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RPL Protocol Limitations, and Open Challenges in Internet of Things: A Review

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Abstract: Low-power and lossy networks (LLNs) are critical components of the IoT ecosystem. These networks are distinguished by common characteristics such as low resources and a high rate of packet loss. In 2012, the Routing Protocol for Low-Power and Lossy Networks (RPL) was suggested as a routing protocol for such networks. Even though RPL is now standardized and widely acknowledged, there are still areas for improvement, such as load balancing, stability, routing, and mobility support. This review work focuses the limitations and open challenge in RPL. Many researchers are attempted to address this issue in the literature by developing various routing measures that address various aims. This review work makes assessment of the RPL works, their strengths and shortcomings, and provides future directions on the issues.

Keywords: IoT, LLNs, RPL, Routing, Challenges.

I. INTRODUCTION

In recent years, the Internet of Things (IoT), a system of interconnected and integrated objects with computational capacity, has become a popular and rapidly increasing idea. However, it is no longer just a theoretical notion; IoT is now being employed in a variety of applications ranging from smart homes and autonomous driving systems to linked cities and smart grids. By 2025, the number of IoT devices is estimated to reach over 75 billion, reflecting a five-fold growth over the previous decade. While home automation apps account for over half of all IoT device connections, linked work and connected city applications have grown in popularity in recent years [1,2].

Due to the restricted resources of a high number of IoT devices, studies recommended for such networks should take into account numerous limits such as computational power, storage space, and energy. These networks are known as Low-Power and Lossy Networks (LLNs) in the literature [3]. Because LLNs make up a substantial portion of IoT systems, addressing their limitations is critical for both industries and research. In this area, research has mostly concentrated on enhancing LLNs stability and lowering energy usage [4]. The Routing System for Low-Power and Lossy Networks (RPL) is a well-known routing protocol for such resource-constrained devices [5] that tries to offer bidirectional communication between LLNs topology nodes. Although it is designed primarily for multipoint-to-point (MP2P) communication, it also supports point-to-point (P2P) and point-to-multipoint (P2MP) network traffic. While research work agrees that RPL has the potential to progress and prosper, it also has some flaws, such as a proclivity for load imbalance, stability, multi path selection, and a lack of attention on mobility, all of which must be addressed. These flaws impede widespread acceptance of RPL as a routing standard, which is critical given the expected exponential rise in the number of IoT devices over the next decade [6]. Furthermore, the benefits and shortcomings of the RPL protocol were investigated, as well as future research directions to improve load balancing and routing. The examined works were determined to be largely unsalable and network/domain-specific, with a notable lack of consideration for mobility [7-9].

This review work is organized with six sections. The current section introduces IoT part, Section 2 and 3 summarizes the generic information on LLNs and RPL based on the existing surveys, Section 4 explains the limitations of RPL. In section 5 shows the simulators experience from reviewed works and finally in section 6, state the conclusion and findings of this review study.

II. LOW-POWER AND LOSSY NETWORKS

LLNs are made up of nodes with limited memory, power, and computational capabilities. Another restriction in such networks is communication. Low data speeds, restricted frame sizes, substantial packet losses, limited communication ranges, and changing network topologies are typical LLN communication features [10]. LLNs are proposed for use in a variety of application domains, including smart homes, smart industries, smart cities, and smart military systems, each with its own set of limitations and needs in terms of energy, routing, overhead, reliability, and performance [11,12].

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Figure 1 depicts an example LLNs network structure. The network's resource-constrained nodes link to the Internet through the LLN Border Router, which does not have the same resource limitations [13]. While all nodes in such networks can interact with one another, traffic in such networks typically flows from sensor nodes to a sink node (LLN border router), as in normal data gathering applications.

