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PRIORITY RPL FOR IOT BASED SMART MANUFACTURING INDUSTRIES

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ABSTRACT
A routing protocol used in heterogeneous transport networks for low-power, lossy networks. This is a routing protocol for wireless networks. This protocol follows the same specifications as Zigbee, 6 lopan is IEEE 802.15. 4 Enables both many-to-one and one-to-one communication. To address the need for enhancing in this study proposes a novel methodology called RPL-PG (Routing Protocol for Low-Power and Lossy Networks Priority Generation). Initially sensors like Temperature, Humidity, Vibration, Proximity, Gas and Current Monitoring Sensors are used for smart manufacturing. Consequently, Destination Oriented Directed Acyclic Graph (DODAG) is used for RPL configuration. Based on selected RPL configuration the priority is generated using assign priority count and priority-based queuing. Finally, Fuzzy rules are used to select the RPL path and then update the DODAG finally reached the destination. The study involves setting up a simulated environment using appropriate tools, such as MATLAB. Experimental findings evaluate and compares performance measures, such as Energy Consumption, Network Life Time, Packet Loss Ratio, Packet Delivery Ratio (PDR), E2E Delay, and Network Throughput. The Energy Consumption of the proposed RPL-PG method achieves 43.6 % lower than 38 % and 35.8 % in terms of OMC-RPL and RMA-RP respectively.
Keywords: *Routing Protocol for Low-Power and Lossy Networks, Destination Oriented Directed Acyclic Graph.*

1. Introduction

The Internet of Things (IoT) refers to devices equipped with sensors, computer power, software, and other technology that communicate with other devices and structures over the Internet and various communication networks (Alavikia & Shabro, 2022; Wójcicki et al., 2022). Electronics, communications, and computer science are all part of the Internet of Things (Yudidharma et al., 2023). The name "Internet of Things" is regarded a misnomer because gadgets do not need to be linked to the public Internet, only to a network and be individually addressable (Alsulaimani & Islam, 2022). The IoT refers to the network of physical devices, vehicles, home appliances, and other objects embedded with sensors, software, and connectivity that enables these objects to connect and exchange data (Fekete & Kiss, 2023; Kim et al., 2022). This technology allows for increased automation, improved efficiency, and enhanced connectivity between various devices (Qamar, 2023). IoT has revolutionized various industries, including manufacturing, healthcare, transportation, and smart homes (Celik et al., 2022). It enables seamless integration and communication between devices, allowing for real-time monitoring and control of systems and processes (Bouzidi et al., 2022). A routing system called RPL (Routing system for Low-Power and Lossy Networks) was created for low-power wireless networks that suffer from packet loss (Ullah et al., 2022). It is an active protocol that uses IEEE 802.15.4 and is designed for multi-hop and many-to-one communication, while it can also support one-to-one messaging (Arshad et al., 2022; Tyagi et al., 2022a). RPL may handle a variety of connection layers, including limited link layers, possibly lossy link layers, and link layers used in resource-constrained devices (Behnke et al., 2023). The protocol can establish network routes quickly, communicate routing knowledge, and coordinate topologies efficiently (Wang et al. 2023a). A routing system for Low Power and Lossy Networks (LLN) is a protocol that enables efficient data transmission in these types of networks (Mazloom et al., 2023). These networks are characterized by high node density, limited processing power, and low transmission power (Manikandan et al., 2023; Huang et al., 2023). To overcome these challenges, LLN routing protocols use techniques like power conservation, simplified routing algorithms, and multi-path redundancy to ensure efficient communication between nodes (Kanellopoulos et al., 2023; Al-Hilfi, 2023). Some examples of LLN routing protocols include Ad-hoc On-Demand Distance Vector (AODV), Optimized Link State Routing (OLSR), and Low-Power and Low-Loss Routing (LLLR) (Mezher et al., 2023; Yun et al., 2023).

