ISSN 2581 – 3781

Available Online at www.ajcse.info
Asian Journal of Computer Science Engineering 2019;4(3):1-16

REVIEW ARTICLE

Low Power and Lossy Networks Routing Protocols for IoT Environment: A Survey

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Received on: 20-10-2020; Revised on: 25-10-2020; Accepted on: 28-10-2020

ABSTRACT

The low power and lossy networks (LLNs) routing strategy in wireless sensor networks (WSNs) define the network's lifetime and efficiency. The nodes in characteristics of LLNs (such as low cost, computation, limited storage, and low power) may pose an open challenge to finding an optimum routing protocol in WSNs. To satisfy the unique requirements of the LLNs, the internet protocol version 6 routing protocol for LLNs (RPL) was standardized by the internet engineering task force since 2009 to address the routing problem in such networks. However, numerous studies pointed out since its introduction that in its current form, RPL suffers from problems that restrict its efficiency and its sphere of applicability. In the literature, several solutions have thus been proposed in an effort to address these established limitations. In this survey, we aim primarily to provide a thorough analysis of these research proposals, evaluating whether those proposals have managed to address the identified norm limitations associated with its core operations. While some of the vulnerabilities in the RPL have been successfully resolved, the study found that the strategies suggested are still inadequate in addressing a number of problems. The survey investigates the problems and what are the drawbacks, challenges, and pitfalls to be avoided will thus enable researchers to establish a consistent framework for the most promising strategies to be established in the future, allowing for better implementation of the protocol.

Key words: Internet of things, IPv6, low power and lossy network LLNs, ROLL, routing metrics, RPL, WSN

INTRODUCTION

The internet of things (IoT) describes a type of network that connects everything to the internet on the basis of protocols defined for the sharing and transmission of information through information sensing equipment in order to achieve smart identification, monitoring, management, location, and tracking [Figure 1].[1,2]

The low power and lossy networks (LLNs) routing strategy in wireless sensor networks (WSNs) defines the network's lifetime and efficiency. A typical LLN that consists of a few routers to thousands of resources-restricted actuators and sensor motes with some routing capabilities connected to the outside world (e.g., Internet) through a special LLN Border Router (LBR) that does not have these restrictions on its own. The architecture of a typical LLN is depicted in Figure 2.

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The node's characteristics in LLNs usually defined by limitations on the both node's resources and underlying communication technologies.[3] Node constraints can include power limitations, processing and storage, high reliability and low power consumption requirement, limitations of frame size, low data rates, short data, ranges of communication, and a constantly evolving network topology.[4,5] Such constraints allow the production of efficient routing solutions difficult for LLNs, a task nevertheless making more arduous by the large-scale capacity of such deployment networks, which are supposed to include thousands or more of the nodes.[6,7] During 2009, the Routing Over Low-power and Lossy networks (ROLL) working group basically conducted a detailed analysis and evaluations on the existing routing protocols: Intermediate System to Intermediate System, open shortest path first, *ad hoc* on-demand vector and optimized link-state routing, that led ROLL to found these protocols failed in satisfying the requirements of LLNs, and the requirements of multipoint-to-point (MP2P) application in

WSNs, ROLL has focused on routing protocol design and committed to setting a standardization of the internet protocol version 6 (IPv6) routing protocol for LLNs (RPL) that should match the requirements of application scenarios on IoT: Home automation, industrial control, urban environment, and building automation.

ROLL has developed a new protocol based on IPv6 is called RPL for use in lossy environments to connect resource-limited wireless nodes.[8-12] Since then, multiple studies have indicated that RPL suffers from constraints that can harm its effectiveness and a great deal of study has been aimed at resolving them. There have been few comparative analyses of the success of such efforts.

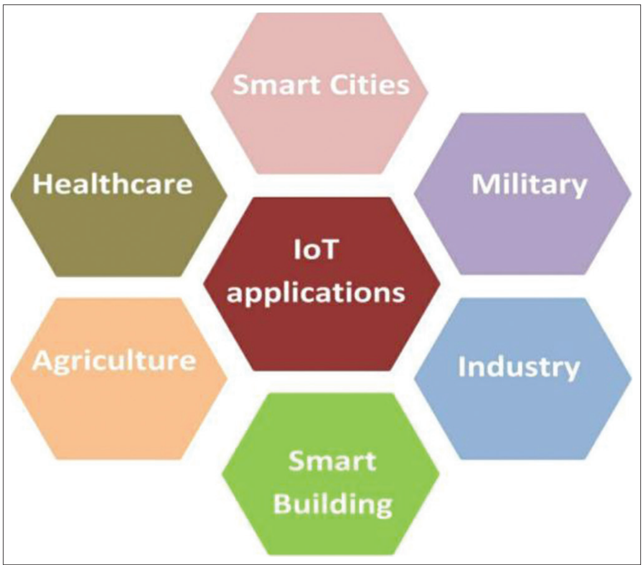

Figure 1: Internet of things applications

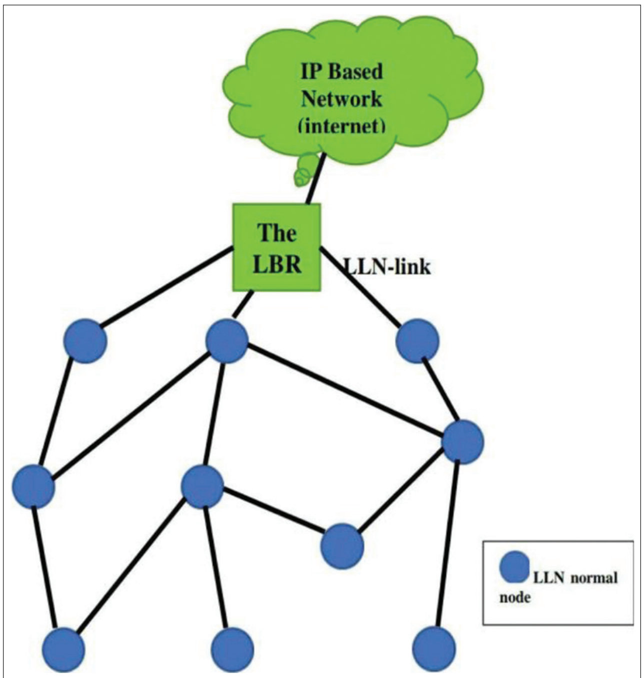

Figure 2: A low-power and lossy network architecture

BACKGROUND THEORY

RPL is an IPv6 dynamic routing protocol designed by ROLL, an internet engineering task force working group as a solution for low power and low-cost communications restricted devices, RPL is a proactive routing protocol based on a distance-vector algorithm.