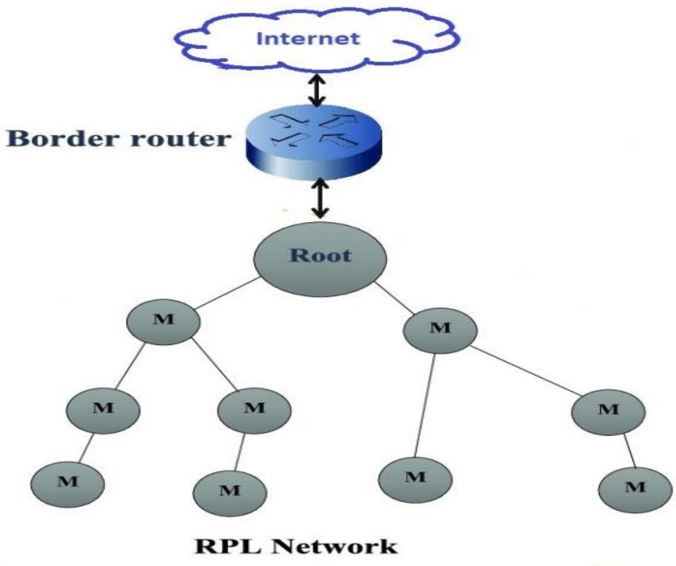

Fig. 1 LLNs Network Structure

Several technologies and standards have been suggested and developed by both standardization working groups and researchers to enable the effective and efficient use of LLNs in IoT. IETF 6TiSCH [14] is charged with resolving MAC layer issues, whereas IEEE 802.15.4 [15] is concerned with the MAC layer and the physical layer of the protocol stack. 6LoWPAN [16] is a well-known technology that provides adaption between the IEEE 802.15.4 standard and upper-layer protocols such as RPL or IPv6. Other technologies used in LLNs include Power-Line Communications (PLC) [17], Bluetooth Low Energy (BLE) [18], and Wi-Fi HaLow [19].

2.1. LLNs Routing

Different LLN features should be taken into account while creating a routing system for these networks. To begin, routing protocols for LLNs should be capable of meeting various features for various application areas. Furthermore, because nodes in LLNs are resource-constrained by nature, developing an effective routing protocol is hampered by various constraints. For example, while energy is one of the scarcest resources for nodes [20], it should not be used by frequent routing of control messages. Different sorts of communication patterns are supported by LLNs. The most typical use is for MP2P traffic, in which sensor nodes collect and report data to a LLNs Border Router (LBR). As with P2MP traffic, communication might also downstream, from the LBR node to sensor nodes. Finally, P2P traffic allows for direct connection between sensor nodes. Distinct requirements, such as centralized or distributed topology, security requirements, and mobility, need different communication modes in LLNs. This complicates the design of efficient routing protocols for LLNs [21,22].

In LLN sensor-based applications, three data interchange types are commonly used: event-based, time-based, and query-based. Sensor nodes in event-based models communicate their results whenever they notice a significant change in their area of responsibility. Sensor nodes in time-based models communicate their data at regular intervals or at a predetermined time. In query-based models, sensor node findings are presented when the nodes receive a specific query. These data exchange models, however, can be combined, resulting in hybrid models. As a result, the selected data exchange architecture is intimately related to node energy consumption, and the stability of routing pathways in the network might impact the frequency of route updates.

Even while sensor nodes are projected to be stationary in most circumstances, real-world examples and future forecasts show that a large percentage of nodes will be mobile. Nodes in healthcare related applications, for example, that gather data from individuals are inherently mobile. As a result, mobility is an important limitation of a potential routing algorithm. Finally, a good protocol for LLNs should be scalable, as they are designed to manage various topologies

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ranging from a few nodes to thousands in various application domains such as home automation , urban, and industrial [23-26].

III. RPL SUMMARY

The IETF tasked the ROLL working group (WG) with publishing an RFC for RPL in 2012 [27]. Since then, the WG has issued further RFCs that describe the core components of RPL, including routing metrics [28], Trickle timer [29], and Objective Function (OF) [30,31]. The fundamental functions and essential components of RPL are covered and summarized in this section.

RPL is a proactive source and distance vector routing method. To depict the network topology, it generates Directed Acyclic Graphs (DAG). In RPL terms, each DAG connected with a single root destination is referred to as a Destination Oriented DAG (DODAG). A network may contain several DODAGs and instances. An RPL instance is a single or more DODAGs that have the same OF.

The path is selected by the OF. As a result, RPL instances play an important role in offering alternative routes, even for the same destination, to achieve different aspects such as lowering energy, ETX, or latency. While a node can be a member of many DODAGs in various RPL instances, it can only join a single DODAG (root) in a single RPL instance. Figure 2, depicts an example RPL network with a single DODAG.

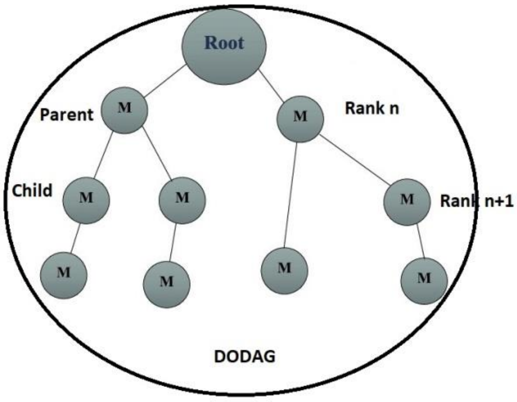

Fig. 2 Example DODAG

Hosts, routers, and LBRs (LLN Border Routers) are the three types of RPL network nodes [10]. Hosts are nodes that can generate data traffic but cannot forward it, whereas routers are nodes that can do both. Finally, LBRs are the roots of a DODAG and may be thought of as a network traffic gathering point. LBRs can build a DAG and serve as edge routers between the LLN and the Internet [32-38]. A single DODAG may include numerous LBRs.

