الصعوبات الاضافية في بعض الحالات بما في ذلك المرونة وتحليلات البيانات الضخمة والأمن والتوافر والاتصال والأداء والتنقل. تركز هذه الدراسة على توفير التوجيه الأمثل الممكن بين بعض بيئات الشبكات المختلفة ، بما في ذلك الشبكات السلكية و أجهزة استشعار لاسلكية وإنترنت الأشياء. ويرد في هذا البحث وصف للتحديات الرئيسية التي ينطوي عليها تصميم بروتوكول التوجيه، فضلا عن الصعوبات التي ينطوي عليها تصميم بروتوكول التوجيه. كما يتم استعراض التصنيفات العديدة لبروتوكولات التوجيه و القيود يغطي الاستعراض مجموعة متنوعة من بروتوكولات التوجيه ، بما في ذلك البروتوكولات التفاعلية ومتعددة المسارات والواعية بالموقع والإرسال المتعدد الهجين والإرسال الجغرافي والواعي بالطاقة. و تمت دراسة بروتوكولات التوجيه الأكثر شعبية، وأدرجت مناقشات لتقنيات التوجيه وتحليلات لمواطن القوة والضعف في مجال البحث القائم .و إجراء تحليل بروتوكولات التوجيه الحالية استنادا إلى أقصر مسار لأقل وقت إرسال وأخيرا، يدرس مجتمع البحوث والمجتمع الأكاديمي الصعوبات التي تواجه التوجيه والتي تحتاج إلى معالجة .

الكلمات المفتاحية : اتباع مسار- انترنت الاشياء –حساس الشبكة اللاسلكي - شبكات قليلة الطاقة و الفقدان .

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I. INTRODUCTION

The Internet of Things is referred to as IoT, which enables items like cameras, medical sensors, lightbulbs, and smoke detectors to communicate with each other and their users. IoT enables items to support daily activities. For example, cars can sync with calendars to track appointments or meetings and determine the optimal routes [1]. "Intercontinental Data Corporation (IDC)" According to a study, thirteen billion linked devices were in use worldwide in 2017, and there may have been over forty billion by 2025 [2].

The routing process is defined as the transportation of data packets from one host to another through a network. Choosing a path for traffic inside a network or across networks is called routing. Routing tables, which keep track of the path record to multiple destinations, are used to transport packets. The collection of guidelines known as protocols allows network devices to communicate with one another. A routing protocol called "RPL" is employed in "Low Power and Lossy Networks" (LLNs) [3]. LLN specifies devices with various applications, such as industrial monitoring, lower power consumption, limited memory, and low processing resource requirements. [4–6], Transportation [7, 8], building automation [9, 10], asset monitoring [11, 12], urban sensor networks [13, 14], smart homes [15,16], and refrigeration [17] are only a few of the industries mentioned. The IETF "Routing Over LLNs (ROLL)" group created RPL [18, 19]. The foundation of RPL is that every network has a sink node with more power and computational capacity than the other nodes [20]. RPL operation is based on determining the distance and direction of any network link. It was created for static networks with little device migration [21]. One of the core problems with RPL is the support for transportation. As a result, the research's strength comes in identifying the problems RPL encountered with IoT device mobility and classifying various solutions by identifying their guiding principles, level of satisfaction, and boundaries. This review paper has the following structure: Literature evaluations and background information are included in Section 2. The research's methodology is described in Section 3. In part 4, we detail the challenges IoT routing experienced. Section 5 provides information on how to address these problems. Finally, in Section 6, we suggest some prospective research fields.

I. BACKGROUND AND LITERATURE REVIEW

1.1 Background

A "Low-power Wireless Personal Area Network (Low PAN)" is a specific type of WSN. (Wireless Sensor Networks) is made up of numerous nodes that are equipped with various kinds of sensors, such as temperature, humidity, and others. However, it was noted that the interoperability between the WSN and the Internet was constrained due to a lack of IP communication infrastructure, so multiple efforts were utilized to establish a structure that might enable the use of IP over LoWPAN. [19,20]. The IETF was promoting IPv6 use in IEEE 802.15.4 networks and formed a working group named IPv6 over Low-power Wireless Personal Area Networks (6LoWPAN), which suggested the use of an adaption layer in the IP stack (i.e., it defined the fragmentation and defragmentation of IPv6 packets in IEEE 802.15.4 frames) [21].

The Routing over Low-power and Lossy Networks (RoLL) working group was created to investigate solutions for developing LLNs after the 6LoWPAN working group was founded [21, 22]. Urban LLNs [23], workplace LLNs [24], remote monitoring LLNs [25], and building automation LLNs [26] all had their routing requirements established by the working group. An LLN network is created by connecting embedded devices with restricted power, memory, and CPU capabilities utilizing connections like IEEE 802.15.4 or low-power Wi-Fi [27]. The Low Power and Lossy IoT networks are depicted in Figure 1. In low-power and lossy networks, RPL is characterized as a distance-vector IPv6 routing protocol that selects the optimum pathways to carry traffic from a sink node to the other nodes. RPL offers a routing solution for lossy and low-power networks and is very adaptable in offering alternatives when default routes are inaccessible. [26]. Utilizing Destination-Oriented Directed Acyclic Graphs, RPL manages topology creation (DODAGs). DODAG has a Directed Acyclic Graphs (DAG) root with just one destination and no external edges. The DODAG root configures the Trickle timing parameters, Min Hop Rank Growth, Path Control Size, and DODAG preference field [27]. One can access DODAG by providing a "DODAG ID" and an RPL

Instance ID. When two or more DODAGs maintain the same RPL instance ID, the RPL instance may be identified. A single RPL instance can contain several DODAGs, and each RPL Instance is implemented by more than one "Objective Function (OF)" [28, 29].