The RPL organizes its physical network in a directed acyclic graphs (DAGs) form, in which each DAG is rooted in one destination and is the destination-oriented DAG (DODAG) under the provisions of RPL.[13] The DODAG marks the final network domain traffic destination bridging the other IPv6 domain topology such as internet,[13,14] in the context of the LLNs, it is called the LBR. RPL mentions the word upward routes to refer to such routes to DODAG root from normal nodes MP2P, while downward routes are called the routes from the DODAG root to other nodes point-to-multipoint (P2MP). To build up routes, each node within the network must choose one of its neighbors as a preferred parent (next-hop) toward the root. In the same way, each node willing to take part in the downward to one of its parents, routing must be announced, preferably a favorite parent. RPL coined the term instance to refer to multiple DODAGs which share the same policies and mechanisms for routing. In a particular physical topology, several RPL instances may coexist simultaneously, and a node may join more than one instance at the same time. However, a node is permitted to associate only one root (DODAG) within each instance.[13] For the sharing of routing information required to construct the routing paths and network topology.

RPL produces a star topology with one sink node (root) at the top and leaves at the bottom; as shown in Figure 3, the leaves always try to reach the sink node (many-to-one) and the down direction is dedicated to traffic coming from the sink (one-to-many).

RPL was designed as a bidirectional routing protocol and can route the traffic in two directions upward and downward. Figure 4 shows the DODAG with storing and non-storing mode.

Storing mode

All RPL routers store information in this mode from the initial node to sink node.[15]

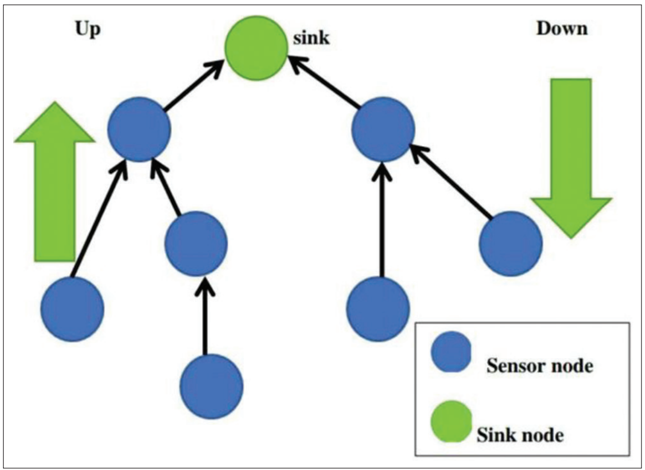

Figure 3: RPL network topology

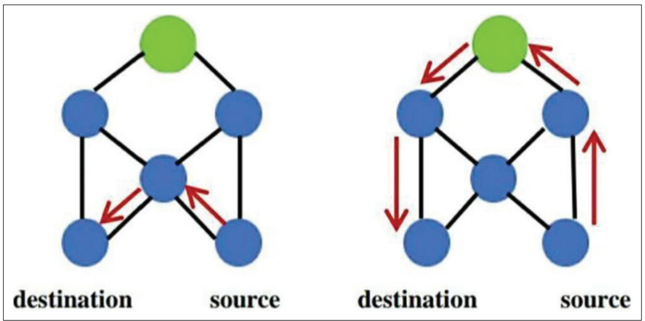

Figure 4: DODAG with storing mode (a); DODAG with non-storing mode (b)

Non-storing mode

First, destination advertising object (DAO) message is generated by each node, when the sink node receives the DAO from all routers, then source routing is used to locate the destination in the network.[15]
RPL provides four control messages ICMPv6 (excluding protection messages), like mentioned below.

DODAG information object (DIO)

DIOs are used to carry applicable details and configuration parameters, allowing a node to discover an instance of RPL, join a particular DODAG, select a candidate collection of kin, and retain DODAG.[13]

DAO

Control message enables a node to spread information about its destination upward running along the DODAG to the root of the DODAG to make the downward routes from the DODAG root to its related nodes may be built.[13]

DODAG information solicitation (DIS)

An RPL node uses this message to request a DIO from the neighboring nodes for joining the DODAG.[13]

Destination advertisement object acknowledgement (DAO-ACK)

The DAO-ACK is unicast by a DAO recipient to the DAO sender to accept that DAO has been issued.[13,16,17]

RPL LIMITATIONS AND DRAWBACKS

Recent studies have assessed the performance of RPL reports, there is a range of weaknesses and limitations which must be addressed.[18-21] A summary of these limitations is presented in Table 1.

Objective function limitations

The questions relating to RPL OFs are discussed in this section, including one-way routing, sub-specification of metric composition, and implicit impact of hop-count.

Single-path routing

In RPL, all traffic once a preferred parent has been chosen will be sent through this preferred parent, as long as it is available, without attempts at load balancing between other parental candidates available.[14,22,23] This behavior can exhaust the power of overload parents, resulting in network disconnections and unreliability issues, as overloaded nodes would likely die earlier.[24]

Under-specification of metrics composition

RPL promotes the use of multiple measures to a route with the optimization of routes based on the combination of many metrics; however, no guidance is given on how such a combination is expected. Therefore, depending on one application requirement may be met by routing metric in the OF, Infringes yet another.[25] The issue of unbalanced traffic is compounded by the fact that normal RPL allows traffic to be transmitted only through the chosen parent, even though there are multiple nominee’s parents available to do the job.

Implied effect for hop-count

In objective functions of the RPL, the cost of routing a particular path, the cost of its constituent ties is determined by adding. Therefore, a path with a larger number of hops would appear more expensive than another path with a relatively small number of hops, while the communal links of the first path may be of better quality. This may be deceptive when taking routing decisions as the route with the minimal number of hops would have a higher likelihood of being chosen, although it may have one or more individual links of very low quality.

RPL downward routes

According to the RPL standard specification in Winter *et al.*,[13] MP2P traffic pattern is expected to be the dominant pattern in the LLN sense, whereas other traffic patterns (i.e., P2MP and P2P) are expected to be less frequent. In line with these standards, RPL optimizes upward traffic routes in a manner that requires less overhead and less routing status. This was done, however, at the expense of rather inefficient construction of downward routes in terms of overhead power, routing condition, and track stretch,[23,26-28] resulting in some problems as follows.

