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A Survey on Issues and Challenges in RPL Based Routing for IoT

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ABSTRACT

Internet of Things (IoT) is an emerging technology that is highly promising and can prove to be inevitable in every field in the near future. The function of the IoT devices is to collect data from the sensor and control the things over through the Internet. These smart devices can be controlled from any place, any time, without any equipment, and without the help of humans. The data collected from the sensor are routed between the users in the form of packets using wired or wireless medium. *RPL (Routing Protocol for Low-Power and Lossy Networks) is the first standardized routing protocol for IoT*environment *that involves low power and lossy networks.* However, it is observed that as the number of nodes and the density of nodes increase, RPL suffers in terms of quality of service offered due to a number of issues. In this paper, we identify the issues and challenges that affect the quality of service of RPL and also summarize the works that have effectively addressed some of these issues to improve the quality of service in the routing process.

***KEYWORD*:**IoT, QoS, RPL, RPL issues and challenges.

INTRODUCTION

Internet of Things introduced by Kevin Aston is one of the technologies that has revolutionized proliferated almost every area of human life. Internet of Things is a new prototype which provides a set of new services to the society that helps to reduce the time and cost of collecting accurate data about the physical environment, which in turn could be analysed to derive useful information.

Since IoT is still in its nascent stage, there is no standard architecture to be employed while building an IoT application. Depending on the application, the architectures that may be used are classified into three-layer, four-layer, five-layer and seven-layer architecture. The three-layer architecture consists of an application layer, network layer and perception layer [37]. The four-layer architecture consists of an application layer, network layer, data processing or supporting layer and perception layer [38]. Business layer, application layer, processing layer, transport layer and perception layer [39] are the layers present in the five-layer architecture.

In the three-layer architecture, the application layer analyses data received from the sensing layer. Encapsulation and routing are the functions of the network layer. Sensors connected to the physical environment collect the data and send them for the further processing. These data are processed by the protocols corresponding to each layer.

Each layer in the IoT has different protocols. LOAD (Lightweight On-demand Ad hoc Distance-vector Routing Protocol), LOADng (Lightweight On-demand Ad hoc Distance-vector Routing Protocol - Next Generation), CORPL (Cognitive RPL), RPL (Routing Protocol for Low Power and Lossy Network) are the network-layer protocols. Constrained Application Protocol (CoAP), Message Queue Telemetry Transport (MQTT), Extensible Messaging and Presence Protocol (XMPP), Representational State Transfer (RESTFUL Services), Advanced Message Queuing Protocol (AMQP) and Web sockets are the protocols of the application layer. Perception Layer protocols are WiFi, Bluetooth, Zigbee smart, DECT/ ULE, Weightless, Z-wave, DASH7, 3G/LTE, Home Plug GP, LoRaWAN, LTE-A, G.9959, 802.11ah and 802.15.4e.

Application Layer Protocols	*CoAP,* *MQTT* *XMPP* *RESTFUL Services* *AMQP* *Web sockets*

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Network Layer Protocols	*LOAD, LOADng, CORPL, RPL*
Perception Layer protocols	*WiFi, Bluetooth, Zigbee smart, DECT/ ULE, Weightless, Z-wave, DASH7, 3G/LTE, Home Plug GP, LoRaWAN, LTE-A, G.9959, 802.11ah, 802.15.4e.*

Figure 1.1 LayerwiseIoT protocols

These protocols use different approaches and sets of rules that have to be followed to establish the communication between the devices. The rules define how to build the communication, transfer data over the network and how to receive the data.

The main focus of this paper is on network layer. In network layer, routing and encapsulation are the two main processes that occur. The data to be transferred are separated and packed into different packets, and this process is known as encapsulation. Routing is the process of finding suitable paths to transfer the packet from the device at one end to the device at another end.

Routing Protocol for Low power and lossy network (RPL) is a popular routing protocol designed and standardized by IETF to support routing in an IoT environment. It is a distance vector routing protocol based on the construction of RPL graphs. RPL graphs are Directed Acyclic Graphs. Routing occurs in upward direction (end node to root node).

In RPL, the routing begins after the construction of the Destination Oriented Directed Acyclic Graph (DODAG). DODAG is based on rank value. Rank value is used to identify the position of the node. Rank value of nodes increase in the downward direction and decrease in upward direction. Rank value is calculated using the OF (Objective function). RPL uses three types of objective functions, namely, HOP, ETX and ENERGY. Each DODAG is formed with an objective function. Default objective function of the DODAG is HOP. Each DODAG is constructed by using a single object function. The objective function is used to construct the DODAG, and it is identified by the objective code point.