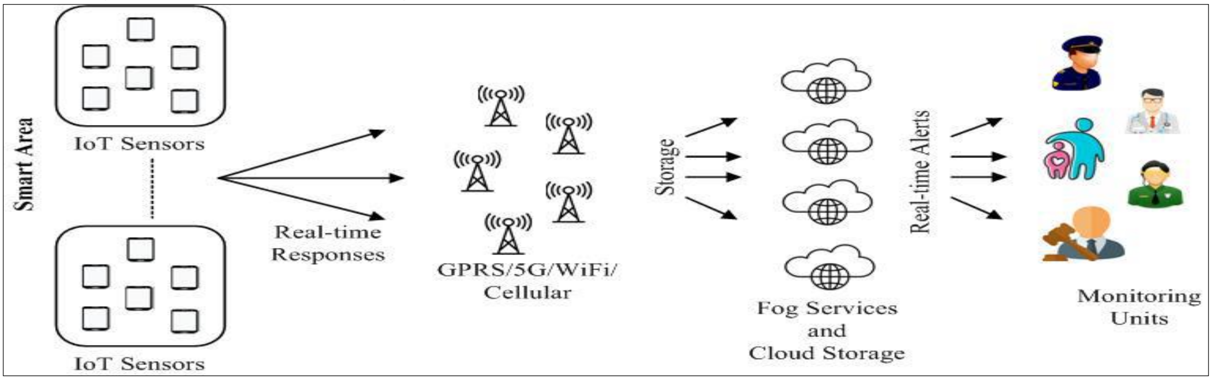

Figure (1). Example for IoT LLNs [30]

The rating of each node is based on its precise position in relation to other nodes. The upward direction of rank rises while the upward direction of rank declines. In this method, rank is decided by the OF. In the RPL instance, OF outlines the process for selecting nodes and the method for optimizing routes. The Objective Code Point parameter, defined under the DIO message option, can be used to identify OF (OCP). OF serves a variety of functions and a range of measurements.

Furthermore, Which DODAG node to be connected is decided by OF. The number of peers who are parents in that DODAG is calculated by OF, along with an ordered list of the parent's estimates [30]. The objective function may be divided into two types: The first is the hop-count-dependent routing statistic known as Objective Function Zero (OF0). The second variation, Objective Function with Minimum Rank and Hysteresis, uses ETX that is cumulative throughout a journey [31]. The average amount of data frames delivered and needed ACK frames are known as ETX for successful packet broadcasting [32].

To transfer data, RPL employs four primary control messages. The first one is the DODAG Information Object (DIO), which enables nodes to locate RPL instances and decide which DODAG parent set they want to belong to. The second approach uses the DODAG Information Solicitation (DIS), which is used to ask RPL nodes for the DIO message [33]. A third type of object is referred to as a "Destination Advertisement Object" (DAO), and it's used to send data to destinations up to the parent in a storing mode and to the DODAG root in a mode without storing. Data is delivered from a node up to the DODAG root in non-storing mode by forwarding messages recursively to DIO parents. When a node is in storing mode, until it finds an ancestor that can access the target prefix, it forwards packets to DIO parents. Fourth place goes to the DAO-ACK message, which is sent by a DAO parent in response to the DAO unicast message. RPL uses a Trickle timer to reduce the cost associated with control messages by only delivering updates when network anomalies are discovered [32,34]. If the node is notified by DIO updates from a neighbour in a consistent state, the redundancy counter is incremented by one. When a node receives more consistent updates in a particular time frame than the redundancy constant, it stops transmitting updates and doubles the listen period. The timer is reset and begins delivering DIO messages more often after receiving an inconsistent update, allowing updates to spread throughout the remainder of the network. The Trickle timer transmits fewer control messages while the network is steady to conserve energy [35].

There are three configuration options for the trickle timer: The redundancy constant, Imin (minimum interval size), and Imax (maximum interval size) (k). The Trickle timer also uses a counter (c), the current interval size (I), and the time that has passed since the last interval (t). There is a distinct interval for each node. The interval begins at Imin and ends at Imax. Sub-intervals are separated by significant intervals [36].