Incompatible modes for downward routing

Although RPL supports two separate downward traffic modes (i.e., storage and non-storage), the standard specifies that deployments that are RPL-compliant can use either non-storage mode or storage mode within the same instance.[13,28] Therefore, when nodes belonging to various instances running different operating modes meet in the same network of RPL, RPL allows nodes from one instance to only join the other instance as a leaf node, contributing to the rise of some interoperability issues. Consider the situation, for example, when a node from one instance located in the middle of a forwarding path joins another incompatible instance as a leaf while it represents the only next-hop available for the DODAG root.[28] Thus, nodes downstream of the new node cannot now connect to the root of it, as the leaf is not permitted to act as a router, and the network is therefore partitioned in both upward and downward directions. One solution is to loosen the restriction and allow nodes to enter incompatible instances as routers with different operating modes. Nevertheless, in downward traffic, a forwarding failure can still occur as a router operating in storage mode would not be able to understand a packet's source header sent by a non-storing peer.[28]

Memory limitations in the storing mode

While RPL is primarily designed for small and memory-constrained sensor nodes, the protocol has the capacity to manage large networks of up to thousands of nodes. In such high-density networks, the need to preserve the routing state is highly likely to exceed the storage capacity of such limited devices. An overflowed node would, therefore, be unable to accommodate all the routing entries needed to be kept in its routing table, resulting in many destinations in its root-inaccessible sub-DODAG enforces root dropping of packets bound for certain unattainable destinations.[28]

In the non-storing mode the problem of long source headers

In RPL non-storing mode, the root is required to connect a source route header in a downward direction for each transmitted datagram.[13] RPL is designed to operate on link layers with a 127-byte maximum transmission unit.[23,29] Of the 127 bytes usable of the physical layer frame, the L2 header has a maximum of 46 bytes, the compressed IPv6 fixed header has a minimum of 2 bytes, and the attached source route has a fixed header size of 8 bytes. In light of this, only 71 bytes remain for the payload of the L3 datagram. Therefore, a maximum of four hops is possible in the source route header as each IPv6 address has a fixed length of 16 bytes without compression.

Under specification of DAO emission

RPL downward routes are that not explicitly specify the timing of DAO transmission. A conservative timing approach can result in the non-transmission of DAOs before routes expire, which will affect the data-plane reliability. This is because the exact estimation of a source route depends on the path segments advertised in its ancestors' DAOs.[23,29]

Routing maintenance (trickle timer) limitations

The RPL norm stipulates that Trickle must be used for the sharing and maintenance of routing information. Trickle's dependency has caused some problems, as described next.

Listen-only period

A key issue in Trickle is the implementation in the first half of each Trickle's interval of a listen-only duration (I). The purpose behind the listening duration is to solve the so-called short-listen problem in asynchronous networks. A node must wait half the period before the transmission of a routing update and load balancing.[30]

Suppression mechanism inefficiency

Another problem relating to the Trickle algorithm is its mechanism of repression. To reduce the overhead power of the network, Trickle suppresses power transmission messages that appear redundant by counting the number of valid messages in a given window and then, if such a number exceeds the preconfigured redundancy constant (*k*), it suppresses any further dissemination of such messages obtained. However, studies have documented that the optimal setting of the redundancy constant is not a trivial task and relies heavily on the application scenario; besides that, if configured incorrectly some problems can emerge,[30,31] respectively. In Vallati and Mingozzi,[30] it was shown, for example, that if the continuous redundancy is not set properly, the suppression mechanism may lead to sub-optimal routes, in particular for heterogeneous topologies with different density areas. That's it. This is because Trickle was originally planned to disseminate updates on code, which are very similar in terms of protocol reprogramming. This is not the case in the sense of routing; however, as two routing update messages originating from different sources can carry different routing details, and therefore, "deleting one or other transmission is not always equivalent."[30]

LITERATURE REVIEW OF RPL'S PROPOSED PROTOCOLS

This section describes the main RPL protocols proposed for enhancing typical RPL:

Objective function enhancements

OF enhancements based on metric composition

Several research work has been carried out to resolve the issue of the composition of the RPL standard's under-specification of metrics.

In Karkazis *et al*.,[32] the authors suggested methods of additive composition and lexical that combine two routing metrics to optimize different aspects of efficiency. They found out that the monotonicity property of the merged metric must retain a loop-free routing protocol. When using an additive composition, the two-component metrics must have the same order relationship to ensure the composite metric is accurate. However, when using lexical composition, the restriction is not required. The study proposes a combined metric of packet forwarding indicator and hop count (HC) to create shorter paths that prevent malicious or selfish actions of nodes. Simulation findings have shown that the lexical combination of these two metrics offers better detection and precise route selection of misbehaving nodes while showing comparable latency compared to the metric of HC alone. The authors also showed that combining metrics of HC and residual energy (RE) in either an additive or a lexical way results in better distribution of energy load between nodes compared to HC alone. While the study provides a strong proposal to distribute energy load between nodes, it does not elaborate on the impact of this combination on network efficiency, a crucial performance parameter by combining the RE and the hop-count. If the analysis uses an aggregated value of the RE metric or a local optimum value is also unclear.

In Chang *et al*.,[33] the authors deal with the problem of RPL depending on one metric only: Energy or reliability. The authors highlighted in this study the problems of unbalanced traffic and, subsequently, the unequal distribution of energy consumption between nodes of the RPL network. The study pointed out, in particular, that the use of expected transmission count (ETX) as a single metric in the RPL network would lead to excessive use of certain routes, especially those with high delivery rates. This excessive use of good-quality paths inevitably leads to network partitioning and decreases network overall lifetime. On the other hand, if energy is chosen as the sole routing metric, the efficiency of the route might be negatively affected. The study proposes a weighted energy-oriented composite metric that takes into account the RE of a node in addition to the ETX to balance the energy consumption of nodes while providing highly reliable pathways. The results of the study show that energy consumption is somewhat balanced by the proposed technique which improves the lifetime of the network by up to 12%. A major problem with the analysis is that the simulation experiments only use up to six nodes, which may be inadequate to draw the stated conclusions. Moreover, the authors did not provide details on how composite metrics would affect the network's reliability.

In Capone *et al*.,[34] RPL Networks Energy Efficient and Reliable Composite Metric is suggested, this composite metric includes consideration of both the reliability indicated by the ETX metric and the energy efficiency to balance energy consumption between nodes and improve the life of the network. The proposed metric is called the Lifetime and Latency Aggregatable Metric (L2AM). A node running L2AM, in particular, combines first the transmitting power of the connection and RE of a node using an exponential equation to generate what is called the primary metric. The ETX metric then multiplies by the primary metric to get the overall composite metric cost; this is what needs to be minimized when choosing the parent of choice. In terms of network lifetime and remaining capacity, the proposed metric is contrasted with the ETX RPL for assessment purposes. The findings showed that in terms of network lifespan, the L2AM outperforms the ETX RPL by up to 56%. Although the analysis states that the gain of the lifetime of the network is accomplished without impacting the efficiency of the network, the study does not reveal any reliable results or explain how the authors draw this conclusion. Furthermore, the researchers used their own bespoke simulator for evaluation purposes, which may be lacking in functionality compared to well-known simulation tools such as Cooja. The study reports set the interval of the Trickle timer to 1 h for emitting DIOs. It seems the authors configured only one interval in their simulations, which is a confounding departure from Trickle protocol's usual service.

