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Review Paper

RPL Protocol Load balancing Schemes in Low-Power and Lossy Networks

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Abstract: The Routing Protocol for Low-power and Lossy Networks (RPL) is the most crucial in the Internet of Things (IoT) for the routing process. The RPL protocol is proposed by the Internet-Engineering Task-Force (IETF)-Routing over low-power and lossy-networks (ROLL) working group for IoT environments routing service. RPL has been improved for a wide range of IoT application scenarios and environments. One of the primary reasons for RPL improvement is load balancing. In Low-Power and Lossy Networks (LLNs), the load balancing can even degrade network performance and node lifetime. In this article, contains the RPL enhanced schemes offered for the load balancing, for IoT/LLNs, and explores future research options.

Keywords: IoT, LLNs, RPL, Routing, node, Load balancing;

1. Introduction

The IoT network is one of the key technologies enabling the smart automation revolution 4.0 and 5.0. The IoT is a complex network interconnected with different physical smart devices that detect and share information about our real-time environment. Each smart object monitors its environment and transfers the perceived information to the sink node via routing protocols with its interconnected smart objects [1]–[4]. A sensor node detects neighbors and paths for relaying the data from one to another and constructs the topology. In this part, an IoT network system requires an effective networking architecture. These smart object features are limited resources, therefore the characteristics and limited resources must be considered by an efficient routing mechanism. Thus, designing and implementing such routing protocol is a complicated task due to the network resource constrains and limitations of these devices. Furthermore, in environmental factors, the IoT network sensors usually face unfavorable. As a result of IoT network routing protocols development is a difficult challenge [5].

The RPL, proposed and standardized by the International Engineering Task Force (IETF), Routing Over Low-Power and Lossy-Networks (ROLL) working - group, is one of the prominent routing protocols that offer IPv6 connection to LLNs devices for implementing the IoT Network. The RPL protocol is built on the IPv6 low-power wireless personal area network (6LoWPAN) that is linked to the IP network via the sink node[6], [7].

IoT network routers typically operate with limited constraints on processing in energy, memory, compute and resources which are called LLNs. Therefore, LLNs have a high possibility of loss rates, low data rates, and instability in IoT networks [8]–[11].

The RPL aims to be useful in a wide range of IoT applications. For this reason, RPL separates packet processing and relying data in routing optimization objectives is minimizing energy, and minimizing latency with constraint satisfaction. The load balancing issues takes first place in network to causes packet losses and delay. Packet losses in LLNs also may affect reliability and robustness of the IoT applications if end-to-end (E2E) delay and packet recovery is not ensured by the upper layer protocol due to resource limitations. Even though the load balancing is degrade the lifetime due to Non-uniform energy depletion in the nodes and conforms to the congestion in the network. The RPL viewpoint of RPL topology, mobility, and security enhancements research effort requirements are mentioned in review surveys [12]–[15].

IoT applications are playing a vital role in the fields of education, agriculture, home automation, and industries. Even nowadays the education field student attendance entry is also operated through IoT devices. IoT-based biometric fingerprint attendance system reduced human efforts and avoided the physical damages of the traditional method. The IoT service-enabled biometrics attendance system implementation is replaced the traditional attendance method in the education field. This type of IoT automated process works under a different operating system (Windows, Unix, Linux) based application to make it possible to manage student attendance from remote locations [16]. This statement shows the importance of IoT applications, the IoT applications are unavoidable technology in all smart fields.

The IoT is a self-organized, autonomous, decentralized, and dynamic network technique, which allows nodes to join and quit at any time and from remote locations. The routing operation is challenging because the node may exit the network while a packet is transferring in its path due to protocol impact. In an IoT network, each node is wireless and simultaneously acts as a host and a router. Several proposed routing methods are supported in IoT service; routing is the core component of network service. The IPv6 features-enabled protocols are majorly classified into flat and hybrid types, the flat type has sub-divisions in the basic categories of reactive and proactive. Because routing protocols are in charge of managing, constructing, and maintaining the network topology, network performance is always dependent on protocol selection. The routing operations of data forwarding, receiving, and path selection also take part in protocols [17].