Figure 2 demonstrates how the Trickle algorithm is used by the root to transmit a DIO message to the neighbours in order to reduce traffic overheads and start the development of a DODAG. Sending a DIS message will initiate the DIO transmission and restart the Trickle timer if Node 3 in Figure 2 wants to add more DIOs without waiting for the DIO message. In order to advertise the graph, the node that received the DIO message determines its rank. To advertise its location and create a downward route, the node broadcasts DAO. For controlling downward routing, two modes—storing and non-storing modes—are used. They are in a storage phase at the time; the nodes store downward routing tables. Due to the temporary nature of the advertised addresses, regular messages are sent in the non-storing mode [37]. Three control messages are used by RPL to create a logical topology, and bi-directional paths between sinks and other nodes are built with the least amount of overhead possible.

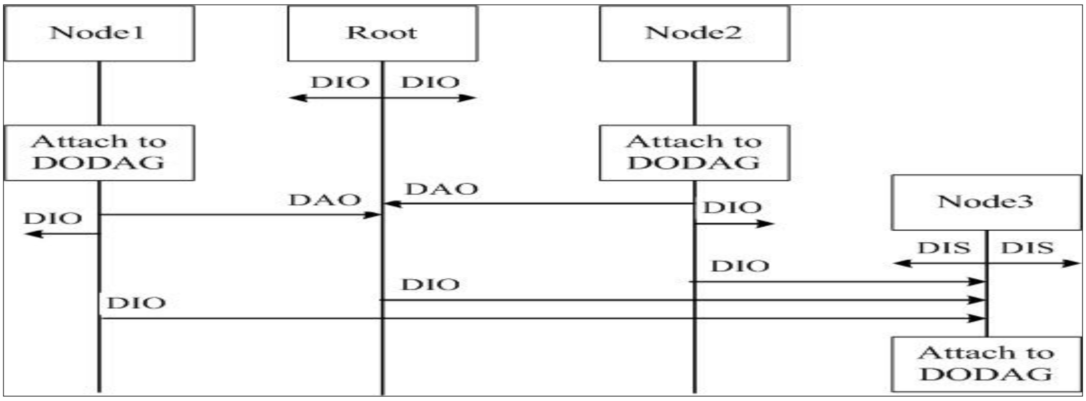

Figure (2). Building approach DODAG [30]

1.1 Literature Review

[37] states that RPL utilizes the RFC 6551 metrics, which are appropriate for situations utilizing 6LoWPAN. The following metrics are the amount of link quality, throughput, node energy, packet delivery, number of hops, delayed, and transmission reliability.

Objective Function Zero (F0), a common objective function, was defined for RPL in [38]. It was created to facilitate communication between various RPL implementations. OF0's operation is streamlined and does not make use of a routing table location. A device chooses its node by taking into consideration its neighbours among those with the lowest rating.

According to [39], the author presented a context-aware method that alters a sensor node's functioning in response to unusual environmental data like temperature, humidity, pressure, etc. This contribution, entitled Situation-Aware Adaptation Approach for Energy Conservation in Wireless Sensor Network (WSN), intends to evaluate how the sensor node performs in the environment by introducing the network's power usage. Context-sensitive computing has become more well-liked and pertinent because it was acknowledged as an essential component of the Internet of Things claims [40]. This is mostly caused by the possibility of context-sensitive systems changing their behaviour without explicit user input. Context-Aware Objective Function (CAOF), proposed by [39], is a context-sensitive objective function that is based on altering the sensor node's state over time. The function described in [40] utilized a weighted total of three metrics: the degree of battery power, the amount of node connection, and the node's location in the routing table relative to its parent node.

Described in [41] is the Scalable Context-Aware Objective Function (SCAOF). Local environmental monitoring in a Scalable environment alters the RPL protocol. Both simulation and field testing benefited from the SCAOF's performance. The outcomes of the experiments demonstrate that SCAOF may improve the Quality of Service (QoS) and extend the network's service life in the various agricultural simulation scenarios. An Intelligent Energy Effective Objectives Function is provided in [42]. (SEEOF). With SEEOF, RPL is used to create an IPv6 mesh topology for IoT applications based on smart meters. In order to increase the network longevity, it was also designed to consume energy efficiently. According to simulation tests, using SEEOF can extend network lifetime by up to 27%. The results also show that SEEOF distributes energy demand across battery-powered devices more equally, extending the lifespan of these devices For Internet of Things (IoT) applications that need more significant levels of energy efficiency and data transmission reliability, [43] presents an Energy Efficient and Path Reliability Aware Objective Function (ERAOF). The ERAOF requires the usage of node energy and link quality measurements. ERAOF chooses a route while taking into account both the energy utilized and the link quality, in contrast to the findings presented in [26]. This feature served as the basis for including it in the comparative analysis conducted for this study.

The works mentioned in [39,40,41,42] had a big impact on our notion. These studies inspired the authors to provide novel techniques for five primary reasons: I, utilizing measurements suitable for 6LoWPAN settings, (ii) averaging the metrics, (iii) using an energy-efficient objective function, and (v) utilizing a context-aware objective function. The proposed tactic is presented in the section that follows.