In Matsuura,[35] the authors pointed out that relying on HC only in the calculation of node ranks can lead to the creation of paths characterized by long physical distances. Since transmitter energy consumption is directly proportional to the square of the distance between communication nodes, this can lead to routes that suffer from higher levels of power consumption. The authors propose a new composite metric based on the distance between the node and its potential parent, the number of children that the potential parent has, and the metric of HCs. By comparing this framework with OF0 and the Karkazis[32] composition metric in terms of power consumption and durability, it is shown that the proposed system succeeds in substantially reducing power. The work suffers from the problem that calculating the locations of a node in actual test bed implementations is not a clear method and so live calculations of physical distance are likely to be either unreliable (e.g., RSSI) or energy-hungry (e.g., GPS).

In Ben Abdessalem and Tabbane,[36] a cross-layer composition is suggested, called RPL-Sleep Collect and Send Protocol RPL-SCSP, which combines the ETX and Queue Loading to provide Quality of Service (QoS) support for the network. The RPL-SCSP implies that, first of all, parent selection is based on the number of packets in the queue (nqpacket). The parent that has a pre-specified threshold between nqpacket one and pre-specified threshold (S), S should be selected as the preferred parent. If nqpacket is used by multiple parents between one and S, then the preferred parent is selected based on the ETX values. The option of a preferred parent based on ETX values is also extended when both parents have nqpacket that is <1 or greater than S. By means of simulation experiments, it was shown that RPL-SCSP decreased the end-to-end delay and improved the life of the network.

In Xiao *et al*.,[37] the study discusses the long single-hop problem introduced in large networks when RPL relies on a single metric, such as HC or estimated cost of transmission. The authors report that because ETX metric adds the nodes' ETX values along a routing path, the number of hops appears to have more effect on the measured rank rather than the quality of transmission. Discusses the long single-hop problem introduced in large networks when RPL relies on a single metric such as HC or estimated cost of transmission. The authors report that because ETX metric adds the nodes' ETX values along a routing path, the number of hops appears to have more effect on the measured rank rather than the quality of transmission. Therefore, since this passes through fewer nodes and accumulates a comparatively smaller cumulative ETX, a node would appear to choose a route with a limited number of hops. Therefore, the measured ETX rank for a route with less hops appears to be lower, even though such a route has constituent ties with a very low quality of transmission. A lengthy single-hop path with a bad transmission quality in a large network will limit the entire network, negatively affecting its reliability. The study proposes to combine the HC and the ETX metrics to produce a composite metric called PER-HOP ETX to overcome this problem. Based on the cumulative value of ETX, the rank is determined along a path separated by the number of hops on that path. Using Cooja, the latest metric is measured and compared with both the MRHOF and OF0 objective functions. The findings indicate that while decreasing power consumption and latency, PER-HOP ETX increases PDR in dense networks. A major problem with the PER-HOP ETX metric proposed in the study is that the combined metric's monotonicity property is not met so that the network might be at risk of looping.

In Kamgueu *et al.*,[38] the authors combined three linguistic variables (routing metrics), namely, delay, ETX, and energy, using a two-stage fuzzy method. The delay and ETX are combined in the first stage to compute what they call QoS. In the second step, the energy and the measured QoS value are combined. The suggested fuzzy-based solution is then evaluated using a real test bed network of 28 sensor nodes against ETX-RPL. Comparison is made between the two protocols in terms of packet loss ratio, power consumption, and routing stability (total amount of preferred parent changes). It is reported that in terms of packet loss ratio, the fuzzy-based approach outperforms ETX-RPL by up to 20% and marginally increases end-to-end latency. In addition, the proposed solution is shown to create a topology of more stable routes with an average change per hour of 6.63 parents compared to ETX-RPL with an average change of 43.522 parents per hour compared to ETX-RPL. The stability of routes seems believed to be the explanation for the superiority of the method proposed; however, there is no rationale for justifying why the fuzzy method is more stable. There is also the loss of justification for the marginally improved delay.

OF enhancements based on multi-path routing

Several multi-path forwarding optimizations have been proposed to address certain performance issues arising from single-path routing in the RPL, and still, other researchers have suggested multi-path forwarding approaches using composite metrics.

In Liu *et al.*,[39] the authors suggested a probability-based load-balancing multi-path method for RPL called LB-RPL. By making each node distribute traffic among its best *k* parents, LB-RPL achieves load balancing depending on their traffic load in terms of rank. By delaying the broadcast of its scheduled DIO message, a parent with a heavy load can signal its status. This allows child nodes to remove the parent from their (top *k*) and, therefore, to exclude it from forwarding more data. Through simulations, it is shown that LB-RPL outperforms RPL in terms of the packet delivery ratio (PDR), delay, and distribution of workload. The implicit signaling proposed delayed DIO has no extra overhead, but a missed DIO may easily be misinterpreted as delayed, giving a false indication of the increased workload at some nodes. In addition, Trickle's DIO's long transmission periods can cause slow recovery.

In Iova *et al.*,[40,41] the authors highlighted the benefits of embedding multi-path forwarding schemes into the RPL protocol. Intuitively, it has been proven that the multi-path mechanisms have a wide spectrum of benefits such as improving fault tolerance, improving reliability, minimizing congestion, and improving QoS. The authors suggested an RPL based on multi-path routing mechanism that allows the protocol to forward traffic for many parents of choice. The study notes that a routing metric must: (1) Capture variations in the quality of the links; (2) use energy-efficient paths to optimize end-to-end reliability; and (3) reduce energy consumption for those nodes that use the most energy (the bottleneck nodes). A new metric is proposed in this regard, called the expected lifetime metric (ELT), which aims to balance energy consumption between network nodes and optimize the lifetime of the bottleneck nodes. The network lifetime is defined as the time before (runs out of energy); the first node dies. The ELT of a particular node is determined by: (1) Calculating the node's throughput on the basis of its own traffic and also the traffic of its children; (2) multiplying the average number of retransmissions by the traffic determined; (3) calculating the time ratio required for transmission on the basis of the rate of transmission of the data; (4) calculating power consumption based on radio transmission power only; and, finally; (5) calculation the ELT as the ratio between the remaining energy of the node and the energy calculated in the preceding step. The bottleneck nodes are first identified and advertised along the topology based on the value determined by the ELT; then, a multi-parent, energy-balanced topology is constructed, in which traffic between parents is balanced with thoughtful consideration of bottleneck nodes. Since several parameters (retransmission count, data rate, transmission power, throughput, and RE) need to be exchanged to determine the rank, this method increases the size of DIO packets, raising the risk of fragmentation. This is an issue in LLNs when multi-path routing is used as separate paths are taken by two fragments belonging to the same packet, raising the possibility of errors and packet loss. In addition, the monotonicity property does not hold for the ELT metric; thus, the study suggests using ETX to create the DODAG and ELT to calculate node rank. To an already confusing protocol, this added additional complexity.