3.1. DODAG Construction

RPL is primarily intended for MP2P traffic by identifying upward routes to a DODAG's root. It does, however, enable P2P and P2MP traffic by building downward pathways. It uses four different sorts of communications to build the network architecture and identify routes. DODAG Information Object (DIO), DODAG Information Solicitation (DIS), Destination Advertisement Object (DAO), and Destination Advertisement Acknowledgement are the message types described in the ICMPv6 protocol (DAO ACK). First, the DODAG root sends DIO signals to construct routes in the upward direction (from child to parent). Then route creation, child nodes send unicast DAO messages to the DODAGs root. When a new node joins the network, DIS messages are sent. In order to join the DODAG, the node requests topological information from its neighbors. DIO messages are generally broadcast messages that are transmitted from the root to its children using the Trickle timer. They might, however, be provided upon request in conjunction with the receipt of a DIS message. A node announces its rank and the goal function to be utilized in a DIO message. The location of a node with relation to the root node is represented by rank. The objective function computes a node's rank based on routing metrics and optimization goals. For example, one of the default OF for RPL routers is OF Zero (OF0) [30], which identifies the node adjacent to the DODAG root as the desired parent. Rank rises in the DODAG's downward direction and falls in the opposite way. The fact that a root node's rank should be lower than that of its child nodes prevents routing loops from forming in the network.

When a node gets a DIO message, it updates its parent candidate set and selects a parent based on the nodes in the set's rank values. It then computes the rank value. If the computed rank is greater than the node's parents (i.e., the node is on

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a downhill path from the parents), the DIO message is updated with the new rank information. Finally, it sends the DIO message to the nodes that are nearby. As a consequence, each network node constructs its upward routes using DIO messages. DAO messages allow a node to send its destination information upwards through the DODAG, enabling for the development of downward routes between the DODAG root and the connected nodes [10].

3.2. Trickle Timer Algorithm

The Trickle timer controls the rate at which DIO messages are sent. When a change in routing information or discrepancy is discovered, the Trickle timer raises the rate of transmission in order to re-circulate updated information. When the network approaches stability, the Trickle timer exponentially slows the rate of transmission to limit the amount of transmissions because there is nothing new to broadcast. In addition, if a node detects that its neighbors are broadcasting the identical control packet that it wants to send, the node suppresses the transmission to decrease network redundancy. RFC 6206 [29] defines the Trickle algorithm. The Trickle algorithm employs four distinct values, where I is the interval time size in milliseconds, which determines the algorithm's running time and real-time; k is an integer used as a redundancy constant; t represents a time within the current interval; and c is the counter value. Transmission can be classified as consistent or erratic depending on the implementation.

First, the algorithm selects an *I* value from the predefined *Imin* and *Imax* values. The second step is to set c =0 and *t* to a random value between *I/2* and *I*. Trickle begins listening, and if a balanced signal is detected, the *c* value is increased. Trickle only allows transmissions when *c* is smaller than the redundancy constant k, implying that a specific amount of time must elapse before initiating another communication. This is referred to as the Trickle algorithm's suppression mechanism. When I irritated *Imax*, the method doubles the duration of the interval and begins over. If Trickle detects an inconsistent transmission and *I* is higher than *Imin*, the timer is reset by setting *I* to *Imin*, and the process resumes from the second step. The phrases consistent and inconsistent have different meanings depending on the application that employs Trickle.

3.3. Objective Functions (OFs)

RPL is provided with two standard objective functions: Objective Function Zero (OF0) [30] and Minimum Rank with Hysteresis Objective Function (MRHOF) [31]. OF0 selects the node adjacent to the DODAG root as the preferred parent, with no consideration for load balancing. In addition, one additional parent is identified as an option in the case that communication with the preferred parent is lost. MRHOF was designed to minimize frequent changes in preferred parents, which affects network stability. The cost of a path for passing among the surrounding nodes that form a path between the origin and destination nodes is calculated using MRHOF. The computation is conducted by adding two values: the cost of the metric of the prospective neighbor node or connection and the cost of the metric broadcast in the sent message. Following this calculation, the node with the lowest route cost is chosen as the desired parent.