I. RESEARCH METHODOLOGY

It was observed that certain studies, such as those in [39 – 42], only address the RPL technique and base their suggestions on comparing the prior research on load balancing. For instance, [40] 's investigation of LLNs and RPL in terms of their limitations and shortcomings highlights various areas for development, such as traffic patterns, load balancing, assessment in real testbeds, and inadequacy of applications in real-world situations. The researchers in [41,42] suggested different ways to improve RPL regarding mobility, security, and upward and downward traffic flow. And other areas, as well as problems with RPL and potential solutions in areas including energy use, mobility, QoS, congestion control, and security.

Contrary to other polls, which each concentrated on RPL, This one did not give much weight to worries regarding RPL mobility or other relevant difficulties despite its crucial components and deficiencies for load balance. The studies that most closely resemble our surveys are Ref. [40], which evaluated a few LLN routing algorithms and assessed the effects of mobility on network performance, and Ref. [41], which looks at the performance of RPL and P2P-RPL protocols.

Additionally, a survey on RPL enhancement in Ref. With an emphasis on network design, mobility, and security, [42] is offered. Unlike prior studies, our proposal employs a qualitative technique to identify the problems that RPL would likely experience as a result of the mobility of IoT nodes. These include the lack of mobile node identification, The network's Trickle algorithm loops, the rank of disconnected mobile nodes, the Expected Transmission Count (ETX) probing delay, the longer handoff times, the lack of sink-to-sink coordination, the lack of positioning information, the absence of positioning data, and more are all problems. In the poll, numerous RPL protocol iterations would be suggested, and they would be categorized into five groups depending on various circumstances. Methods based on 1. "Trickle-timer" that address problems like permanent topology changes in networks caused by node migration are, for example, packet loss caused by the preferred parent selection, slow DIO message probing, and dynamic timer selection. 2. "ETX-based solutions," which concentrate on improving link quality by lowering communication delay, link stability during mobility, cost reduction when designing new network topologies, and slow response to topology changes brought on by delays in ETX probing, inaccessible destinations, and loops within the network3. Solutions based on RSSI, dress handoff delays for better connection quality and routing that is energy and mobility-conscious. 4. "Location-based solutions," which address rapid topology changes and the speed of mobile nodes, solve position uncertainty and disconnections between static and mobile nodes, and 5. Additional options. The survey would then discuss the issues, benefits, and shortcomings of each of the 20 RPL options for each category of these solutions. Additionally, Performance evaluations of RPL mobility under different simulation conditions— In this section, we'll cover energy consumption, packet loss, packet delivery ratio, slowness, node varieties, node count, node density, intervals, simulated length and region, and simulation environment. Other elements to consider are latency, energy consumption, packet drop, packet delivery ratio, and these are some of the most significant contributions:

- To evaluate the challenges RPL faces while working with non-stationary IoT devices.
- To outline various solutions that have been considered in recent studies to lessen the mobility-related difficulties RPL faces.
- To categorize various solutions into separate categories and describe the operation, advantages, and disadvantages of each type of solution.
- To provide potential research directions for the future that may be used to best solve the problems with IoT device mobility.

II. IOT-BASED RPL NETWORKS CHALLENGES

In a network made up of intelligent devices, routing has distinctive features. The RPL routing protocol for low-power lossy networks was created as a result of these features by a new working group (WG) named ROLL. The main challenges that might occur with IoT routing:

1. **Node capabilities:** In contrast to the traditional networks, where the topology of the network was accurately known before the network was established, it is particularly challenging in WSN, an essential part of IoT, to maintain the topology fixed since the nodes are distributed arbitrarily on the field**.**
2. **Diverse devices:** Different devices employ different types of network protocols and support different kinds of applications.
3. **A variety of networking protocols:** The phrase "Internet of Things" (IoT) serves as an umbrella for a number of technologies, including Wi-Fi, WSN, Zigbee, and traditional networks. These technologies all operate on various concepts. They employ various protocol stacks.
4. **Intermittent connectivity:** Because of the battery's short lifespan, the network is always susceptible to change.
5. **Multi-hop communication**: The majority of IoT devices are low-powered gadgets. Since these devices have a small transmission range, they must use a relay mechanism to send data from the source to the destination.
6. **Fault tolerance:** Deployment strategies or energy limitations could always have an impact on the performance of the entire network. Therefore, the routing protocols must include a way to deal with such unforeseen circumstances.
7. **Security:** The issue with routing security occurs as a result of some dishonest actors. Hop-to-hop verification is insufficient. While not entirely, cryptography can lessen the impacts to some extent.

III. SOLUTIONS TO THE RPL ISSUES

As indicated in Figure 3, we can divide the current solutions into five groups in this section.