RPL (Resource-Constrained Budget Low-power IPv6 Optimization) is an IPv6 protocol designed specifically for low-power and low-resource devices such as IoT devices (EST, 2023; Babu et al., 2023). It is used to optimize network performance and battery life by removing unnecessary overhead and requirements from the IPv6 protocol (Feijoo-Añazco et al., 2023; Chappala et al., 2023). RPL allows devices to negotiate their own network settings, and it uses adaptive messaging to minimize the amount of data sent over the network (Ashrif et al., 2023). RPL produces tree-like topologies (Urke et al., 2023). Each network node is assigned a rating that increases as the team moves away from the root node (DODAG) (Wang et al., 2023b). Packets are retransmitted by the node using the minimum range as route selection criteria (Asha & Srivatsa, 2022). A priority list is a collection of priority queue specifications. A priority list determines which queue a packet is assigned to and the maximum length of each queue (Tyagi et al., 2022b). To use a priority list for queuing, it must be assigned to an interface. Multiple interfaces can use the same priority list. You can also create separate priority policies and apply them to different interfaces (Karmakonda et al., 2023). The major contribution of the work has been followed by;

- Initially sensors like Temperature, Humidity, Vibration, Proximity, Gas and Current Monitoring Sensors are used for smart manufacturing.
- Consequently, Destination Oriented Directed Acyclic Graph (DODAG) is used for RPL configuration. Based on selected RPL configuration the priority is generated using assign priority count and priority-based queuing.
- Finally, Fuzzy rules are used to select the RPL path and then update the DODAG finally reached the destination.
- Experimental findings evaluate and compares performance measures, such as Energy Consumption, Network Life Time, Packet Loss Ratio, Packet Delivery Ratio (PDR), E2E Delay, and Network Throughput.

2. Literature Review

In (Mubeen et al., 2017) investigated an initial model to investigate the potential for IoT device to interact with a cloud-based controller aimed at the automation sector. However, they primarily use mitigation strategies to address communication delays brought on by networks, ignoring compute delays and cloud server capacities. Additionally, no specific mathematical model was used to analyze the mitigation system.

In (Zhou et al., 2017) presented a study where they develop a precise formulation for evaluating the performance of IIoT systems by integrating computational capabilities with intelligent features. They create a realistic method for obtaining a threshold by estimating the effectiveness of various computing approaches, and they demonstrate ways to use it in real-world IIoT scenarios. However, the authors fail to account for data synchronization and transmission delays, particularly when using distributed computing.

In (Capone et al., 2014) offered an energy-efficient and trustworthy composite measure for RPL structured network was put forth. To choose the best approach, the suggested composite measure considers the energy efficiency and reliability criteria. Expected transmission count (ETX), a link statistic, is used to take reliability into account. Additionally, the network may have frequent parent changes as a result of the congestion alleviation procedure, which makes the network unstable and unsuitable for an IIoT network used for emergency monitoring.

In (Alishahi et al., 2018) suggested an optimized multi-class RPL (OMC-RPL) variant of the RPL protocol. Developing the upgraded OF using a composite routing metrics was the main goal of OMC-RPL. In order to enable multi-class traffic, it combines four weighted metrics utilizing software-defined networking (SDN) approaches. With the aid of the particle swarm optimization technique, the weights of the metric are established. Out of the four measures, the energy metrics is regarded as a supplemental (optional) metric and is thus applied when necessary. Although the OMC-RPL takes into consideration a variety of indicators, notably the energy consumption variable, this virtualized implementation of RPL might not satisfy the needs of the IIoT applications since it restricts the nodes' energy profiles.

In (Murali & Jamalipour, 2018) has suggested an innovative mobility-aware and energy-efficient parent selection strategy for LLNs. Based on many routing indicators, including ETX, predicted lifespan, the received signal strength indicator (RSSI), and length between the mobile node and the parent node, the parent selection algorithm chooses the best parent. The authors also suggested dynamic Trickle, an improved variation of the Trickle timer. This approach of choosing a parent primarily addresses the problem of moving between a single parent to another because of mobility.

In (Farag et al., 2019) suggested RMA-RP a dependable mobility-aware routing system for dynamic IIoT frameworks. They address the challenge of intermittent connectivity caused by the movement of mobile sensor nodes in industrial automation scenarios. RPL is an energy-saving and dependable routing system for static networks, however it is unable to handle routing in dynamic IIoT systems. Simulation results demonstrate that RMA-RP outperforms existing approaches, achieving higher packet delivery ratio and significant reductions in delay and network overhead.