1.1 Routing protocol importance

The routing protocols enable and distribute the routing information between interconnected devices which includes a router, node, hop, topology, route, and other network-related components. This routing information will frequently change over time based on the network conditions. The simplest level of understanding the routing provides the basic communication information about the network structure. This structured information is unique and easily identified by each connected device. In an IoT network routing information from the child to the parent/root is an essential part of a Wireless Sensor Network (WSN). The unplugged or mobile sensor nodes are used in IoT networks in terms of constrained method, which refers LLNs.

1.2 Routing classification

Routing functions are path discovery and selecting path between networks devices for message transmission, and they securely transferred message from source to destination. An information exchange each other scenario the routing in IoT is wide concept without the requirement of human intervention, the IoT applications are varying objects in different fields. IoT application devices are generally composed with strong restriction on computation, memory and energy utilization. Hereafter the IoT devices are referred as nodes. Based on real time implementation IoT applications objectives nodes can have different hardware capacities. In some cases routing can perform based on the local context of with or without Internet connection. Based on route creation principles low-power IoT networks, the routing protocols(set of rules for communications) can be classified as proactive and reactive[18].

The LLNs and/or IoT framework the routing protocols are classified into different factors based on the work nature of routing architecture, the following three types are primary classification in routing:

Proactive: In this routing scheme, each node maintains timely routing information by frequently communicating with its immediate neighbor node for routing data updates. Proactive-type protocols maintain data on all routes throughout the network structure, even if a node is not required, so each node registers their routes information to all other nodes in the network. These protocols exchange control messages between nodes on an interval basis to update the route information of each node in the network and also response when a new node enters or another node is no longer available within the network structure.

Reactive: An on-demand-based network structure formation is known as a reactive routing protocol. The routes are discovered and constructed based on the node requirements. The route discovery and maintenance operations are majorly presented in this method for performing the routing operations. The first operation of the route discovery process floods the route request data to the entire network and finds the optimal path for the transmission of packets between the source and the destination nodes. The second operation of maintenance will consider the route as the topology in the network, the topology formation is dynamic in nature of network requirements.

Hybrid: The hybrid scheme may combine the proactive and reactive protocol and performs the combination operations as the required network structure. This type of scheme will alleviate the individual protocol flaws and improve the network performance optimally. The hybrid approach implementations are only possible in a conditioned network structure.

IoT networking protocols are important for communication between the different types of devices in the IoT system. Thus, the IoT protocols differ from the regular protocol and they will have to fulfill various constraints. In addition, the IoT network has the network stack layer to perform various network functions for communication. Each layer has different responsibilities for data exchange and network maintenance and various standardized protocols [19].

The Figure 1 shows the protocol major network protocol classifications. Since the RPL protocol standardization, it has created significant attraction in the IoT network industry and research. The reason is that provides efficient and optimal routing operations among nodes in LLNs/IoT, maintains Quality of Service (QoS), and it is flexible in adaption to various network topologies.

In addition, the RPL protocol is employed in low-power constrained mechanisms and affords self-organizing and self-healing methods to control frequent network performance failures. Technically, the RPL adopted the IPv6 standard and it has more potential benefits, including flexibility, scalability, de-facto method, and reliability. Its memory addressing range is suitable for an extensive percentage of IoT network nodes.

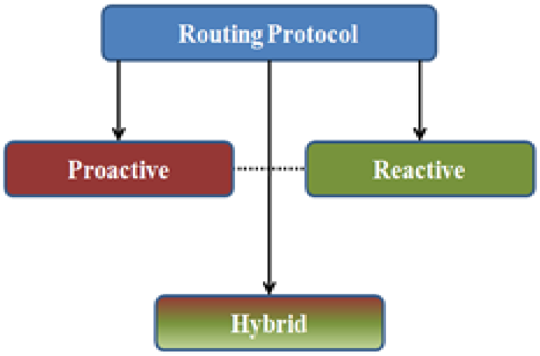

Figure 1: Routing protocol classifications

It is worth the standard that the RPL is developed with resource-constrained devices, allowing it to handle the variety of IoT/LLNs network applications. The standardized RPL is a proactive distance-vector loop-free Destination Oriented Directed Acyclic Graph (DODAG) features-enabled routing protocol. Quieter, the RPL network instance constructs a DODAG tree topology based on a set of predefined node-based and link-based metrics and constraints, the ideal de-facto method of Objective Functions (OFs) contributes to from the node rank, responsible for selecting a parent node in the DODAG topology. The OFs functionalities perform various operations until establishing the optimal DODAG topology by selecting the most efficient routes in an upward and downward direction to the destination node [20].