Instant ETX Probing for a New Neighbour

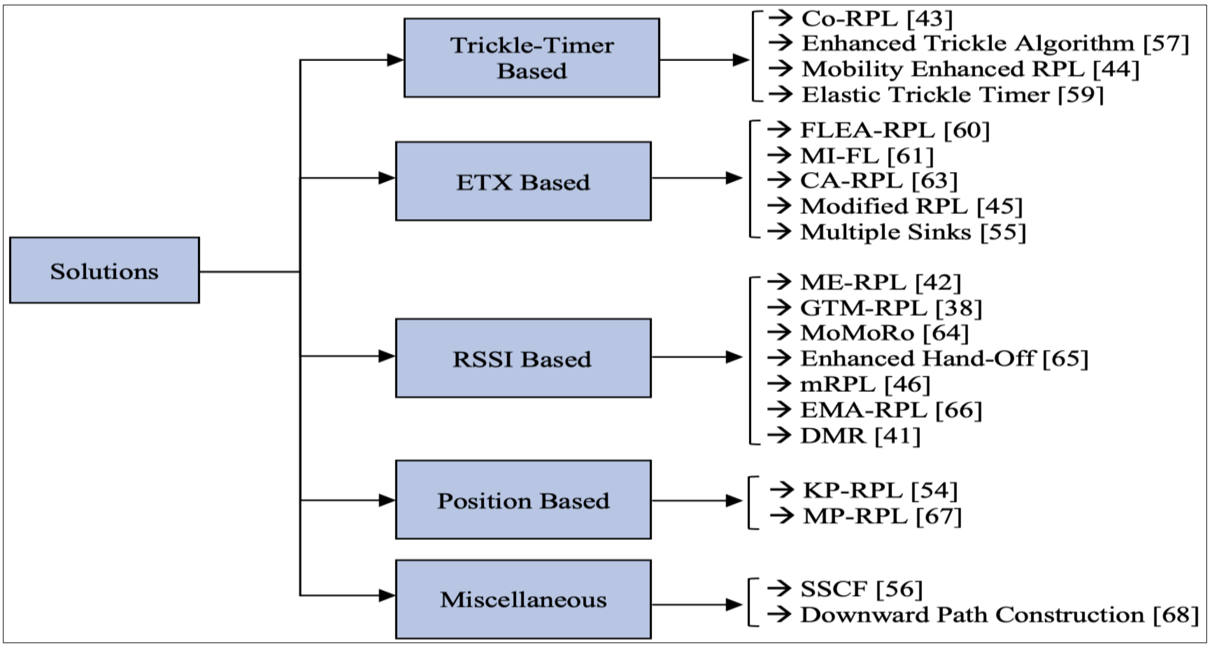

Figure (3). RPL problem solutions classification [30]

A node prepares PING request messages for the new neighbours' ETX values when it finds new neighbours. Based on its new neighbours' and parent's ETX values, the node determines whether to change its parent. The scheduling of ETX probing may postpone selecting a preferred parent if the new neighbours have a lower ETX value than the existing parent. This problem is particularly noticeable in highly mobile networks due to the quick rank changes brought on by constantly changing nodes. Instead of being scheduled to start later, ETX probing is started immediately. In this way, it will be simple for the new neighbours to choose the best parents.

The fundamental concept, problems solved, and advantages and disadvantages of the "Trickle Timer-based Solutions" are briefly described in Table 1.

Table (1). Solutions Based on Trickle Timers

Solution	Functional Concepts	Advantages	Disadvantages
Co-RPL	enhances mobile node tracking, which eliminates frequent node failures.	Co-RPL has a 20 percent lower loss rate, a 50 percent lower energy usage, and an average delay of 2.5 seconds when compared to standard RPL.	The effect of sink mobility on network performance is not covered by Co-RPL.
Superior Trickle Algorithm	DIS message broadcasts are constantly estimated based on Doppler frequency to support node mobility.	reduces energy usage to 72.5 MJ, the packet failure rate to 0.3%, and the DIS message count to 52.7%.	There is no discussion of ways to reduce high PLR caused by mobile nodes that do not match the time intervals for choosing parent nodes.

1.1 Loop Detection and Avoidance

A node loses contact with the AP for a brief period of time when it departs the AP's service region. The node tries to re-establish communication with the AP through its neighbours. The node may decide to choose that neighbour as its parent if the neighbour's rank is lower than its own (which is at infinity). Node 2 recently exited the AP's coverage region, as shown by Figure 3(a), and now has a rank of infinite. As soon as Node 1 gives it a DIO message, it increases its rank to 4. A DIO message from Node 3 may get lost in the course of transmission, failing to inform Node 3 of the parent of Node 2. When Node 2 is Node 1's parent, Node 1 transmits packets to Node 2.

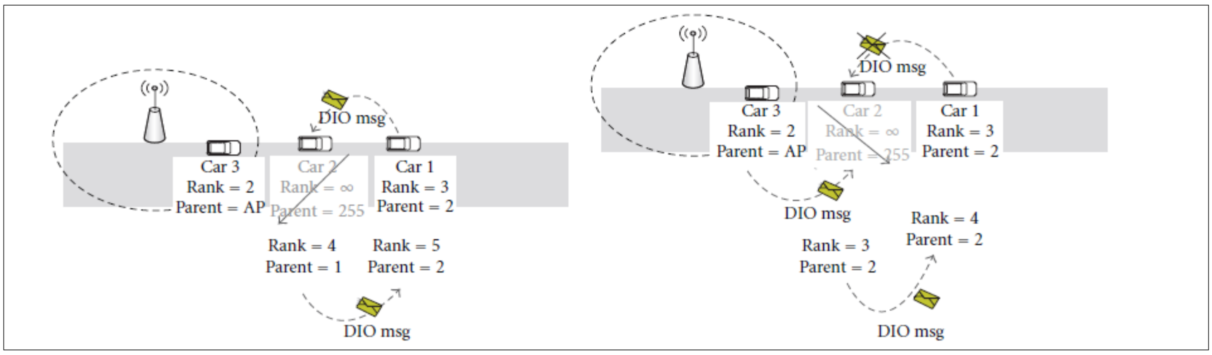

Figure (4). shows how to prevent loops [19].