Four types of messages are used in RPL to construct the DODAG. They are DIO (DODAG information object), DAO (Destination Advertisement Object), DAO-ACK (Destination Advertisement object acknowledgement) and DIS (DODAG information solicitation).

A DIO message is generated at the root node. In figure 2.2, 1 is the root node. Nodes 2, 3, 4 are the neighbour nodes of the root node. The DIO message is multicast to the neighbour nodes until it reaches the destination. DAO is the message generated by the node with information like rank, Flags, Reserved and DAO sequence. DAO message is sent by a node from where it receives the DIO message. For example, Nodes 2, 3 and 4 send the DAO message to the Root Node 1.

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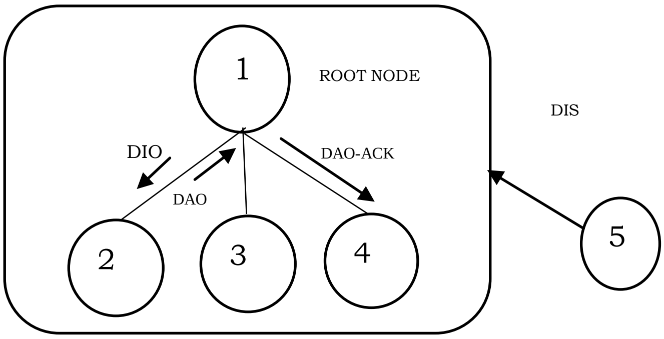

Figure 1.2 RPL Control Messages

DAO-ACK is the message sent by the root node to join the DODAG. For example, the Node 1 sends the DAO-ACK message to Nodes 2, 3, 4. DIS message is used by the node to join the DODAG. Node 5 is the mobile node that wants to join the DODAG.

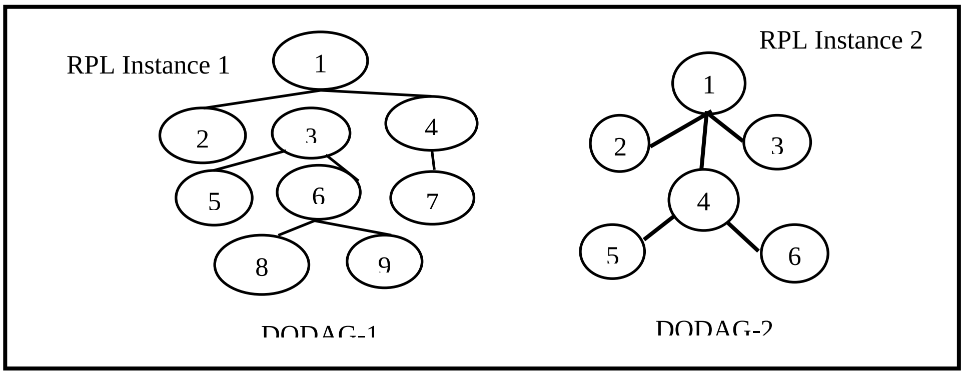

Figure 1.3 RPL Control Messages

In this paper, issues related to RPL that affect Quality of service are explored. The rest of this paper is organized as follows: Section 2 presents the existing works, Section 3 elaborates on the issues that affect the Quality of service in RPL, Section 4 presents problems addressed in the RPL, metrics used to analyse the performance and the simulators that are used and Section 5 presents the summary.

Issues that affect the Quality of service in RPL

The performance of the RPL protocol can be evaluated by using various simulators, namely, Open-Sim, COOJA, Matzlab, TOSSIM, Sens-LAB testbed and so on. The issues involved in packet transfer using the RPL routing protocol affect the quality of service in routing. Figure 1.4 shows the issues and challenges in using RPL. Path selection, parent selection, mobility, Load balancing, energy, HOP are some of the few issues that affect the performance of the RPL protocol that is widely adopted for routing in IoT environments.