The network instance load balancing is the method of sharing or distributing the set of parameters equally across the network. The balanced load in the DODAG parent node makes their communication process more efficient and optimizes the routing process and improves the network performance. The uneven DODAG topology formations have a high possibility of overloaded parent nodes affecting the network performance parameters (node lifetime, high traffic, congestion).

In this review article, the section 2 outlined the fundamental components of RPL protocol, the section 3 discusses load balancing importance, section 4 summarizes existing load balancing schemes for RPL protocol and the section 5 conclusion of the load balancing.

2. RPL components overview

The RPL protocol is a distance-vector, proactive, IPv6 features enabled and it supports and provides, Point-to-Point (P2P), Point-to-MultiPoint(P2MP), and MultiPoint-to-Point (MP2P) traffic patterns which includes upward or downward direction flow as per LLNs application requirements [21].

2.1 DODAG topology

The initial process of topology construction flows from the root node and forms the Destination-Oriented Directed Acyclic-Graph (DODAG) for interconnecting the nodes in the LLNs. In this DODAG tree topology contains leaf and root nodes, each leaf node has one or more roots and assigns the rank for inter-routing and establishes the connection to LLNs Border Routers (LBR) in the manner of loop-free.

This DODAG can be operated in either storing mode (each node maintains the route information) or non-storing (the route information maintained by the root node). The DODAG topology formation process follows the following ICMPv6 control message which all are contains the DODAG related information:

- DIO: DODAG information Object
- DAO: Destination Advertisement Object
- DIS: DODAG Information Solicitation

The DODAG root node broadcasts the DIO control message to its neighbors. DIO messages are received by neighbors and processed. The processed DIO message is transmitted to other nodes until reaches the leaf node. A node can join any DODAG in the RPL instance (Collection of DODAGs), if any node decides to join the DODAGs, calculates the path cost to the DIO sender and then compare the cost then join the decided DODAG based on rank. If once the neighbor joined the DODAG, the current node has the perfect route to the DODAG root node. Next, the newly joined node calculates its current rank (position on the tree) and replies through DAO to its parent for participation confirmation. In case of any node is not received the DIO message, the newly joining node has DIS option intimation request sending periodically to its nearest nodes. The DAO-ACK send by a node to its parent for confirmation and then starts the routing process in the formed DDOAG, meanwhile that any new node is ready to join the existing DODAG, the DOADG will reconstruct based on the rank and always the rank should increase from root to leaf.

The following Figure 2. Presents the simplified flow diagram of the DODAG topology formation process. Node B receives the DIO control message from the root node A; and replies to the DIO to the root of A. After that, the B node act as an intermediate parent to other nodes and sends the DIO to C; then C replies to the DAO, then the same process will occur in C and D based on the DIS message in the scope limitation. After all the nodes acquire the root the DAO relay will happen from leaf to root (D-C-B-A). These all the control message containers are have the various related information about the DOADG like RPL-instance-ID, rank, IPv6-header, type, metric and etc.

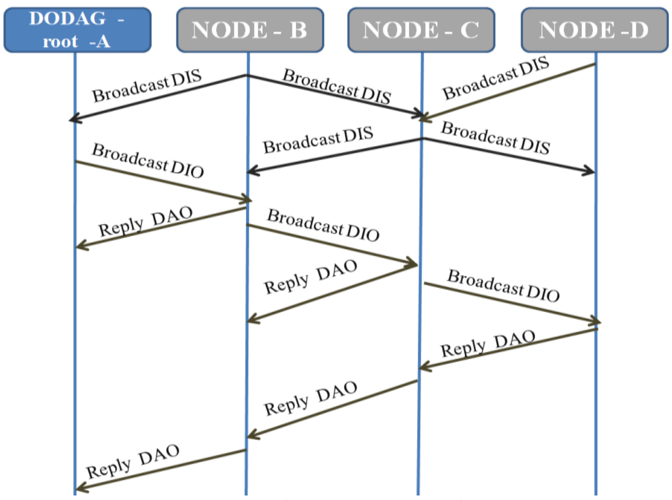

Figure 2: Flow diagram of DODAG topology formation process.