In (Onwuegbuzie et al., 2020) recommended an SPPB-RPL (Shortest Path Priority-based RPL). Not only does the SPPB-RPL scheme route data with varying priorities, but it also optimizes network performance. Its application on a smart campus is given as an example. The class of service (CS) method is used to categorize and prioritize data into separate priority classes. The standard RPL DIO base object was then extended to handle the prioritized data classes, and the Dijkstra Algorithm (DA) was used to construct the optimal shortest routing path going to the destination node, guided by the data's priority. When compared to other schemes, SPPB-RPL performed the best, with a packet delivery ratio of 99.98% and the lowest latency.

In (Mishra & Khatua, 2023) offers a reliable and delay-efficient multi-path RPL (RDMP-RPL) that maximizes both reliability and delay. While calculating dependability, it takes buffer and channel loss probability into account. It incorporates queueing and network delays when calculating delays. Furthermore, the protocol proposes a way for selecting backup parents to fulfill end-to-end latency criteria. The results show that RDMP-RPL maintains a packet delivery ratio (PDR) of at least 99% and an end-to-end delay (EED) of no more than one second for a packet to reach the destination from any of the source nodes for grid topology. However, given random topologies, the number of hops might surpass 5. In circumstances where the traffic rate, mobility, and number of nodes exceed a certain threshold, RDMP-RPL cannot meet the rigorous criteria.

2.2. Research Gap

By analyzing the literature in detail, the following research gaps were identified related to the proposed research problem:

- Although, several advancements are made in priority RPL, IOT faces a number of Challenges identified are lack of ontological knowledge of what counts as RPL, how it is assessed and its validity and integrity. The data reveal high demands regarding training on issues of assessment and raising awareness of RPL at the institution.
- Most of the articled focused only on energy- efficient routing, including single-hop and multi-hop routing and very few articles include the security while transmitting the data in routing.

3. Research Methods

In this section, a novel methodology called RPL-PG (Routing Protocol for Low-Power and Lossy Networks Priority Generation). Initially sensors like Temperature, Humidity, Vibration, Proximity, Gas and Current Monitoring Sensors are used for smart manufacturing. Consequently, Destination Oriented Directed Acyclic Graph (DODAG) is used for RPL configuration. Based on selected RPL configuration the priority is generated using assign priority count and priority-based queuing. Finally, Fuzzy rules are used to select the RPL path and then update the DODAG finally reached the destination.

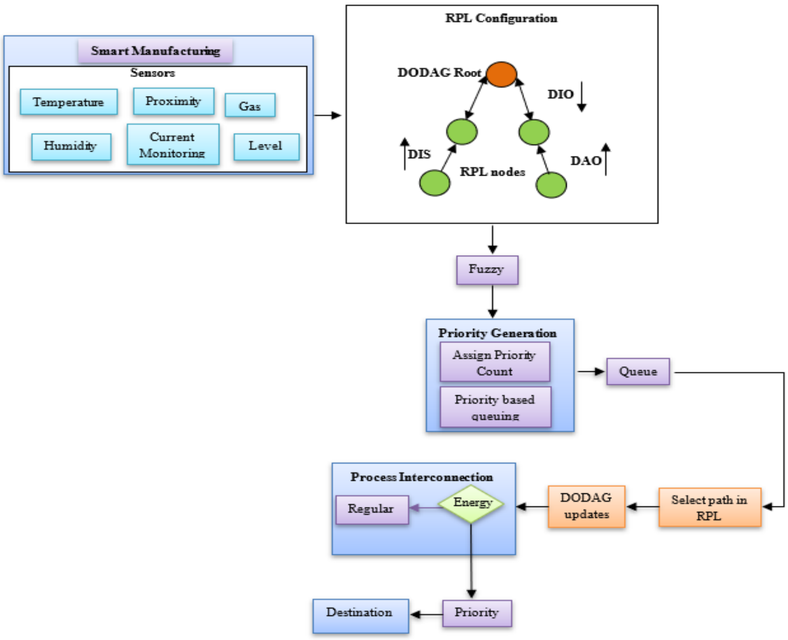

Fig. 1. Proposed RPL-PG

3.1 Sensors

A sensor is a piece of electrical equipment that generates an output signal to identify actual occurrences. In general, a sensor is a device, module, machine, or subsystem that monitors environmental changes or detects events and transmits that data to other electronic devices, most frequently a computer processor.