In Lodhi *et al.*,[42] the authors pointed out the problem of RPL being a single path routing protocol and also the inability to provide multi-path routing for target functions. The ultimate objective of the research is to provide multi-path routing functionality for RPL that will allow the protocol to react effectively to congestion. The authors suggest an extension named a multi-path RPL (M-RPL) that offers many ways of congestion that are temporary. In M-RPL, the forwarding nodes detect congestion using the PDR. If a forwarding node on a routing path detects that the PDR has decreased below a given threshold, the node sends a warning to its children, informing them of congestion by means of DIO messages. By splitting its forwarding rate in half, the child node that hears the message about congestion advertisements begins multi-path routing. Only a second packet is subsequently sent to its original congested parent, while the others are forwarded to every other parent from its parent list. The proposed protocol, in terms of energy consumption, latency, and throughput, is evaluated using Cooja and compared to RPL with MRHOF. Because of its splitting mechanism, their simulation results show that M-RPL has higher performance and lower energy consumption per bit than RPL. The findings have shown that while the M-RPL delay is initially comparable with the RPL, this changes when congestion starts. Initially, when multiple paths are implemented, M-RPL experiences greater latency, but when the network stabilizes, MRPL outperforms RPL in terms of latency. The issue is that DAO messages are costly in terms of energy use and overhead because they are sent end-to-end.

In Tang *et al.*,[43] the authors propose a hybrid metric-based multi-path forwarding strategy. The authors point out that in situations where a sudden rise in traffic volume creates congestion, resulting in substantial delay and packet loss, the objective functions of the two single-metric RPLs are vulnerable. The authors propose a multi-path routing protocol for congestion avoidance, called CA-RPL, whose primary objective is to allow the network to respond to sudden events quickly and reliably. To minimize the average delay toward the DODAG root, known as DELAY ROOT, they have built a composite routing metric built in the ContikiMAC duty cycle protocol. A node saves time just by learning the wake-up stage of its candidate parents under this metric and then sending the packets to a first awake parent. To measure the route weights, CA-RPL is a hybrid multi-path routing metric that combines the current proposed DELAY ROOT with both the number of packets received and ETX. Cooja with Contiki OS is used to equate DODAG root's proposed method with the standard RPL in terms of throughput, packet loss ratio, latency, and packet reception number (PRN) per unit time. The experimental results show that the proposed protocol decreases network congestion and increases the PRN with up to 50%, the output by up to 34%, and the packet loss by up to 25%. Compared to RPL, the average delay was 30%. The protocol proposed is based on ContikiMac, which assumes that all nodes have identical wake-up intervals that may not be present in all LLN scenarios. Moreover, the DIO message carries several additional fields, which raises the possibility of fragmentation.

In Wang *et al.*,[44] the authors stated that the ETX metric used in RPL is inefficient in quantifying link quality as it only "reflects a single linkquality." The study proposes a quality-conscious Link RPL referred to as LQA-RPL to resolve this problem. LQA-RPL measures the rank of a node based on the consistency of the links with all its neighbors, this is derived from the ETX and is described as the probability of failed transmissions predicted. When a node has more than one parent in its parent set, the node uses multi-path routing, choosing the parent with the most RE to serve as the next-hop relay node to the DODAG root. In terms of the packet transmission ratio, energy usage, and network lifetime, LQA-RPL is evaluated and contrasted with RPL with HC. The published findings showed that, in terms of PDR, LQA-RPL outperforms RPL, which is due to the higher number of candidate parents. It was also shown that LQA-RPL can balance energy consumption as a result of its capacity to disperse traffic to multiple candidate parents on the basis of RE, prolonging the lifetime of the network. An apparent problem with the proposed protocol is that, while the problem statement focuses on illustrating the inappropriateness of the ETX metric to measure the reliability of connections, it is compared to RPL with HC. Thus, comparing the suggested combined metric with ETX would seem more reasonable as both measure connection reliability.

In Alishahi *et al*.,[45] the authors suggest an optimization based on virtualization and software-defined networking techniques for RPL known as optimized multi-class RPL (OMC-RPL). The study asserts that when providing QoS, standard RPL faces two important problems. The first is the lack of an objective role that is holistic and detailed. For example, an objective function may increase the delay, but at the cost of higher energy consumption, because with the minimal delay, all packets overuse the same paths. The second issue is that RPL does not accept a data classification process, which is crucial in ensuring the QoS. Therefore, a comprehensive, objective feature is required that supports multiple data classes. The OMCRPL steps are as follows: The first one, the nodes send the information needed to construct its virtual DODAG to the SDN controller using one-hop communication; and so, the SDN controller determines the node ranges in the network by each traffic class using a specific weighted-metric objective function. The propagation delay (PD), node congestion (NC), and link congestion (LC) are the key parameters of the proposed objective function. Energy considers a secondary parameter and is thus integrated into the objective function in such a way as to exclude or consider it as desired. The weight values of such objective function parameters were calculated using the particle swarm optimization (PSO) process. OMC-RPL is simulated with four different traffic groups and Objective Function Parameter weight values were found using the PSO algorithm and Compared to the regular ETX-RPL in terms of end to end latency, packet loss, network lifetime, and overhead traffic. In terms of the end-to-end delay for the traffic class that needs minimal delay, OMC-RPL then outperforms RPL and also shows better performance than RPL in terms of PDR for the traffic class that needs reliability. It is also found that because it can use a backup parent to replace a failed one, OMCRPL responds better to network failures. In terms of network life, OMC-RPL outperforms RPL by up to 41% and displays stronger energy delivery fairness by about 18%. The study also states that the combination of the SDN controller with OMC-RPL decreases the amount of control packets exchanged by approximately 62% compared to both OMC-RPL and standard RPL and minimizes energy consumption by more than 50% compared to standard RPL. The reporting interval to the SDN is not quoted for SDN-based OMC-RPL, although it may have a major impact on the overhead control plane.