2.2 Objective Functions (OFs) and Metrics

The IETF-WG standardized two objective functions in RPL to perform the routing operations along with static or dynamic metrics. These decoupling technique OFs are related to performing rank computations and parent selection using constrained metrics for the optimized routing process. The RPL OFs are specified in RFC-6550 [22] and named Objective-Function Zero (OF0) and Minimum Rank with Hysteresis Objective-Function (MRHOF).

The OF0 specifications are defined in RFC-6552 [23] and allow nodes to find the shortest path between two nodes and then interoperation of routing using hop-count metrics. This OF0 is using only one metric to perform the routing path selection operation and which does not provide the guaranteed optimized path in the DODAG. The MRHOF specified in RFC-6719 [24] uses the additive metrics method for performing the parent selection and routing operations like Expected Transmission Count (ETX), hop count, latency, and so on.

2.3 Trickle Algorithms

In RPL Protocol the third fundamental component is the Trickle timer algorithm, using this algorithm is to perform the routing operations under the time interval. The objective of Trickle is to broadcast routing details between DODAG topology nodes in energy efficient manner. The Trickle has the following two mechanisms to archive the objective; it increases and decreases the signaling rate adaptively to the changes in the network.

The trickle timer algorithm employs a power-saving feature known as the duty cycle. It works by turning off the radio if there is no data packet is received by the node. The radio, on the other hand, only turns on when packets must be broadcast. Furthermore, the trickling algorithm is designed to send packets and updated packets continuously and flexibly. The first strategy is utilized in a network; when an inconsistent state is detected, the algorithm increases the signaling rate to take control of the situation. The suppression approach is utilized when a node detects that its neighbors have amassed enough transmission numbers for a packet; this process saves energy by inhibiting transmission [25].

The second mechanism is, to remove the transferred routing information in a node that has the same and ensure the flexibility and reliability of basic network primitive. The Trickle allows the DODAG to fast network convergence for forming DODAG topology and reduces the congestion in low energy consumption. In RPL, RFC-6206 [26], [27] specification Internet draft mentions the set of LLNs applications as reliable broadcast and routing. In addition, it manages the time between resource discovery and listening to incoming and outgoing information, while the nodes communicate with their neighbors. These three components are fundamental to the RPL protocol to perform the routing in IoT.

3. Load Balancing in RPL

The standardized RPL protocol has several features like robust, exiguous delay, fast configuration, a loop-free tree, and self-repair. However, the DODAG load imbalance requires some significant enhancement improvements in RPL [28], [29].

More typically, RPL is dealing with load balance distribution in LLNs, which may lead to quick energy on the parent node, and congestion in data traffic distribution. Further, this unbalanced problem has more impacts on the overloaded node and a high possibility of bottleneck route selection. Many extension RPLs have by way of new OFs are successful in providing improved energy efficiency, performance, reliability, and network lifetime by providing alternate paths.

However, the load imbalance in the RPL issue has a high challenge that is not addressed satisfactorily. The load imbalance issues in RPL is critical to operating large-scale IoT networks for applications like such as emergency or periodical response scenario and this imbalance load has the possibility of problems like energy depletion, parent switching, bottleneck, thundering herd, early parent node death, increased congestion, network instability, and poor performance. There are various phenomenon possibilities to form the unbalanced topology in RPL, in this section for understanding, we addressed the thundering herd possibilities example with Figure 3.

Figure 3, represents P1 and P2 are the parent node, A to D nodes are under constructed topology and the nodes of E to H are ready to join the topology according to DODAG control messages.