3.1.1 Temperature Sensor

A device for sensing temperature is a temperature sensor. This might refer to the temperature of the air, a liquid, or a solid material. There are several sorts of temperature sensors, and each one measures temperature using a particular set of methods and tenets.

3.1.2 Humidity Sensor

A humidity sensor is a device that detects, measures, and reports air's relative humidity (RH) or the quantity of water vapour present in a gas mixture (air) or pure gas. Moisture measurements are connected to moisture adsorption and desorption processes.

3.1.3 Vibration Sensor

Vibration sensors or vibration detectors monitor machine vibration levels for inspection and analysis. Maintenance personnel utilise industrial vibration sensors to monitor conditions and determine the strength and frequency of vibration signals. In the oil and gas business, vibration sensors for surveillance applications are used to monitor engines, crucial pumps, fans, gearboxes and compressors.

3.1.4 Gas Sensor

A gas sensor is a gadget that helps us understand the amount of gas in the environment and how it moves naturally. Gas sensors employ electrical impulses to detect and show changes in the amount and type of gas composition in the environment.

3.1.5 Proximity Sensor

"Proximity sensors" refer to sensors that detect items without making physical touch, as opposed to sensors like limit switches that need physical contact to do so. Object movement and presence data are converted into electrical impulses using proximity sensors.

3.1.6 Current Mointoring sensor

A level sensor is a component that measures the level of a tank or vessel in fluid control systems. It is capable of measuring levels in a wide range of free-flowing media, powdered solids, including liquids, and granular solids.

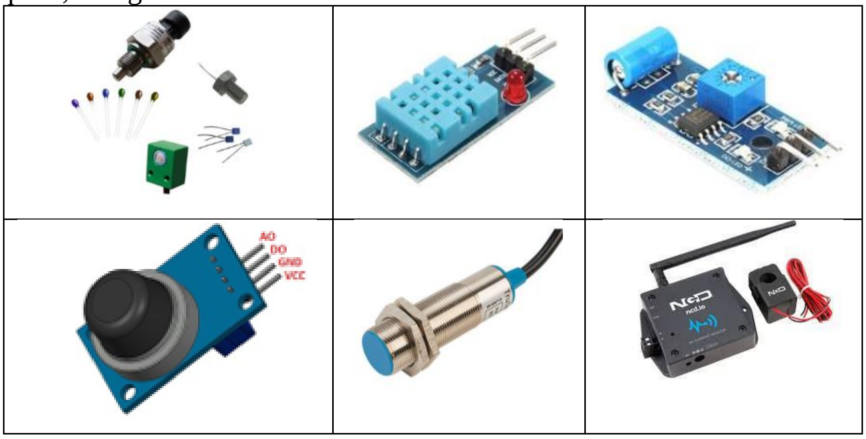

Fig. 2. IoT smart Monitoring Sensors

3.2 RPL Configuration

A prominent routing system known as RPL was specifically designed for low-power and lossy networks, as those found in IIoT deployments. It enables efficient communication between resource-constrained entities with constrained power, memory, and computational capabilities. RPL establishes a network topology and routes packets through a multi-hop mesh network, in order to optimize energy usage and reduce the loss of packets. The LLN is formed as a Destination Oriented Directed Acyclic Graph (DODAG) by the distance-vector routing protocol RPL. A DODAG structure is made by extending the Directed Acyclic Graph (DAG) utilized in RPL. One sink node, the DODAG root, is the final destination of all data. Each node's distance from the DODAG root is indicated by an integer called RANK. The DODAG root has the lowest RANK, with RANK strictly increasing in the downward direction and strictly decreasing in the upward direction. The Objective Function (OF) specifies the process to calculate the RANK and integrate several criteria to construct the communication channels. RPL uses Trickle Algorithm to construct the DODAG by exchanging DIO (DODAG Information Object) messages. These messages contain information about the node's rank, preferred parent, and other relevant DODAG parameters. To facilitate the downstream RPL traffic, DAO propagates the destination data towards the source. Figure 7 illustrates the RPL control messages