IV. LIMITATIONS, DRAWBACKS, AND OPEN CHALLENGES OF RPL

RPL, while established as the standard routing protocol of LLNs, has significant shortcomings, as revealed by a slew of recent research [8-10]. Load imbalance is one of RPL's drawbacks, as large scale LLNs are usually always distributed non-uniformly [33]. Load imbalance in a network can develop for a variety of reasons. One such cause is the hotspot issue [34]. This issue arises when the parent node or a node forwarding a message encounters network congestion, causing this node to expend its resources to handle excessive message flow. Hotspots are more common when a node is close to the root. This issue eventually depletes that node's and system's resources, reducing network lifespan. The authors of [35] noted two more issues that might contribute to load imbalance. The first issue is known as "thundering herd," and it arises when a node with a superior transmission line enters the RPL-based network. This may cause changes in a large number of nodes, thereby affecting network stability. The second issue, known as a "randomly imbalanced network," happens when two parent candidates have the same rank value, resulting in random selection of the parent. By chance, this method has the potential to generate load imbalance. The reset of this subsection will explain noteworthy limitations, drawbacks, and open challenging factors of RPL in more detail, as well as their issue of load balancing.

4.1. Energy consumption

Given the restricted resources of the nodes in an LLN, one of the key limitations for creating an effective routing algorithm is energy consumption. As a result, the primary goal of any RPL study is to reduce energy usage and increase network longevity. RPL is designed to reduce energy usage with the use of a Trickle timer. However, according to [36], the efficacy of Trickle timer reduces in mobile situations. Energy usage is inextricably tied to load balancing, and an unbalanced network would almost likely result in higher energy consumption.

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4.2. Reliability

The frequency of dropped packets and the average latency of sending packets between end-points are used to assess reliability in the context of RPL. Greater dependability, as a rule, comes at the expense of increased energy consumption, often in the form of retransmissions or acknowledgments. Finding a suitable balance is thus one of the aims of RPL improvement. Load imbalance can also contribute to network dependability issues.

4.3. Congestion

Network congestion, like in real-world instances, is one of the primary causes of increased energy consumption, increased latency, and poor dependability in LLNs [37]. Congestion and load balancing are also connected topics, as an unbalanced network will inevitably lead to congestion.

4.4. Objective Functions (OFS)

One of the key constraints of RPL's parent selection process is that it always uses the same parent when forwarding a packet to the root. Because this single-path forwarding disregards the load balancing factor [38], it would result in power depletion or the demise of overburdened parent nodes, perhaps leading in network disconnections. RPL allows utilizing both single and multiple routing metrics. While using a single metric may satisfy one condition, it may result in additional inefficiencies inside the network. For example, while the Expected Transmission Count (ETX) allows RPL to select the most trustworthy channel [39], it may also result in early network segmentation owing to the lack of any load-balancing method that would prevent energy-constrained nodes from depleting node power. As a result, recommendations for improving load balancing in the literature tend to employ various indicators. However, the RFC not defined the usage of multiple metrics, with the exception of multiple instances [46], in which distinct instances with various routing objectives are implemented with different routing metrics to meet those objectives. The cost of routing a path in RPL is computed by adding the costs of the links that make up the path. As a result, a road with a high number of hops seems to have a high cost compared to a route with fewer hops, even when the former path may include higher-quality linkages. This may lead the protocol to selects routes that appear to be low values (e.g. LQL) yet consist of lower-quality connections when making routing decisions [40].

4.5. Stability

In RPL terminology, stability might have two separate meanings: route stability and node stability. The validity lifetime of a routing path is linked to route stability. Because movement is largely dismissed in the literature, most investigations merely refer to node stability, or the validity period of the favored parents [42]. Please keep in mind that node stability and route stability are closely connected concepts, as node depletion may result in route alterations. In general, reduced network stability leads to increased overhead and energy usage. Current systems that attempt to address load balancing in RPL often induce network instability, which is an undesirable side effect [43]. As a result, an effective solution must include both stability and mobility, as real-world conditions require. In order to balance the load and increase RPL performance in general, the solutions invariably include parent selection techniques or multipath routing. Due to the constant change of parents, great stability may not always be accomplished, and finding a compromise between stability and load balancing may be a more realistic objective. The incidence of control messages such as DIO, DAO, and DIS messages that flow through the node can be used to calculate node stability. This may not always signify low stability, because nodes with a greater number of offspring will often have a higher amount of messages travelling through. Another frequent way for calculating the ratio is to use the same transmission path between nodes.