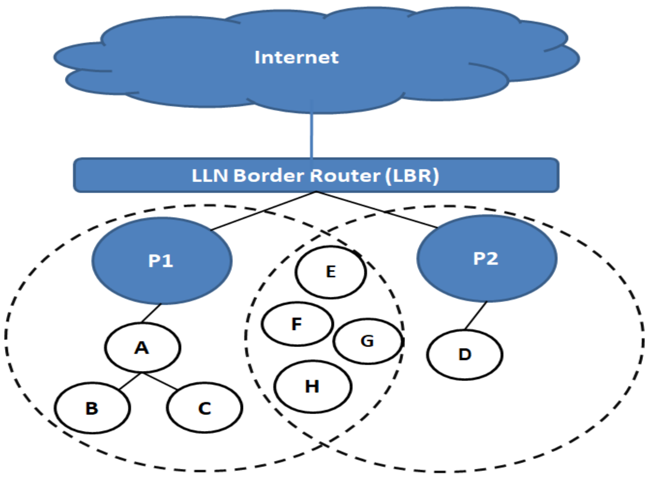

Figure 3: Example phenomenon topology

In this scenario, the DODAG formation possibilities are represented in Table 1. In this Table 1 representation physically we can understand, if all the new nodes are joined into P1, the P1 gets overloaded or if the new nodes are joined with P2 then the P2 gets overloaded, anyway this case there is no balanced root in topology. In this situation, the P1 or P2 may get overloaded, congestion and early death.

Table 1: Example topology node formation

Root nodes	Child nodes	Possibility nodes	Child count
P1	A,B,C	E,F,G,H	3
P1	A,B,C, E,F,G,H	-	7
		OR	
P2	D	E,F,G,H	1
P2	D, E,F,G,H	-	5

4. Schemes for Load balancing

This section reviews the existing load balancing scheme solutions to enhance the load balance in LLNs. The more number of schemes are proposed to solve the unbalanced topology among which some of the significant schemes are summarized. At the end of this section, we evaluate the schemes in terms of primary features, routing metrics, and metrics performance assessment in Table 2.

To build the multipath DODAGs, and maintain the parent set receiving more than one DIO control message with child count is proposed in the Heuristic Load Distribution algorithm (HeLD) [30]. This proposed work formulated the optimized network flow distribution and solve the local information utilization. In this work traffic flow of each node compares the received packet traffic rates of its current parent in a one-to-one. The received packet traffic rates are not satisfied in the two parents; the same traffic metric values are equalized and adjusted between the two parents and help the parents to maintain the equal depth of nodes in the topology. The Expected Life Time (ELT) metric was calculated for N nodes and proposed multipath RPL method to balance the energy consumption[31], this method's objective is to increase the lifetime of constrained nodes instead of simply using the high energy node to forward the packets. This method contributed to identifying the energy of bottleneck nodes along with the route and dividing it traffic flow among all intermediate parents. Each node computes and assuming that the lifetime of the bottleneck duration if that duration is high the current node will be removed from the existing parent and try to join the new optimal parent.

In [32], introduced the Queue Utilization RPL (QU-RPL) was to handle the congestion and load balancing issues. The queue utilization considers the parent selection and made the modifications on TinyRPL, the stability metric is inherited and permits the node to select its parent when the routing metric stability exceeds the boundary. In the part congestion control indicator, maximum values met the threshold, if both indicator conditions are satisfied in this method, the current node gets the possibility to change the parent to avoid the herding impact.

The network workload imbalanced is alleviated in LB-RPL[33] , by using of two approaches, which detects the load imbalance and optimize the data relay route in link layer communication qualities. To alleviate workload imbalance, this scheme forwards packets using root nodes, initially, each node considered as potential next node for packet forwarding. Based on the channel condition find packet loss probability is forward to parent node. The second scheme provides the imbalance mitigation through DIO control message timer interval and measured the workload through the buffer counter utilization. The buffer counter utilization is computing the average number of packets available certain duration or total packets loaded in the buffer. If a parent node has busy in current round, the more delay will take part of next round process.

The power –Controlled RPL (PC-RPL)[34] addressed the load imbalance and hidden edge node problem, most packet losses occurred at links rather than queues as traffic demand grew, and the link losses were caused by packet collision owing to the hidden node terminal problem. Furthermore, when packets were substantially lost in queues, this happened only at a few bottleneck nodes with massive imbalanced topology sub-trees. To address the issues, PC-RPL uses the hop-count, RSSI, and ETX metrics and the most unique feature of this PC-RPL is that highly uses the RSSI values adaptive method.