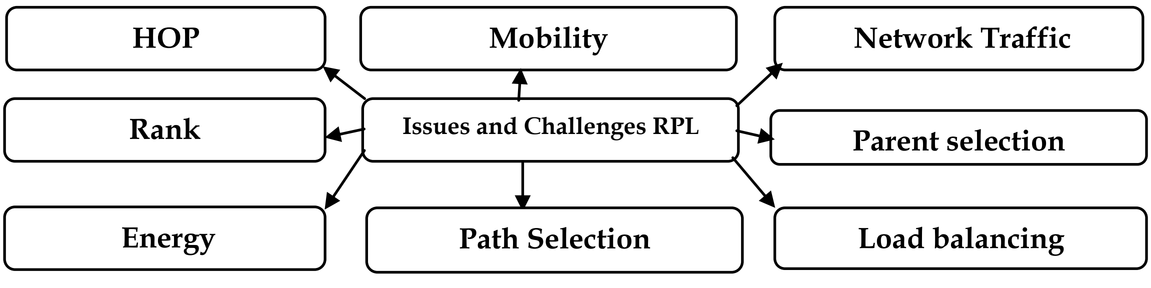

Figure 1.4 Issues and Challenges of RPL

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Rank

Rank value is used to identify the position of the node. In RPL, the rank value is calculated based on the objective function. Once the request is initiated on the sink node, the DIO message is generated. From the sink node, DIO messages are broadcasted to the neighbour nodes. Rank value is calculated based on the objective function. The calculated rank value is sent by the node through the DAO message to the sink node.

In some cases, a malicious node sends the fake rank value to the root node. If this malicious node is selected as parent, issues like the mishandling of packets, replacing original packet and delivering fake packets will arise. This may lead to increase in the packet loss and decrease in the packet delivery ratio. Routing process will be initiated from the beginning. Rank attack is one of the major drawbacks of the RPL routing protocol.

Path Selection and parent selection

In RPL, path selection is an important process in transferring the packet. Path selection is the process of finding a way to transfer the packet from the end node to the sink node. During the routing process, the node follows certain conditions to deliver the packet in the minimum time period, with high packet delivery ratio, low packet loss and so on. The process of reconstructing the path by choosing the alternate parent is known as parent selection. A node will select the parent node based on the rank value. While transferring the packet, some interruptions may occur; and if so, it makes the path unstable.

Mobility

The node present in the DODAG may be dynamic or static. Root node will be static in all the network environments. The intermediate node selected for transferring the packet may be static or dynamic. Node mobility is the main reason for path failures. This characteristic of the node affects the normal process in DODAG. RPL standard does not support mobility. More precisely, there is no mechanism in the RPL standard that fully supports mobility. Once the node has left from its position, either the parent-selection or the path-selection process is initiated to transfer the packet. Many researchers have started to address this problem to overcome this issue and to improve the performance of the RPL.

Path failure and Path reconstruction

Path failure leads to a path reconstruction of the DODAG from the beginning, which affects the performance and quality of the routing protocol. Again, the DODAG construction is to be initiated to complete the incomplete process. Path reconstruction is the process to find an alternative path to transfer the packet. This reconstruction of DODAG occurs when the node has left from its position.

In case of node failures, RPL can use any of the two methods to repair the route: local repair and global repair. In the local repair, if a parent node detects node failure, the node tries to repair the route by routing through the node’s parent. The global repair can be initiated only by the sink node. This causes additional control messages overhead.

Energy

Energy is an important key factor for the node. Nodes present in the DODAG have different energy levels. Some nodes have a short span of life. If the short spanned nodes are selected for routing, the node gets decayed and leave from the DODAG. This leads to incomplete execution process.

Let us consider for example that a node having less energy is selected as parent to transfer the packets in the DODAG. This may lead to issues as follows: the node may leave from the path before it completes the process; incompleteness in routing may result in the increase in packet loss; or in some cases, if the node consumes more energy it may also lead to decaying of the node and reducing the life time of the node.

Congestion

Congestion in a network may occur if the number of packets sent to the network is greater than the number of packets a network can handle. Congestion control refers to the technique to control the congestion level and keep the load below the capacity. In congested networks, the packets may take too much time to execute the routing process. In the network, the packets are executed based on the priority. In some cases, after some time, the process is declined and a new path-selection or parent-selection process will be initiated to complete the process.

Review of Literature

Ala al-Fuqahaet al. [1], have presented an overview of the Internet of Things [IoT], enabling technology, protocols, application and research issues. The authors classified and explained layer-wise

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protocols supported by IoT, common operating systems used in IoT environment, building blocks and technologies of IoT.

An algorithm to construct a path for routing in RPL is proposed by Miklos molnar et al [2]. Greedy algorithm, exact algorithm, k-limited algorithm are the algorithms proposed to overcome the issues like execution time, Quality of DODAG and missing nodes. These three algorithms seems to consume more energy in the routing process which is the drawback of this work.