4.6. Mobility

While RPL protocol is not intended to be mobile, real-world applications might incorporate mobile nodes. However, in its current aspect, RPL does not distinguish between mobile and non-mobile nodes, limiting its adaptation to dynamic networks. For example, if a mobile parent moves the network, the child nodes may experience unexpected packet loss since they are unaware that their chosen parent has departed the topology. The Trickle timer algorithm itself has some mobility concerns, since it may respond slowly to a rapidly changing mobile network, or it may not respond at all at the appropriate moment. RPL might be designed to meet mobility needs, such as situating mobile nodes in leaves or using Trickle timers to transmit control messages often; however, these solutions may result in enormous quantities of routing control message traffic [44].

V. SIMULATION EXPERIENCE

Many of the studies described were not evaluated in a real-world setting, instead relying on network simulators. Figure 3 depicts the distribution of simulators used in the reviewed studies. As can be seen, COOJA is the most popular of the simulations. The key reason for its popularity is because COOJA runs on Contiki-OS, an open-source operating system

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aimed at IoT devices in general. While this makes COOJA accessible and simple to use, it also has certain performance limitations, such as low performance or crashes when modeling an environment with a large number of nodes.

5.1. Evaluations

While simulations are important for proof-of-concept research, they may not fully reflect all features of real-world settings. Almost a 25% of the works assessed tested their ideas on genuine testbeds, with fewer than 30 nodes employed in these testbeds, as in home automation applications. Even simulator studies were carried out with a small number of nodes. In order to evaluate the performance of each research more reliably, a standard testbed for assessment is also required. While the RPL standard is intended to run on LLNs with a few dozen to thousands of sensor nodes [27], some of the studies [44-47] employed tiny networks (consisting of less than 50 nodes). The low number of nodes in the assessed networks cannot be regarded appropriate, as at least 20 nodes are required to see the multi-hop properties of RPL [8]. Furthermore, the scalability of the offered systems is rarely addressed.

5.2. Reliability

While several research [48,49-50] offer load-balancing increases by dispersing the energy load across the nodes, they do not comment on their outcomes, particularly in the context of network dependability, which is an essential performance requirement. As a result, the majority of the assessed publications were only focused with energy and its ensuing implications on routing. PDR and throughput are two metrics that may be used to assess network reliability and inform route selection. Lack of reliability performance may result in rapid energy depletion and excessive overhead, and also connected to instability. Using more objective optimization techniques to determine a trade-off between reliability and a balanced network might be a promising future research path.

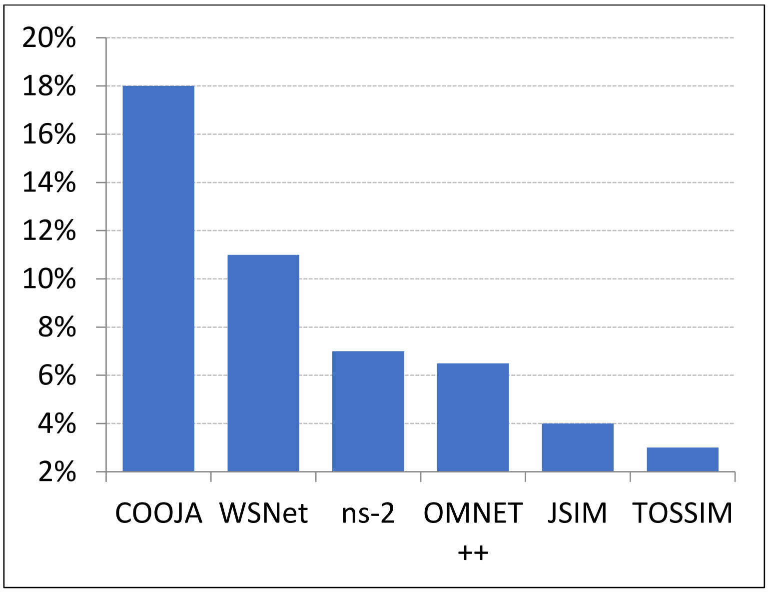

Fig. 3 Simulator Utilization on Exiting Works

5.3. Choice Performance Metrics

The identification of a load-balanced network was not consistent among the studies considered. Several performance measures were used in the works to evaluate their suggested techniques or schemes, and a common set of evaluation metrics would be required to efficiently and effectively evaluate and compare the works. Most works evaluated their approaches using network longevity, residual energy, and PDR, rather than more complex and precise criteria like load distribution and load homogeneity.