Table 2: Existing load balancing scheme evaluation

Proposed Schemes	Features	Routing Metrics & Constraints	Evaluation Parameters
LB-RPL [33]	Forwarding packets using multiple parent nodes. Timer to proportion workload	Buffer utilization counter, Packet-drop probability	PDR, Packet loss, Packet delivery delay
HeL D [30]	Maintaining the balanced parent set and equal depth from the root	Hop- count, ETX	Throughput, Collisions, Link drop ratio, Network life time
EA-LB [31]	Dividing traffic between multi parents, to spread traffic load uniformly to energy based bottleneck nodes.	ELT, ETX, transmission power	PDR, Lifetime, Energy consumption, and parent changes
QU-RPL [32]	Select the parent based on queue utilization	ETX, hop-count, queue	PDR, routing overhead, scalability
PC-RPL [34]	Hidden node terminal problem and load balance by jointly controlling routing topology	Hop-count, ETX, LQI, RSSI	PRR, hop-count, E2E ETX, Parent switching , Transmission count
MAC-aware routing [35]	Extend reliability metric by considering packet losses in MAC contention and distribute load	LQI, Busy channel probability, MAC layer retransmission, Reliability constraint	end-to-end reliability

In [35],proposed two new measures that uses the information from the MAC layer to predict reliability and improve the network lifespan through load-balancing while fulfilling reliability restrictions. The R-metric, for example, reflects the end-to-end (E2E) reliability between a node and a root. The R-metric is extended ETX at the MAC layer by accounting of packet losses caused by MAC layer produced congestion. R-metric is calculated based on the probability computation that a packet is transmitted successfully over the link on each path, within a maximum number of back-offs and retransmissions at the MAC layer basis that the reliability of each link depends on the busy channel probability, the consideration of channel Link Quality Indicator (LQI) value, and the MAC parameters used to find the probability.

5. Conclusion

Since the RPL standard, is a high-rated LLNs/IoT routing protocol, the number of research surveys and contributions were conducted on various aspects to enhance the RPL, load balancing-related concerns are limited and contributions are countable in LLNs/IoT routing protocols. To the best of our research knowledge, there are no previous review works like ours. In this review study, we analyzed the research literature with the goal of understanding the load balancing needs and the significance of DODAG in RPL. More specifically, the trends in routing metrics composite design techniques were discussed in further depth. Many techniques actively use route diversity through forwarding packets via numerous parents on a packet-by-packet basis. We also offered future research directions, such as RPL design that takes into account more competent limited metric platforms without compromising the standardized RPL, examination through real-world implementations and experimentation, and application of RPL protocol instances. Congestion control techniques for RPL are planned to continue to adapt to new demands as diverse IoT application scenarios evolve, and increased load balancing will also be carried out with various metrics.

References

[1] J. Santosa and G. Kurniawan, "IOT BASED LOW-COST PLATFORM FOR SMART ORNAMENTAL PLANT MONITORING SYSTEM," *J. Theor. Appl. Inf. Technol.*, vol. 99, no. 24, pp. 6102–6117, 2021.

[2] P. Sethi and S. R. Sarangi, "Internet of Things: Architectures, Protocols, and Applications," *J. Electr. Comput. Eng.*, vol. 2017, pp. 1–25, 2017, doi: 10.1155/2017/9324035.

[3] N. H. Motlagh, M. Mohammadrezaei, J. Hunt, and B. Zakeri, "Internet of things (IoT) and the energy sector," *Energies*, vol. 13, no. 2. MDPI AG, 2020. doi: 10.3390/en13020494.

[4] S. Dhingra, R. B. Madda, A. H. Gandomi, R. Patan, and M. Daneshmand, "Internet of Things Mobile–Air Pollution Monitoring System (IoT-Mobair)," *IEEE Internet Things J.*, vol. 6, no. 3, pp. 5577–5584, Jun. 2019, doi: 10.1109/JIOT.2019.2903821.

[5] A. Osorio, M. Calle, J. D. Soto, and J. E. Candelo-Becerra, "Routing in LoRaWAN: Overview and Challenges," *IEEE Commun. Mag.*, vol. 58, no. 6, pp. 72–76, Jun. 2020, doi: 10.1109/MCOM.001.2000053.

[6] J. G. Ko, A. Terzis, S. Dawson-Haggerty, D. Culler, J. Hui, and P. Levis, "Connecting low-power and lossy networks to the internet," *IEEE Commun. Mag.*, vol. 49, no. 4, pp. 96–101, 2011, doi: 10.1109/MCOM.2011.5741163.

[7] A. Verma and V. Ranga, "Security of RPL Based 6LoWPAN Networks in the Internet of Things: A Review," *IEEE Sens. J.*, vol. 20, no. 11, pp. 5666–5690, Jun. 2020, doi: 10.1109/JSEN.2020.2973677.