Hussian [3], discussed issues like QoS, heterogeneity, scalabilities, security, privacy and interoperability. Also, he has pointed out that by addressing these issues, the performance of the RPL protocol can be improved. Challenges and research opportunities are described in terms of heterogeneity, interoperability, scalabilities, security, privacy and Quality of Service.

Suresh babu et al. [4]., have discussed the protocols that are used for routing in IoT. The authors have classified routing protocols into two types: standard and nonstandard routing protocols. The working of network layer is separated into two parts: routing (finding the path to transfer the packets) and encapsulation (creating the packet that to be sent). A brief explanation of application and challenges of IoT is also presented in this article.

Mohamed Khalgui et al. [5]., have proposed an approach to improve the QoS (Quality of Service) and congestion-aware routing in the RPL. By using this technique, the author addressed the problem of path failure. Once the path failure occurs, a new control message is broadcasted to complete the routing process. This work is simulated in the Contiki operating system. CPLEX tool is used to obtain the solution to the problem that occurs in routing. After ensuring the network’s time and energy feasibility, the performance of the metrics are evolved. New control messages like NDR and NDR-ACK are used to reconstruct the path. Here, the packet loss and energy consumption are low with more hop count during the routing.

In [6], Mohamed Lehsaini et al. proposed an enhanced Internet of multimedia things named as free bandwidth (Free-Bw)-RPL. In this work, based on the available bandwidth of the node in the network, the path-construction process has been carried out. This approach has been used to find the best path to transfer the packet, reduce the execution time, and to improve the performance of the RPL protocol. Metrics that have been considered in this work are PDR, End-to-End delay, throughput, energy consumption and energy consumption per packet. Cooja simulator has been used to evaluate the performance of the metrics. The authors have suggested that this work can be extended by focusing on the Objective Function energy and HOP.

Behnam Farzanch et al. [7]., discussed the problem of parent selection. To overcome this issue, the authors proposed a work named VIKOR method. The main aim of the authors was to increase performance routing and to improve the QoS in the services. Performance metrics like average energy consumption, End-to-End delay, Packet delivery ratio and throughput in Simulator were used. The authors have suggested that this work can be enhanced by considering HOP and ETX. The drawback of this work is that the performance of the node is decreased when the number of nodes increases.

Mishra et al. [8]., redesigned the RPL routing protocol to overcome the issues of link failures. To solve these issues, the authors have proposed a technique to select the best parent in the network. Three factors, namely, energy, interference and congestion were used to select the best parent. For the evaluation of this work, metrics like network delay, packet delivery ratio and radio duty cycle were considered during the simulation. The drawback of this work is that the authors have considered only energy. This may lead~~s~~ to increase in HOP count and retransmission of packets. If the retransmission rate increases, it may lead to enormous packet loss.

Ghaith Moab et al. [9], analysed the performance of protocols like 6LOWPAN and RPL. Here, Cooja simulator has been used to evaluate the performance of the RPL. QoS parameters like throughput, end-to-end delay and jitter were used to evaluate the performance of this work. Through this analysis, it was noted that the performance of 6LOWPAN was better when compared to RPL. Some drawbacks were observed during the simulation. When the node in the network increases, the performance gets decreased. The authors suggested that these drawbacks observed during the evaluation need to be addressed to improve the performance of the RPL.

From this review, it is clear that the performance of RPL needs to be improved by addressing the problems observed. Many of the drawbacks observed are related to improper analysis and lack of quality aspects.

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Summary of works that have addressed the issues in RPL

The following Table 1.1 summarizes the works found in the literature in which attempts have been made to resolve the above mentioned issues in order to enhance the performance of the RPL protocol. The metrics used to evaluate their performance and the simulators used are also presented.