5.4. Selection of Quality Paths

If the metrics are not properly analysed (for example, merely using hop-count or latency), a road that appears to be a better choice may in reality perform worse (in terms of energy consumption or delay) when compared to a path with a larger number of hops. Furthermore, several of the works [51] that only evaluated the immediate nodes while choosing routes tended to be unaware of the overall network. In [43], for example, this resulted on worse performance in uncongested networks since the approach primarily sought for congestion avoidance within its area.

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5.5. Understanding of Environment

All of the metric-based research examined in this study used artificial measures. However, because of their unique properties, including as low-power nodes and lossy connections, LLNs are complicated ecosystems. Furthermore, numerous trade-offs, such as dependability and/or stability, should be addressed while creating a routing protocol for this complicated context. When complicated trade-offs must be weighed, humans are not very effective at making smart decisions. When there is motion, it may be much more difficult to comprehend the surroundings. Techniques based on artificial intelligence may be more adapted to such complicated and/or dynamic challenges. However, only a few methods [52-53] studied the application of AI-based algorithms for load balancing optimization.

VI. Conclusion

The difficulty of load balance and routing path selection in RPL was recognized in this study, and actions targeted at improving RPL were then reviewed. The papers studied were divided into two groups: The review revealed how each of these efforts intended to enhance load balancing and improve the routing methods in RPL, The evaluation also revealed that no optimal approach to enhance load balancing and path selection in RPL has yet been discovered. Further modification and tweaking of routing metrics and OFs would most likely result in minor increases that would be offset by other disadvantages. As a result, fresh strategies are required to further the work in this RPL protocol performance improvement in IoT field. Techniques such as employing numerous instances, leveraging additive method for composite metric creation, and threshold determination have yet to be completely investigated.

References

[1]. Cisco, Cisco visual networking index: Forecast and trends, 2017– 2022 white paper, 2020, (Visited December 2019) [Online]. Available: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visualnetworking-index-vni/white-paper-c11-741490.html.

[2]. Statista, Internet of Things (IoT) connected devices installed base worldwide from 2015 to 2025 (in billions), 2016, (Visited December 2019) [Online]. Available: https://www.statista.com/statistics/471264/iot-number-of-connecteddevices-worldwide/.

[3]. J.W. Hui, D.E. Culler, Extending IP to low-power, wireless personal area networks, IEEE Internet Comput. (4) (2008) 37–45.

[4]. B. Ghaleb, A.Y. Al-Dubai, E. Ekonomou, A. Alsarhan, Y. Nasser, L.M. Mackenzie, A. Boukerche, A survey of limitations and enhancements of the IPv6 routing protocol for low-power and lossy networks: A focus on core operations, IEEE Commun. Surv. Tutor. 21 (2) (2018) 1607–1635.

[5]. J. Manyika, M. Chui, P. Bisson, J. Woetzel, R. Dobbs, J. Bughin, D. Aharon, Unlocking the Potential of the Internet of Things, McKinsey Global Institute, 2015.

[6]. Poorana Senthil Kumar S Subramani B, "Evolutions of Low power and Lossy Networks Protocols in the Internet of Things: Review," ITEE J. Inf. Technol. Electr. Eng., vol. 11, no. 3, pp. 1–12, 2022, [Online]. Available: http://www.iteejournal.org/Archive_june_2022.php

[7]. H.-S. Kim, J. Ko, D.E. Culler, J. Paek, Challenging the IPv6 routing protocol for low-power and lossy networks (RPL): A survey, IEEE Commun. Surv. Tutor. 19 (4) (2017) 2502–2525.

[8]. Kharrufa, H.A. Al-Kashoash, A.H. Kemp, RPL-based routing protocols in IoT applications: A review, IEEE Sens. J. 19 (15) (2019) 5952–5967.

[9]. Lamaazi, N. Benamar, A comprehensive survey on enhancements and limitations of the RPL protocol: A focus on the objective function, Ad Hoc Netw. 96 (2020) 102001.

[10]. I.E.T.F. (IETF), RFC 6550, RPL: IPv6 routing protocol for low-power and lossy networks, 2012, (Visited December 2019) [Online]. Available: https://tools.ietf. org/html/rfc6550.

[11]. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, Wireless sensor networks: a survey, Comput. Netw. 38 (4) (2002) 393–422.

[12]. P. Levis, N. Patel, D. Culler, S. Shenker, Trickle: A self-regulating algorithm for code propagation and maintenance in wireless sensor networks, in: Proc. of the 1st USENIX/ACM Symp. on Networked Systems Design and Implementation, vol. 25, pp. 37–52.