[8] E. K. Pister, E. C. S. S. D. S. P. Thubert, and T. Phinney, "Industrial Routing Requirements in Low-Power and Lossy Networks," *IETF Network Working Networks, Request for Comments: 5673*, 2009. https://www.rfc-editor.org/rfc/rfc5673 (accessed Jan. 02, 2023).

[9] J. Buron, A. Brandt, and G. Porcu, "Home Automation Routing Requirements in Low-Power and Lossy Networks," *Internet Engineering Task Force (IETF) Request for Comments: 5826*, 2010. https://www.rfc-editor.org/rfc/rfc5826 (accessed Jan. 02, 2023).

[10] D. B. M. Dohler, T. Watteyne, T. Winter, "Routing Requirements for Urban Low-Power and Lossy Networks," *Internet Engineering Task Force (IETF)*, 2009. https://www.rfc-editor.org/rfc/rfc5548 (accessed Jan. 02, 2023).

[11] O. Iova, P. Picco, T. Istomin, and C. Kiraly, "RPL: The Routing Standard for the Internet of Things... Or Is It?," *IEEE Commun. Mag.*, vol. 54, no. 12, pp. 16–22, Dec. 2016, doi: 10.1109/MCOM.2016.1600397CM.

[12] H.-S. Kim, J. Ko, D. E. Culler, and J. Paek, "Challenging the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL): A Survey," *IEEE Commun. Surv. Tutorials*, vol. 19, no. 4, pp. 2502–2525, 2017, doi: 10.1109/COMST.2017.2751617.

[13] H. Bello-Salau, A. M. Aibinu, Z. Wang, A. J. Onumanyi, E. N. Onwuka, and J. J. Dukiya, "An optimized routing algorithm for vehicle ad-hoc networks," *Eng. Sci. Technol. an Int. J.*, no. xxxx, 2019, doi: 10.1016/j.jestch.2019.01.016.

[14] P. O. Kamgueu, E. Nataf, and T. D. Ndie, "Survey on RPL enhancements: A focus on topology, security and mobility," *Comput. Commun.*, vol. 120, no. July 2017, pp. 10–21, May 2018, doi: 10.1016/j.comcom.2018.02.011.

[15] 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

[16] A. P. Anagha Jadhav, Sudarshan Dutonde, Archana Todarmal, "IoT Based Biometric Attendance System for Smart Classroom," *Int. J. Sci. Res. Comput. Sci. Eng.*, vol. 8, no. 4, pp. 58–57, 2020, [Online]. Available: https://www.isroset.org/journal/IJSRCSE/full_paper_view.php?paper_id=2007

[17] H. F. GATETE Marcel, "Routing In Mobile Ad-Hoc Networks Coupled With IoT Technologies- A Review," *Int. J. Sci. Res. Comput. Sci. Eng.*, vol. 10, no. 6, pp. 49–60, 2022, [Online]. Available: https://www.isroset.org/pdf_paper_view.php?paper_id=3000&6-ISROSET-IJSRCSE-08170-63.pdf

[18] N. Nasser, L. Karim, A. Ali, M. Anan, and N. Khelifi, "Routing in the Internet of Things," in *GLOBECOM 2017 - 2017 IEEE Global Communications Conference*, Dec. 2017, pp. 1–6. doi: 10.1109/GLOCOM.2017.8253955.

[19] M. M. Martín-Lopo, J. Boal, and Á. Sánchez-Miralles, "A literature review of IoT energy platforms aimed at end users," *Comput. Networks*, vol. 171, 2020, doi: 10.1016/j.comnet.2020.107101.

[20] S. A. Fatemifar and R. Javidan, "A new load balancing clustering method for the RPL protocol," *Telecommun. Syst.*, vol. 77, no. 2, pp. 297–315, Jun. 2021, doi: 10.1007/s11235-021-00760-7.

[21] B. Djamaa, M. R. Senouci, H. Bessas, B. Dahmane, and A. Mellouk, "Efficient and Stateless P2P Routing Mechanisms for the Internet of Things," *IEEE Internet Things J.*, 2021, doi: 10.1109/JIOT.2021.3053339.