Algorithm.1 RPL-based Emergency Priority Protocol

// Initialization
Initialize RPL parameters
Initialize emergency priority protocol parameters
// RPL Configuration
Construct DODAG structure using RPL
Set objective function for route selection
// **Emergency Priority Protocol Configuration**
Assign priority levels to emergency messages
Set up priority-based queuing mechanism
// Main Loop
while (network is active) {
// Data Generation
Generate regular data packets
Generate emergency data packets
// **Packet Routing**
for each data packet {
if (packet is emergency) {
Apply emergency priority mechanisms
Select highest priority path using RPL

Forward the emergency packet along the selected path
} else {
Apply regular routing mechanisms
Select path using RPL based on objective function
Forward the regular packet along the selected path
}
}
// **Update DODAG**
if (DODAG needs update) {
Update DODAG based on network changes
Broadcast DIO messages to propagate changes
}
// **Process Incoming Packets**
for each received packet {
if (packet is emergency) {
Process emergency packet with priority handling
} else {
Process regular packet with regular data handling
}
}

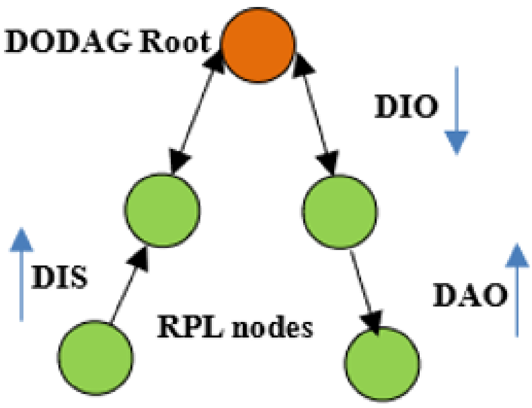

Fig. 3. RPL Configuration

By integrating the emergency priority protocol with the RPL routing protocol stack, emergency messages can be given higher priority, bypassing regular data traffic for immediate attention. Once integrated, the emergency priority protocol employs various techniques to prioritize and expedite emergency messages. Priority-based queuing separates emergency messages into dedicated queues, giving them preferential treatment during forwarding, even in congested network conditions. This ensures prompt delivery of emergency data. Moreover, the combination utilizes mechanisms like route optimization and path redundancy to ensure reliable and robust communication during emergencies. It dynamically adjusts routing paths to avoid congested or unreliable links, enabling the real-time delivery of data to emergency responders or critical systems.

3.2.1 Priority RPL

RPL is the distance vector routing protocol that underpins DODAG, as well as many other characteristics such as control traffic limitation and local repair. The RPL design allows each node to employ her DODAG recognition, construction, and maintenance in a customizable manner. Figure 4 illustrates the Routing using Priority RPL.

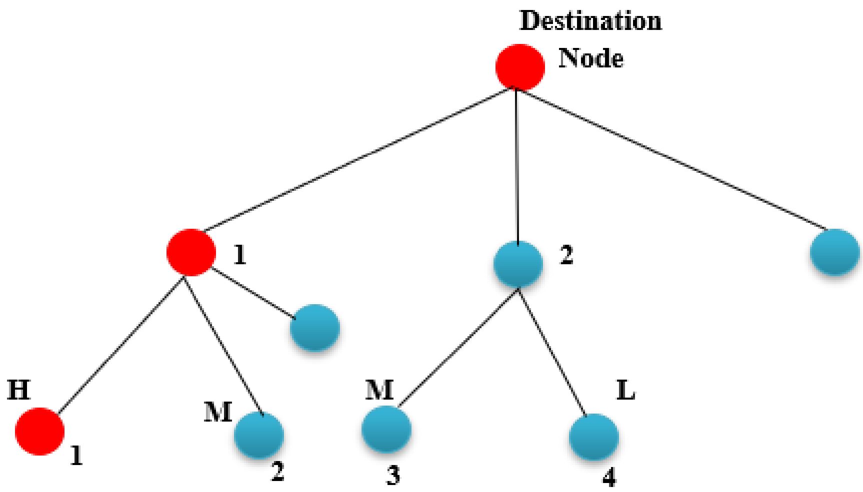

Fig. 4. Routing using Priority RPL

Figure 3 depicts the priority RPL Fuzzy rules initially classify three inputs: traffic, data value, and queue length. Priority determined by fuzzy output, such as High, Medium, or Low. A red node in the fuzzy output implies a higher priority.