[13]. J.A. Gutierrez, M. Naeve, E. Callaway, M. Bourgeois, V. Mitter, B. Heile, IEEE 802.15. 4: a developing standard for low-power low-cost wireless personal area networks, IEEE Netw. 15 (5) (2001) 12–19.

[14]. D. Dujovne, T. Watteyne, X. Vilajosana, P. Thubert, 6TiSCH: deterministic IPenabled industrial internet (of things), IEEE Commun. Mag. 52 (12) (2014) 36–41.

[15]. A.F. Molisch, K. Balakrishnan, C.-C. Chong, S. Emami, A. Fort, J. Karedal, J. Kunisch, H. Schantz, U. Schuster, K. Siwiak, IEEE 802.15. 4a channel model-final report, IEEE P802 15 (04) (2004) 0662.

[16]. G. Mulligan, The 6LoWPAN architecture, in: Proceedings of the 4th Workshop on Embedded Networked Sensors, ACM, 2007, pp. 78–82.

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ISO 3297:2007 Certified ⋇ Impact Factor 7.918 ⋇ Vol. 12, Issue 1, January 2023

DOI: 10.17148/IJARCCE.2023.12131

[17]. N. Pavlidou, A.H. Vinck, J. Yazdani, B. Honary, Power line communications: state of the art and future trends, IEEE Commun. Mag. 41 (4) (2003) 34–40.
[18]. C. Gomez, J. Oller, J. Paradells, Overview and evaluation of bluetooth low energy: An emerging low-power wireless technology, Sensors 12 (9) (2012) 11734–11753.
[19]. W.-F. Alliance, Wi-Fi Alliance Introduces Low Power, Long Range Wi-Fi HaLow, www.wi-fi.org, 2016.
[20]. Q. Tang, L. Yang, G.B. Giannakis, T. Qin, Battery power efficiency of PPM and FSK in wireless sensor networks, IEEE Trans. Wireless Commun. 6 (4) (2007) 1308–1319.
[21]. A. Brandt, J. Buron, G. Porcu, T. Italia, Home automation routing requirements in low-power and lossy networks, RFC 5826, 2010.
[22]. J. Martocci, W. Vermeylen, N. Riou, P.D. Mil, Building automation routing requirements in low-power and lossy networks, 2010.
[23]. K. Pister, P. Thubert, S. Dwars, T. Phinney, Industrial Routing Requirements in Low-Power and Lossy Networks, Citeseer, 2009.
[24]. M. Dohler, D. Barthel, T. Watteyne, T. Winter, Routing requirements for urban low-power and lossy networks, 2009.
[25]. S. Movassaghi, M. Abolhasan, J. Lipman, D. Smith, A. Jamalipour, Wireless body area networks: A survey, IEEE Commun. Surv. Tutor. 16 (3) (2014) 1658–1686.
[26]. R. Cragie, P.v.d. Stok, A. Brandt, E. Baccelli, Applicability statement: The use of the routing protocol for low-power and lossy networks (RPL) protocol suite in home automation and building control, Consultant (2016).
[27]. T. Winter, P. Thubert, A. Brandt, J. Hui, R. Kelsey, P. Levis, K. Pister, R. Struik, J. Vasseur, R. Alexander, RFC 6550: RPL: IPv6 routing protocol for low-power and lossy networks, IETF request for comments, 2012.
[28]. J. Vasseur, M. Kim, K. Pister, N. Dejean, D. Barthel, Routing metrics used for path calculation in low-power and lossy networks, in: RFC 6551, IETF, 2012, pp. 1–30.
[29]. P. Levis, T. Clausen, J. Hui, O. Gnawali, J. Ko, The trickle algorithm, Internet engineering task force, RFC6206, 2011.
[30]. P. Thubert, Objective function zero for the routing protocol for low-power and lossy networks (RPL), 2012.
[31]. P. Levis, O. Gnawali, The minimum rank with hysteresis objective function, 2012.
[32]. Gaddour, A. Koubaa, RPL in a nutshell: A survey, Comput. Netw. 56 (14) (2012) 3163–3178.
[33]. X. Liu, J. Guo, G. Bhatti, P. Orlik, K. Parsons, Load balanced routing for low power and lossy networks, in: 2013 IEEE Wireless Communications and Networking Conference, WCNC, IEEE, 2013, pp. 2238–2243.
[34]. L.B. Saad, C. Chauvenet, B. Tourancheau, Simulation of the RPL routing protocol for IPv6 sensor networks: two cases studies, in: International Conference on Sensor Technologies and Applications SENSORCOMM 2011, IARIA, 2011, pp. 256–273.
[35]. J. Hou, R. Jadhav, Z. Luo, Optimization of parent-node selection in RPL-based networks, Internet Engineering Task Force (IETF) draft, 2017.
[36]. C. Cobarzan, J. Montavont, T. Noel, Analysis and performance evaluation of RPL under mobility, in: 2014 IEEE Symposium on Computers and Communications, ISCC, IEEE, 2014, pp. 1–6.
[37]. H.A. Al-Kashoash, F. Hassen, H. Kharrufa, A.H. Kemp, Analytical modelling of congestion for 6LoWPAN networks, ICT Express 4 (4) (2018) 209–215.
[38]. J. Vasseur, N. Agarwal, J. Hui, Z. Shelby, P. Bertrand, C. Chauvenet, RPL: The IP routing protocol designed for low power and lossy networks, in: Internet Protocol for Smart Objects (IPSO) Alliance, vol. 36, 2011.
[39]. P.O. Kamgueu, E. Nataf, T.D. Ndié, O. Festor, Energy-Based Routing Metric for RPL (Ph.D. thesis), INRIA, 2013.
[40]. Clausen, U. Herberg, M. Philipp, A critical evaluation of the IPv6 routing protocol for low power and lossy networks (RPL), in: 2011 IEEE 7th International Conference on Wireless and Mobile Computing, Networking and Communications, WiMob, IEEE, 2011, pp. 365–372.
[41]. W. Xiao, J. Liu, N. Jiang, H. Shi, An optimization of the object function for routing protocol of low-power and lossy networks, in: The 2014 2nd International Conference on Systems and Informatics, ICSAI 2014, IEEE, 2014, pp. 515–519.
[42]. X. Yang, J. Guo, P. Orlik, K. Parsons, K. Ishibashi, Stability metric based routing protocol for low-power and lossy networks, in: 2014 IEEE International Conference on Communications, ICC, IEEE, 2014, pp. 3688–3693.
[43]. H.-S. Kim, J. Paek, S. Bahk, QU-RPL: Queue utilization based RPL for load balancing in large scale industrial applications, in: 2015 12th Annual IEEE International Conference on Sensing, Communication, and Networking, SECON, IEEE, 2015, pp. 265–273.
[44]. Y. Chen, J.-P. Chanet, K.-M. Hou, H. Shi, G. De Sousa, A scalable context-aware objective function (SCAOF) of routing protocol for agricultural low-power and lossy networks (RPAL), Sensors 15 (8) (2015) 19507–19540.