Routing maintenance enhancements

In Coladon *et al*.,[46] through mathematical analysis, the study demonstrates that the single redundancy constant adopted by Trickle will lead to higher transmission loads and higher energy consumption rates for those nodes with few neighbors. To mitigate this issue, the study proposes an enhancement of Trickle, where each node determines its own variant of its redundancy constant as a result of its degree. Each node will set its redundancy constant to one with a number of neighbors smaller than a pre-specified threshold, called the offset. The constant of redundancy of other nodes should be set by subtracting from the offset number of neighbors and taking the ceiling of dividing the value by another predetermined value called the phase. Simulations show that in comparison with standard Trickle, the proposed algorithm balances the distribution of transmission between network nodes. The work did not demonstrate the effect of the proposed improvement either on the efficiency of the built routes or on the power consumption in the network. Furthermore, the implementation of two new criteria, the phase and the offset, adds uncertainty, which is best prevented.

In Djamaa and Richardson,[47] the authors highlighted the issue of increased latency arising from the implementation of the Trickle algorithm's listen-only duration. An optimized-trickle (Opt-Trickle) is suggested to fix this issue. The authors note that nodes receiving inconsistent transmissions at the same time immediately reset their timers (returning to Imin), thus displaying a form of implied synchronization. In fact, such a synchronization removes the need for a fixed listen-only duration of the first interval and enables the affected nodes to choose a random time, *t*, from the {0, Imin} range. This is Opt-Trickle's only update. The problem is that assumes a 100% duty-cycle MAC protocol, which is neither sensible nor practical. In addition, Opt-Trickle also has a listening-only duration at subsequent intervals, which would lead to increased latency, particularly in a loss-free network where a transmitted multicast message is not guaranteed to reach all its destinations at its first transmission during the first interval.

RPL downward routes enhancements

In Gan *et al.*,[48] the authors try to mitigate the problem of restricting capacity in storage mode. They note that the RPL storage mode needs each node in its sub DODAG to preserve all other nodes' routing status, and many nodes may not even have sufficient resources for this, especially those near the root. The authors propose memory-efficient RPLs (MERPL) to overcome this problem. The main concept here is that a node that exceeds a pre-defined threshold of N by routing entries should allocate a child to its sub DODAG to operate as its store. Then, the overloaded node can delete all the routing entries whose next hop is the delegated child from its routing table. Then, all those destinations that can be reached through the delegated child should be advertised in a separate DAO to the DODAG root. Network nodes use a hybrid method of non-storing and storing operating modes to carry out forwarded decisions downward. To validate MERPL, the average amount of routing table entries, average path length, and the amount of items in the source root are compared to the standard RPL. With network sizes of 576 and 1204 nodes, a Python language simulator is used. The results show that MERPL actually reduces the requirements for routing entry storage, particularly at nodes close to the root. When N is set to 10, the average number of items in a source route is decreased by 61.5% relative to RPL. The MERPL average path length in non-storing mode is also shown to be shorter than that in RPL, in storage mode, just a little longer. No other simulation parameters are mentioned other than the number of nodes and, in particular, there is no explicit specification on how the N value should be set.

In Kiraly *et al.*,[49] a different approach is stated for overcoming storage limitations in RPL storage mode. It is noted here that if a node fails to store a new routing destination entry, the information should not be further propagated, as it will not be ready to forward it to that destination. A negative consequence of this action is that a path is partially constructed but useless because routers higher in the DODAG, including the root, cannot reach the destination. The authors suggest D-RPL, which incorporates multicast propagation into RPL storage mode, to address this issue. Here any node that fails to announce a destination, or even for one of children, unique multicast community should register first. The DODAG root will then use the multicast address of this special category to communicate with those destinations inaccessible through the regular operation. The multicast can be implemented in the RPL protocol itself by any acceptable protocol, such as multicast protocol for low power and lossy networks or by the multicast mechanism. Cooja measures DRPL with Contiki and contrasts PDR, radio duty cycle, and end-to-end delay with the regular RPL. The results of the simulation show that D-RPL achieves substantially better performance with a 6-fold increase compared to ContikiRPL in terms of PDR. In terms of the average duty cycle, both protocols have similar performance when the number of nodes is <60, but because of its higher delivery rates, DRPL has a higher average duty cycle above that size. Even the average end-to-end delay in D-RPL increases compared with RPL, but this is due to the SMFR forwarding mechanism, which opts to delay the forwarding of packets at each hop for a specific period to avoid collisions. Finally, it is concluded that there is a higher cost of transmitting packets using D-RPL in terms of latency and average service cycle, "but this cost is only charged for packets that would not otherwise be delivered at all." The authors claimed that the additional cost "is only paid for packets that would otherwise not be delivered at all," if we presume that all node routing tables overload at the same time, this may only hold true.

Other proposed protocols that supports mobile sensors

In Gara *et al*.,[50] the authors proposed the protocol Mod-RPL tailors the trickle timer to match versatility. As a first step toward that goal, any mobile node relies on the RSSI to determine when its preferred parent gets out of the communication range. Based on that calculation, the DIO interval is modified by the mobile node. Cooja simulator checks this protocol considering a static sink, 10 senders and a varying number of mobile nodes (ranging from 20 to 100). Mobile node velocities range from 0 m/s to 10 m/s. This protocol reduces overhead, but it is difficult to decide when the parent is still mobile when a mobile node is out of parent range.

In Bouaziz *et al*.,[51] the authors suggest a new constructive protocol called EC-MRPL, which prohibits mobile sensors from functioning as RPL routers: Only static nodes can serve as parents to ensure the reliability of the core RPL DODAG. The parent of a mobile node is responsible for monitoring the mobile node link and choosing an alternate parent if necessary. ECMRPL increases the reliability of the routes using mobile sensors as leaf nodes only. The parent's failure, however, triggers a network contact loss. This protocol is tested using the Cooja simulator with a static sink and a single mobile sensor that follows a random walk pattern with constant velocity (v=2 m/s) with horizontal movements from one corner to another.