Car 1's DIO messages have been updated to prevent looping, and Car 2 discards the DIO message from Car 1 after changing its rank to 4 and parent to Car 1.

By adding the parent's ID to the DIO message, we demonstrate the fix. A node will reject a DIO message it gets from a neighbour if the node's ID and the parent ID matched. As shown in Figure 1(b) for the same scenario, Node 2 will disregard Node 1's DIO message in order to prevent a loop because Node 1's DIO message indicates that Node 2 was Node 1's parent. The method also detects loops and breaks them.

5.2 Instant DIOs in relation to The New Parental Election

DIOs enable nodes, such as A, to ascertain their rank with respect to the node from whom they are getting the DIO message. Rank order is used to build the parent-child connection and the tree structure. After selecting a node to serve as its preferred parent, an immediately sends a DIO message to announce its new rank. This is distinct from the RFC standard in that DIO messages are not issued contingent on the trickle timer's expiration. We use a more aggressive approach despite the tackle timer's capacity to increase DIO msg frequency when topology alters. The tree may then be quickly modified to reflect the dynamic topology as a result.

5.3 Instant DAOs after New Parental Election

A node can create downward pathways to its progeny with the use of DAOs. Once a node, let's say A, determines who its parent is, a DAO message is instantly sent to tell A's children of its parent routes. A node "shall postpone broadcasting the DAO message to obtain DAO information from other nodes for which it is a DAO parent," according to the RFC [1]. This contradicts itself. However, the delay impairs packet delivery in a mobility environment like VANETs since routes are not promptly adjusted. Packet delivery is improved in exchange for higher overhead and more frequently occurring DAOs. Aggregation in sensor networks makes intuitive sense because nodes don't move around often, and routes don't need to be modified regularly low volume of traffic [30].

IV. CONCLUSION AND FUTURE DIRECTIONS

Since RPL was primarily created for fixed-node IoT applications, even if mobile IoT applications are becoming more and more popular, it was unable to adapt to the dynamic changes in mobile infrastructures. While several mobility aware RPL iterations have recently been presented, much more work needs to be done to advance a more effective version of this protocol that might be used by several mobile IoT applications. To enable researchers in academia or business to create multipurpose or application-specific versions of this protocol for mobile situations, it is first important to assess and compare RPL's performance in the presence of diverse mobility models.

This study tries to do a variety of in-depth analyses in this area. RPL encounters a number of issues when IoT devices are mobile, including An ETX probing experiment identified problems that need to be resolved, including the loss of sink-to-sink cooperation, problems with the rank of detached mobile nodes, a rise in turn delays, and a complete lack of position information, loops in the network, and problems with the Trickle algorithm, including link breakage and packet loss as a result of nodes moving. We also show alternative strategies that have been suggested in the literature to alleviate these mobility problems experienced by RPL. Our work splits these answers into five sections: Answers based on the trickle timer, the ETX, the RSSI, the position, and other answers. The pros and cons of each approach, as well as the underlying ideas and problems they address, are all carefully considered. This study also suggests several research directions that will help future researchers to provide more effective suggestions for reducing the mobility problems in RPL.

References

[1] Madakam, S.; Ramaswamy, R.; Tripathi, S. Internet of Things (IoT): A Literature Review. J. Comput. Commun. **2015**, 3, 164–173. [CrossRef]

[2] IoT Growth Demands Rethink of Long-Term Storage Strategies, Says IDC. Available online: https://www.idc.com/getdoc.jsp?containerId=prAP46737220 (accessed on 28 December 2020).

[3] Raza, S. Medium Access Control Protocols for Reliable Communication in Low-Power Industrial Applications. Ph.D. Thesis, Otto-von-Guericke Universität Magdeburg, Magdeburg, Germany, 2020.

[4] Farag, H. Enabling Industrial IoT Applications: Supporting Reliable and Real-Time Data Delivery. Ph.D. Thesis, Mid Sweden University, Östersund, Sweden, 2020.

[5] Kim, S.; Kim, C.; Cho, H.; Jung, K. A Hierarchical Routing Graph for Supporting Mobile Devices in Industrial Wireless Sensor Networks. Sensors 2021, 21, 458.

[6] Bharat, B.; Gadadhar, S. Requirements, protocols, and security challenges in wireless sensor networks: An industrial perspective. In Handbook of Computer Networks and Cyber Security; Springer: Berlin/Heidelberg, Germany, 2020; pp. 683–713.

[7] Azadeh, Z. Remote Patient Monitoring: Health Status Detection and Prediction in IoT-Based Health Care. In IoT in Healthcare and Ambient Assisted Living; Springer: Berlin/Heidelberg, Germany, 2021; pp. 89–102.