[22] T. Winter *et al.*, "RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks," *Internet Engineering Task Force (IETF)*. Internet Engineering Task Force (IETF), pp. 1–157, 2012. [Online]. Available: https://tools.ietf.org/pdf/rfc6550.pdf

[23] E. C. S. P. Thubert, "Objective Function Zero for the Routing

Protocol for Low-Power and Lossy Networks (RPL)," *Internet Eng. Task Force*, pp. 1–14, [Online]. Available: http://www.rfc-editor.org/info/rfc6552

[24] P. L. Gnawali, O, "The Minimum Rank with Hysteresis Objective Function," *Internet Eng. Task Force*, vol. 1, pp. 1–13, 2012, [Online]. Available: https://www.rfc-editor.org/rfc/pdfrfc/rfc6719.txt.pdf

[25] R. Masadeh, B. AlSaaidah, E. Masadeh, M. R. Al-Hadidi, and O. Almomani, "Elastic Hop Count Trickle Timer Algorithm in Internet of Things," *Sustain.*, vol. 14, no. 19, pp. 1–19, 2022, doi: 10.3390/su141912417.

[26] P. Levis, T. H. Clausen, J. W. Hui, O. Gnawali, and J. Ko, "The Trickle Algorithm," *Internet Engineering Task Force (IETF) Request for Comments: 6206*, 2011. https://www.rfc-editor.org/info/rfc6206 (accessed Jan. 02, 2023).

[27] A. S. Kassab, K. G. Seddik, A. Elezabi, and A. Soltan, "Realistic Wireless Smart-Meter Network Optimization Using Composite RPL Metric," *8th IEEE Int. Conf. Smart Grid*, pp. 109–114, 2020.

[28] Z. Magubane, P. Tarwireyi, A. Abu-Mafouz, and M. Adigun, "Extended Context-Aware and Load Balancing Routing Protocol for Low power and Lossy Networks in IoT networks (ECLRPL)," in *2021 3rd International Multidisciplinary Information Technology and Engineering Conference (IMITEC)*, Nov. 2021, no. February 2022, pp. 1–9. doi: 10.1109/IMITEC52926.2021.9714710.

[29] J. V. V. Sobral, J. J. P. C. Rodrigues, R. A. L. Rabêlo, J. Al-Muhtadi, and V. Korotaev, "Routing Protocols for Low Power and Lossy Networks in Internet of Things Applications," *Sensors*, vol. 19, no. 9, p. 2144, May 2019, doi: 10.3390/s19092144.

[30] M. N. Moghadam and H. Taheri, "High throughput load balanced multipath routing in homogeneous wireless sensor networks," in *2014 22nd Iranian Conference on Electrical Engineering (ICEE)*, May 2014, no. Icee, pp. 1516–1521. doi: 10.1109/IranianCEE.2014.6999775.

[31] O. Iova, F. Theoleyre, and T. Noel, "Exploiting multiple parents in RPL to improve both the network lifetime and its stability," in *2015 IEEE International Conference on Communications (ICC)*, Jun. 2015, vol. 2015-Septe, pp. 610–616. doi: 10.1109/ICC.2015.7248389.

[32] H.-S. Kim, J. Paek, and 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)*, Jun. 2015, pp. 265–273. doi: 10.1109/SAHCN.2015.7338325.

[33] Xinxin Liu, Jianlin Guo, G. Bhatti, P. Orlik, and K. Parsons, "Load balanced routing for low power and lossy networks," in *2013 IEEE Wireless Communications and Networking Conference (WCNC)*, Apr. 2013, pp. 2238–2243. doi: 10.1109/WCNC.2013.6554908.

[34] H.-S. Kim, J. Paek, D. E. Culler, and S. Bahk, "Do Not Lose Bandwidth: Adaptive Transmission Power and Multihop Topology Control," in *2017 13th International Conference on Distributed Computing in Sensor Systems (DCOSS)*, Jun. 2017, vol.2018-Janua, pp.99–108. doi: 10.1109/DCOSS.2017.23.

[35] P. Di Marco, G. Athanasiou, P.-V. Mekikis, and C. Fischione, "MAC-aware routing metrics for the internet of things," *Comput. Commun.*, vol.74, pp.77–86, Jan.2016, doi: 10.1016/j.comcom.2015.05.010.

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