Table 1.1 Issues addressed to enhance the performance

Author(s)	***Issue addressed***	***Metrics used for analysis of the performance of the proposed work***	***Simulator***
S.B.Gopal et al.[10]	*Energy consumption and mobility*	*Average Power Consumption* *Hops*	*Cooja 3.0*
Ren-Hung Hwang et al. [11]	*energy efficiency of multicast traffic*	*Successful delivery ratio* *All successful delivery ratio* *End-to-end delay* *Energy consumption*	*Cooja simulator*
MarcBarcelo et al. [12]	*Energy consumption*	*Network densities* *Traffic load* *Fairness*	*Matlab*
Ming Zhao et al. [13]	*energy-efficiency and reliability*	*Number of nodes alive* *Number of dead nodes* *Packet delivery ratio (PDR),* *Network lifetime* *Energy consumption of the network* *Energy consumption per data received* *End-to-end delay* *Routing control overhead*	*Cooja and TOSSIM*
Sahar RezagholiLalani et al. [14]	*reliability and energy-efficient communication*	*Packet Delivery Ratio* *Energy Consumption* *Control Packet Overhead*	*Cooja simulator*
Guillermo GastónLorente et al. [15]	*Bidirectionality of Multicast packets*	*radio transmissions,* *energy consumption, and* *higher packet delivery*	*Cooja simulator*
AzadehZamanifar et al. [16]	*power consumption of mobile nodes*	*packet loss,* *cost* *delay,* *success ratio* *power consumption*	*Cooja environment*
Soon-Woong Min et al. [17]	*Mobility*	*Packets reception ratio* *End-to-end packet reception ratio* *End-to-end transmission latency* *Average latency*	*OpenSim*
In`es El Korbi et al. [18]	*Mobility*	*Route stability* *Packet loss rate*	*Cooja simulator*
Hossein Fotouhi et al. [19]	*Mobility management*	*Hand-off delay* *Total packet overhead* *Packet delivery ratio(PDR)* *Memory overhead*	*Cooja simulator*
OlfaGaddour et al. [20]	*Mobility*	*packet loss ratio* *average network latency*	*Cooja simulator*
Muhammad Omer Farooq [21]	*Mobility*	*packet delivery ratio* *per-packet end-to-end delay* *control overhead*	*Cooja simulator*
Emilio Ancillotti et	*Mobility*	*packet loss rates*	*Cooja simulator*

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al. [22]		*Link quality variations and link failures mobility.*	
Muhammad Omer Farooq [23]	*control overhead*	*PDR delay Memory requirement.*	*Cooja and testbed*
Karel Heurtefeux et al.[24]	*Node failure*	*Data Packet Delivery Ratio Control Packet Overhead Number of Update per Minute Average Path Length Average Rank Level*	*sensLAB testbed*
DjamilaBendouda et al.[25]	*fault management*	*packet delivery ratio, control overhead delay*	*COOJA simulator*
OlfaGaddour et al.[26]	*Mobility*	*Delay hops ETX (Expected transmission count) LQL (Link Quality Level).*	*COOJA simulator*
D. R. Ganesh et al.[27]	*Fault Mobility*	*Packet delivery ratio Packet received ratio packet injection rate Packet loss rate End-to-end delay Energy consumption*	*COOJA simulator*
HadjerBouzebiba [28]	*Quality of Service*	*end-to-end delay, throughput, packet delivery ratio energy consumption*	*COOJA simulator*
HananeLamaazi et al.[29]	*Energy average delay*	*network lifetime reliability*	*COOJA simulator*
S.Sankar[30]	*Load Energy Efficiency*	*Average End-to-End Delay Average Packet Loss Ratio Average Remaining Energy Average End-to-End Delay Throughput Network Lifetime*	*COOJA simulator*
FatemehSafara et al.[31]	*Energy efficiency*	*Routing overhead Delay End-to-end delay Energy consumption*	*Network simulator NS2*
Xiyuan Liu et al.[32]	*multi-hop connectivity*	*HOP*	*OMNeT++*
Hyung-Sin Kim et al.[33]	*Load-Balancing Congestion Control*	*Packet delivery performance Routing Overhead HOP*	*TinyRPL*
Sebastian L. Sampayo et al.[34]	*Load-Balancing*	*Lifetime Packet Delivery Ratio Latency Control overhead*	*Cooja simulator*
BaraqGhaleb et al.[35]	*Load-Balancing*	*Reliability network lifetime power consumption*	*Cooja simulator*

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CONCLUSION

Internet of things (IoT) is an innovative and developing technology. More number of IoT devices have been invented and contributed to the society for the use of various applications. RPL is one of the popular routing protocol used in IoT. The main focus of this protocol is routing. Devices are developed are used to helps in transferring data collected from devices in the network. Still, more and more number of devices are being invented to reduce the work of human beings. The main focus of this article is to highlight the issues and challenges of routing protocol for low power and lossy network (RPL) with the belief that the performance of RPL can be improved by addressing these issues. The quality of service is an important factor that plays a major role in the successful functioning of any network even in the case of IoT also. QoS is determined by performance of the service. There are a number of issues that need to be addressed to improve the performance of RPL. In this article, a few important issues and the works that address these issues are summarized. Our future work is to develop the effective techniques to address the drawbacks in these works.

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