In Gaddour *et al*.,[52] the authors proposed a protocol called CO-RPL, proposed that the network can be divided into certain circular regions, called coronas, defined by a certain radius (typically corresponding to the maximum transmission range) and centered around the root of the DODAG. Each corona is defined by a corona ID. This corona ID provides the distance from the mobile node to the sink. Every node belongs to a single corona. This corona principle allows the parents to be selected from the closest sensors (i.e., the same corona ID). In practice, a node selects as the best parent, the candidate that has the minimum corona ID, and if the possible candidates have the same corona ID, then the one with the best link quality is chosen. CO-RPL adapts the transmission rate of DIO messages according to the sensor speed to work with sensor mobility without overwhelming the network with DIO messages. In addition, a

Table 1: A summary of RPLs limitations and drawbacks

The problem	Description	Side effects
Single path routing for objective function	No attempt of load balancing because the node keeps forwarding traffic only to its preferred parent.	No-load balancing which adversely affects both reliability and energy efficiency
Underspecification of metrics composition for objective function	There are no rules for how many metrics can be mixed	Jeopardizing the protocol's ability to benefit from combining multiple metrics
Implicit hop-count impact for objective function	A route of better the global quality (usually because of its fewer number of hops) can include one or more links with critically low-quality links that weaken its apparent quality	Affect any aspect of success negatively
Incompatible modes for downward routing	It is not specified the downward MOPs to understand each other.	Network partitions and forwarding failure
Memory limitations for downward routing	Each node must preserve in its sub-DODAG the routing entries of all nodes that may not be feasible for memory-constrained nodes	Memory overload, which endangers reliability and scalability
Long source headers for downward routing non-storing mode	Transmitted packet must hold all nodes' addresses to their destination	Higher overheads which endanger reliability and scalability
Underspecification of DAOs emission, for downward routing	It is unspecified when a node must transmit its DAO	The problem of inefficient implementations
Listen-only period for routing maintenance timer	A node must wait half the period before the transmission of a routing update and load balancing	Problems of slow convergence
Suppression mechanism Inefficiency for routing maintenance timer	The node must suppress a specific routing update if it is heard that the same routing update was transmitted by a number of neighbors	If not configured correctly, forming suboptimal routes

new DIO message is instantly transmitted by a mobile node that enters the DODAG, ignore the trickle timer. CO-RPL prevents the loss of packets by 1-detecting sensor disconnection quickly and 2-looking for an alternate path: When a node does not receive a DIO message from its parent, it must send DIS messages to its children to avoid transmitting data packets until an alternate parent is identified. This protocol is tested using the simulator Cooja. All nodes adopt a random mobility model (except for the static sink): And mobile node's destination, speed, and direction are chosen randomly and independently. Thus, CO-RPL induces a large contact overhead due to the high-periodical broadcast rate associated with DIO messages, congestion, and an increment of energy consumption.

In Cobarzan *et al.*,[53] to deal with mobile nodes, the authors present the Reverse Trickle timer. The fact that they are mobile is declared by mobile nodes. However, in this case, a mobile node can only operate as a leaf node. This work supposes that the longer the mobile node stays attached to the same parent, the more it is likely to travel beyond the coverage of the parent. As such, if a node advertises its versatility, its parent decreases dramatically the (Reverse) Trickle timer. In a nutshell, when a DIO message is received, this timer begins with the maximum value allowed and is halved. If the minimum value is reached, the Reverse Trickle timer is reset (i.e., is given the highest value).

By considering a scenario with only one mobile node traveling along a linear trajectory with a constant speed of 2 m/s, simulations were conducted using the WSN simulator. In comparison, the actual experiment was conducted with 100 static nodes and 10 mobile nodes randomly moving within the area protected by the fixed nodes. The sink of DODAG is located in the center of the network region [Table 2 and Figure 5].

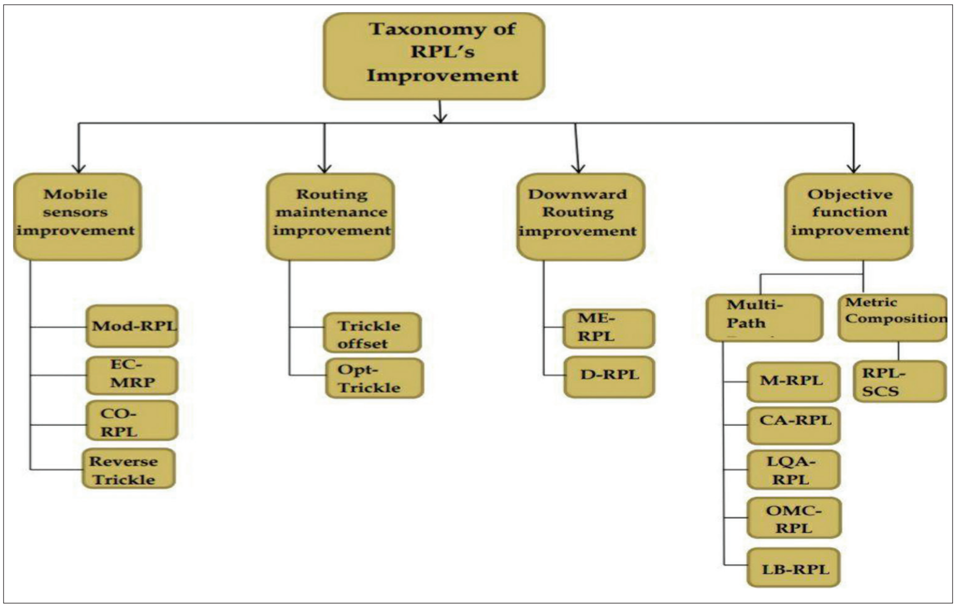

Figure 5: *Taxonomy* of RPL's improvement protocols

Table 2: RPL protocols survey table

Protocol and reference number	Metrics	Brief description	Advantages	Disadvantages and drawbacks
[32]	HC and PFI or HC and RE	Combines HC and PFI to help identify malicious nodes better. HC and RE also combine for load balancing.	Better distribution of energy load between nodes compared to hop count alone.	Quite low-quality paths can still be chosen without real test bed experiments.
[33]	RE and ETX	RE and ETX combine for load-balancing.	Improves the lifetime of the network by up to 12%.	Just up to 6 nodes for analysis. Paths of very poor quality can still be chosen.
[34]	Energy, transmit power, and ETX	It combines RE and ETX with a mechanism to reduce the effect of highly depleted nodes to improve reliability and energy efficiency.	In terms of network lifespan, the L2AM outperforms the ETX RPL by up to 56%.	Claimed unreported or justified reliability, no clarity on how DIO intervals were chosen.

(Contd...)