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[45]. D. Todoli-Ferrandis, S. Santonja-Climent, V. Sempere-Paya, J. Silvestre-Blanes, RPL routing in a real life scenario with an energy efficient objective function, in: 2015 23rd Telecommunications Forum Telfor, TELFOR, IEEE, 2015, pp. 285–288.

[46]. S. Sennan, Energy and load aware routing protocol for internet of things, Int. J. Adv. Appl. Sci. 7 (2018) 255–264.

[47]. L.-H. Chang, T.-H. Lee, S.-J. Chen, C.-Y. Liao, Energy-efficient oriented routing algorithm in wireless sensor networks, in: 2013 IEEE International Conference on Systems, Man, and Cybernetics, IEEE, 2013, pp. 3813–3818.

[48]. S.A. Alvi, F. ul Hassan, A.N. Mian, On the energy efficiency and stability of RPL routing protocol, in: 2017 13th International Wireless Communications and Mobile Computing Conference, IWCMC, IEEE, 2017, pp. 1927–1932.

[49]. D.T. Delaney, L. Xu, G.M. O'Hare, Spreading the load in a tree type routing structure, in: 2013 22nd International Conference on Computer Communication and Networks, ICCCN, IEEE, 2013, pp. 1–7.

[50]. J. Nassar, N. Gouvy, N. Mitton, Towards multi-instances QoS efficient RPL for smart grids, in: Proceedings of the 14th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, & Ubiquitous Networks, 2017, pp. 85–92.

[51]. P. Karkazis, H.C. Leligou, L. Sarakis, T. Zahariadis, P. Trakadas, T.H. Velivassaki, C. Capsalis, Design of primary and composite routing metrics for RPL-compliant wireless sensor networks, in: 2012 International Conference on Telecommunications and Multimedia, TEMU, IEEE, 2012, pp. 13–18.

[52]. A. Sebastian, S. Sivagurunathan, Load balancing optimization for RPL based emergency response using Q-learning, MATTER: Int. J. Sci. Technol. 4 (2) (2018).

[53]. S. Sankar, P. Srinivasan, Fuzzy logic based energy aware routing protocol for internet of things, Int. J. Intell. Syst. Appl. 10 (10) (2018) 11.

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