[8] Wu, T.-Y.; Wang, T.; Lee, Y.-Q.; Zheng, W.; Kumari, S.; Kumar, S. Improved Authenticated Key Agreement Scheme for Fog-Driven IoT Healthcare System. Secure Commun. Netw. 2021, 2021, 1–16.

[9] Kavita, J.; Veena, A. A Survey on IoT-Based Healthcare System: Potential Applications, Issues, and Challenges. In Advances in Biomedical Engineering and Technology; Springer: Berlin/Heidelberg, Germany, 2021; pp. 459–471.

[10] Doshi, H.; Shankar, A Wireless Sensor Network Application for IoT-Based Healthcare System. In Data-Driven Approach towards Disruptive Technologies: Proceedings of MIDAS; Springer: Singapore, 2020; pp. 287–307.

[11] Haque, H.M.U.; Zulfiqar, H.; Ahmed, A.; Ali, Y. A context-aware framework for modeling and verification of smart parking systems in urban cities. Concurr. Comput. Pract. Exp. 2019, 33, 5401.

[12] Ma, X.; Hu, X.; Weber, T.; Schramm, D. Experiences with Establishing a Simulation Scenario of the City of Duisburg with Real Traffic Volume. Appl. Sci. 2021, 11, 1193. [CrossRef]

[13] Frenken, M.; Flessner, J.; Hurka, J. Building Automation and Control Systems for Healthcare in Smart Homes. In Handbook of Large-Scale Distributed Computing in Smart Healthcare; Springer: Berlin/Heidelberg, Germany, 2017; pp. 87–119.

[14] Wibhada, N.; Ridnarong, P.; Aimaschana, N. Remote air conditioning control system based on ZigBee wireless Sensor Network for building. In Proceedings of the IEEE 2015 International Computer Science and Engineering Conference (ICSEC), Chiang Mai, Thailand, 23–26 November 2015; pp. 1–6.

[15] Admire, M.; Muthoni, M. Implementation of middleware for internet of things in asset tracking applications: In-lining approach. In Proceedings of the 2015 IEEE 13th international conference on industrial informatics (INDIN), Cambridge, UK, 22–24 July 2015; pp. 460–469.

[16] Mhlaba, A.M.; Masinde, M. An Integrated Internet of Things Based System for Tracking and Monitoring Assets–the case of the Central University of Technology. In Proceedings of the IST-Africa 2015 Conference Proceedings, Lilongwe, Malawi, 6–8 May 2015.

[17] Choudhary, P.; Bhargava, L.; Suhag, A.K.; Choudhary, M.; Singh, S. An Era of Internet of Things Leads to Smart Cities Initiatives Towards Urbanization. In Digital Cities Roadmap: IoT-Based Architecture and Sustainable Buildings; Wiley: Hoboken, NJ, USA, 2021; pp. 319–350.

[18] Ishaq I, Carels D, Tekle Mariam G, Hoebeke J, Abeele F, Poorter E, etal. IETF

Standardization in the Field of the Internet of Things (IoT): A Survey.J. Sens. ActuatorNetw.2013;2:235–87.

[19] Anhtuan L, Loo J, Lasebae A, Vinel A, Yue C, Chai M. The impact of the rank attack on network topology of routing protocol for low-power and lossy networks. Sens. J. IEEE 2013; 13:3685–92.

[20] Latif, K.; Javaid, N.; Ullah, I.; Kaleem, Z.; Malik, Z.A.; Nguyen, L.D.; Abbas, Z. DIEER: Delay-Intolerant Energy-Efficient Routing with Sink Mobility in Underwater Wireless Sensor Networks. Sensors 2020, 20, 3467. [CrossRef]

[21] Ko, J.; Terzis, A.; Dawson-Haggerty, S.; Culler, D.E.; Hui, J.W.; Levis, P. Connecting low-power and lossy networks to the internet. IEEE Commun. Mag. 2011, 49, 96–101. 34. Dohler, M.; Watteyne, T.; Winter, T.; Barthel, D. Routing Requirements for Urban Low-Power and Lossy Networks. RFC 5548. 2009, https://datatracker.ietf.org/doc/html/rfc5548 (accessed on 1 September 2021).

[22] Pister, K.; Thubert, P.; Dwars, S.; Phinney, T. Industrial Routing Requirements in Low-Power and Lossy Networks. Citeseer. 2009, https://datatracker.ietf.org/doc/rfc5673/ (accessed on 1 September 2021).

[23] Porcu, G.; Buron, J.; Brandt, A. Home Automation Routing Requirements in Low-Power and Lossy Networks; RFC 5826; IETF Secretariat: Fremont, CA, USA, 2010.

[24] Martocci, J.; Mil, P.; Riou, N.; Vermeylen, W. Building Automation Routing Requirements in Low-Power and Lossy Networks; RFC 5867; IETF Secretariat: Fremont, CA, USA, 2010.

[25] Kharrufa, H.; Al-Kashoash, H.; Kemp, A.H. A Game Theoretic Optimization of RPL for Mobile Internet of Things Applications. IEEE Sens. J. 2018, 18, 2520–2530.