Table 2: *(Continued)*

Protocol and reference number	Metrics	Brief description	Advantages	Disadvantages and drawbacks
[35]	Number of children, HC, and distance from parents	Combine the number of children nodes, distance and the HC.	Reducing power compared with the study in Karkazis *et al*.[32]	High fragmentation risk. No indication of the method used for simulation.
RPL-SCSP[36]	ETX and queue loading (nqpacket)	Combines the Queue Loading and ETX to provide (QoS) support for the network. The RPL-SCSP implies that, first of all, parent selection is based on the number of packets in the queue (nqpacket).	Decreased the end-to-end delay and improved the life of the network.	No actual experiments on test beds reliability of the network
[37]	HC and ETX	Combine hop count and ETX by taking the ETX average to prevent long single-hop issues.	Decrease power consumption and latency.	It does not satisfy the monotonicity property. Excessive churn suffering.
[38]	Delay, ETX, and energy	To improve stability, reliability, and energy efficiency, it combines delay, ETX, and energy.	That in term of packet loss ratio, the fuzzy-based approach outperforms ETX-RPL by up to 20% and improves stability.	There is no reason for improved stability and slightly improved delay. Paths that are of very poor quality can still be picked.
LB-RPL[39]	Rank and top k	Making each node distribute traffic among its best k parents.	LB-RPL outperforms RPL in terms of the packet delivery ratio, delay, and distribution of workload.	A missed DIO can easily be misinterpreted as overdue, providing a false indication at some nodes of increased workload. In addition, Trickle's DIO's long transmission periods can cause slow recovery.
[40,41]	Traffic, Data-rate, Transmit power, RE, and ETX	Implementing a new metric called ELT and utilizing multi-path forwarding with a view to managing energy consumption.	Improving fault tolerance, improving reliability, minimizing congestion, and improving QoS.	Higher Fragmentation Risk. The propriety of monotonicity is not satisfied.
M-RPL[42]	N/A	During congestion, multiple routes are used as a way to resolve such congestion.	Higher performance and lower energy consumption per bit than RPL.	More overhead because of the new control messages. How the threshold is set for congestion is unclear.
CA-RPL[43]	Received packet number, DELAY ROOT, and ETX	Design of a composite multi-path routing metric to reduce congestion arising from the emergency scenarios sudden events.	Decreases network congestion and increase the PRN, the output, and the packet loss.	Higher Fragmentation Risk. No actual experiments on test beds.
LQA-RPL[44]	ETX and RE	Create a new ETX-based version and combine it with RE to enhance reliability and load balance.	LQA-RPL can balance energy consumption, prolonging the lifetime of the network.	For comparison purposes, no reliability metric is used. There is a violation of the monotonicity property. The simulation system used for analysis is undisclosed.
OMC-RPL[45]	PD, (LC), NC, and energy	Combining four weighted measurements and using virtualization technique and SDN to support multiple traffic classes.	Responds better to network failures, extend network lifetime.	Unrealistic communication meant to be one-hop. No information on how the NONSDN-based OMC-RPL interacts with DIOs. The SDN-based OMC-RPL reporting interval is not provided.
Trickle offset[46]	N/A	Calculates the redundancy factor as just a node degree feature.	Decrease power consumption.	By adding two new configuration parameters, the addition of a complexity. Due to the listen-only duration, slow convergence time.
Opt-Trickle[47]	N/A	Allows nodes in the first interval to select the random time, t, from range [0, I min].	Decrease latency.	However, rapid convergence time is moderate in lossy networks, as there is In the corresponding cycles, listen-only time.
ME-RPL[48]	N/A	To carry out the forward decisions in the downwarding direction, mixing the non-storing and storing modes of operation.	Reduces the requirements for routing entry storage, particularly at nodes close to the root.	How to set the pre-specified factor N value is unclear. For assessment, an unpopular simulation technique is used.

(Contd...)

Table 2: ***(Continued)***

Protocol and reference number	Metrics	Brief description	Advantages	Disadvantages and drawbacks
D-RPL[49]	N/A	Use the multicast to address the memory limitations in the RPL storing mode, when the memory of the node overflows.	High performance in the term of storage limitations in RPL storage mode.	More complexity was introduced by multicast and it could often be counterproductive.
Mod-RPL[50]	RSSI	Any mobile node relies on the RSSI to determine when its preferred parent gets out of the communication range. Based on that calculation, the DIO interval is modified by the mobile node.	Reduces overhead, low energy consumption.	It is difficult to decide when the parent is still mobile when a mobile node is out of the parent range.
EC-MRPL[51]	N/A	Only static nodes can serve as parents, distribute the consumption between different nodes that are static.	Increase the reliability of the routes.	The parent's failure, however, triggers a network contact loss.
CO-RPL[52]	N/A	The network can be divided into certain circular regions, called coronas, defined by a certain radius. Corona ID provides the distance from mobile node to the sink. Every node belongs to a single corona. Parents can be selected from the closest sensors.	Low packet loss.	High overhead, high energy consumption, high control messages. Low stability.
Reverse trickle[53]	N/A	The longer the mobile node stays attached to the same parent, the more it is likely to travel beyond the coverage of the parent. As such, if a node advertises its versatility, its parent decreases dramatically the (Reverse) Trickle timer. In a nutshell, when a DIO message is received, this timer begins with the maximum value allowed and is halved.	Low control message and low energy consumption.	It is difficult to estimate that mobile node stability often decreases over time because it is closely related to the mobility model.

CONCLUSION

This paper offers an overview of the various protocols for Low-Power and Lossy Networks utilized. This survey addresses the shortcomings and disadvantages of RPL. Several protocols have been paid attention to control the power, and several are on efficiency and reliability. Other than such protocols, there are drawbacks such as the device mobility mechanism, not paying attention to the code change parameter, and increasing the rate of packet loss. We analyzed extensively the uptodate research initiatives proposed to resolve the shortcomings of RPL and looked at the obstacles and pitfalls they encountered. We find that, while a lot of solutions have been implemented to further improve the efficacy of the RPL, most of these solutions have significant drawbacks that undermine the achievement of the goals pursued and, thus, many problems that were meant to be resolved by those extensions remain open to study. These pitfalls include: The impractical conditions of operation, the absence of actual large-scale assessments of test beds, the under-specification of metric composition, and the greater difficulty caused by some proposed solutions. Furthermore, we found that RPL has a serious problem of scalability in bi-directional large-scale networks and none of the solutions suggested have addressed this issue effectively, which may be the main reason for undermining large-scale RPL deployments. We have also found that the advent of long-range wireless technologies with lower power will adversely affect the adoption of RPL and challenge the viability of multi-path routing as a whole. In light of this paper, we stressed the need for further scientific research to highlight the key research directions, in particular, those that impede the adoption of the norm in large-scale deployments.

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