[26] Gnawali, O.; Levis, P. The Minimum Rank with Hysteresis Objective Function. Internet Engineering Task Force (IETF) RFC: 6719. 2012. Available online: https://datatracker.ietf.org/doc/html/rfc6719 (accessed on 1 September 2021).

[27] Cobarzan, C.; Montavont, J.; Noel, T. Analysis and performance evaluation of RPL under mobility. In Proceedings of the 2014 IEEE Symposium on Computers and Communications (ISCC), Madeira, Portugal, 23–26 June 2014; pp. 1–6.

[28] Hong, K.; Choi, L. DAG-based multipath routing for mobile sensor networks. In Proceedings of the ICTC 2011, Seoul, Korea, 28–30 September 2011; pp. 261–266.

[29] Sankar, S.; Srinivasan, P. Mobility and Energy Aware Routing Protocol for Healthcare IoT Application. Res. J. Pharm. Technol. 2018, 11, 3139. [CrossRef]

[30] Zawar Shah , Andrew Levula , Khawar Khurshid , Jawad Ahmed , Imdad Ullah and Sushmita Singh, Routing Protocols for Mobile Internet of Things (IoT): A Survey on Challenges and Solutions, 09,2021 Electronics, 2320.

[31] Martocci, J.; Mil, P.; Riou, N.; Vermeylen, W. Building Automation Routing Requirements in Low-Power and Lossy Networks; RFC 5867; IETF Secretariat: Fremont, CA, USA, 2010.

[32] Kharrufa, H.; Al-Kashoash, H.; Kemp, A.H. A Game Theoretic Optimization of RPL for Mobile Internet of Things Applications. IEEE Sens. J. **2018**, 18, 2520–2530. [CrossRef]

[33] Gnawali, O.; Levis, P. The Minimum Rank with Hysteresis Objective Function. Internet Engineering Task Force (IETF) RFC: 6719. 2012. Available online: https://datatracker.ietf.org/doc/html/rfc6719 (accessed on 1 September 2021).

[34] Cobarzan, C.; Montavont, J.; Noel, T. Analysis and performance evaluation of RPL under mobility. In Proceedings of the 2014 IEEE Symposium on Computers and Communications (ISCC), Madeira, Portugal, 23–26 June 2014; pp. 1–6.

[35] Gaddour, O.; Koubäa, A.; Rangarajan, R.; Cheikhrouhou, O.; Tovar, E.; Abid, M. Co-RPL: RPL routing for mobile low power wireless sensor networks using corona mechanism. In Proceedings of the 9th IEEE International Symposium on Industrial Embedded Systems (SIES 2014), Pisa, Italy, 18–20 June 2014; pp. 200–209.

[36] El Korbi, I.; Brahim, M.B.; Adjih, C.; Saidane, L.A. Mobility enhanced RPL for wireless sensor networks. In Proceedings of the 2012 Third International Conference on the Network of the Future (NOF), Gammarth, Tunisie, 21–23 November 2012; pp. 1–8.

[37] Vasseur J., Kim M., Pister K., Dejean N., Barthel D. Routing Metrics Used for Path Calculation in Low-Power and Lossy Networks. IETF; Fremont, CA, USA: 2012. RFC 6551. [Google Scholar]

[38] Winter T., Thubert P., Brandt A., Hui J., Kelsey R., Levis P., Pister K., Struik R.,

Vasseur J.A.R. Rpl: Ipv6 Routing Protocol for Low-Power and Lossy Networks, RFC 6550. [(accessed on 24 January 2018)];2012 Available : http://tools.ietf.org/html/rfc 6550

[39] Jayaraman P.P., Haghighi P.D. SA-A-WSN: Situation-aware adaptation approach for energy conservation in wireless sensor network; Proceedings of the 2013 IEEE Eighth International Conference on Intelligent Sensors, Sensor Networks and Information Processing; Melbourne, Australia. 2–5 April 2013; pp. 7–12. [Google Scholar]

[40] Gaddour O., Koubaa A., Baccour N., Abid M. OF-FL: QoS-aware fuzzy logic objective function for the RPL routing protocol; Proceedings of the 2014 12th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt); Hammamet, Tunisia. 12–16 May 2014; pp. 367–372. [Google Scholar]

[41] Chen Y., Chanet J., Hou K., Shi H., Sousa G. A Scalable Context-Aware Objective Function (SCAOF) of Routing Protocol for Agricultural Low-Power and Lossy Networks (RPAL) Sensors. 2015;**15**:19507–19540. doi: 10.3390/s150819507. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

[42] Abbasbandy S., Amirfakhrian M. The nearest trapezoidal form of a generalized left right fuzzy number. Int. J. Approx. Reason. 2006;**43**:166–178. doi: 10.1016/j.ijar.2006.04.001. [CrossRef] [Google Scholar]

[43] Driankov D., Hellendoorn H., Reinfrank M. An Introduction to Fuzzy Control. Volume XV. Springer; Berlin/Heidelberg, Germany: 1993. 316p [Google Scholar]