3.3 Fuzzification

The process by which the input values are transformed into the fuzzified values is known as "fuzzification." This system might function in two different ways. Let's assume that f_s is the Fuzzy singleton, which can be expressed as,

$$f_s(d) = \begin{cases} 1 & if\ d = s \\ 0 & otherwise \end{cases}$$

Also, if F_s is Fuzzy set, then,

$$\mu_{f_s} = \begin{cases} 1 & if\ d = s \\ decrease\ from\ 1 & when\ moving\ from\ s \end{cases}$$

Table 1 - Variables With A Variety Of Inputs And Outputs

Fuzzification Input: Traffic (T)		
Value	Notation	Range
Small	S	0.0-0.5
Medium	M	0.25-0.4
High	H	0.45-1
Fuzzification Input: Data Value (DV)		
Value	Notation	Range
Less	Le	0.0-0.5
Average	Av	0.25-0.85
More	Mo	0.45-0.1
Fuzzification Input: Queue Length (QL)		
Value	Notation	Range
Long	Lo	0.0-0.5
Middle	Mid	0.3-0.7
Short	S	0.45-1
Output variable: Node Priority		
Low	L	0-0.5
Medium	M	0.25-0.75
High	H	0.5-1

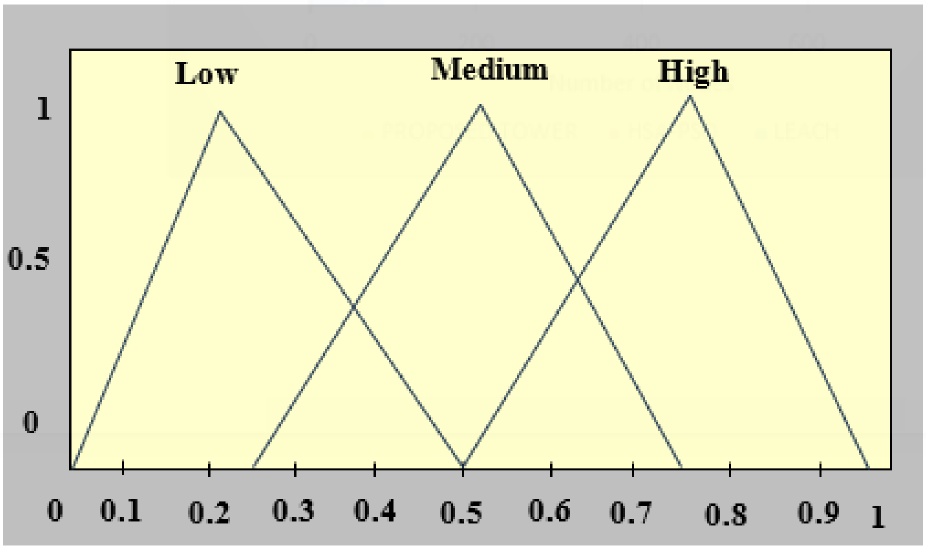

Fig. 5. Output Of Gaussian Membership Function

Each fuzzy set has a MF that establishes the level of membership for a specific value within the fuzzy set. In fuzzy sets, several shapes can be found. Because they can frequently provide an accurate representation of the expert knowledge while also considerably simplifying the computing process, gaussian are utilized as MF's. Figure 5. shows how the inputs and outputs can be represented using MF.

3.1.2 Inference Engine

The popular and extensively used inference engine known as Mamdani type inference is chosen. For inference engines, the basic rule is,

IF x is A and y is B THEN z is C

There are two inputs present here. The least membership degree of the input parameters will be the output in this sort of scenario. In the inference system, we have created a fuzzy-based IF-THEN rule that may be stated as,

IF Residual Energy is {Low, High} AND Centrality of Node is {Near, Far} THEN the Probability is {Maximum, Minimum}

The rule-based lock has been generated in accordance with the IF-THEN rule is shown in table 2.

Table 2 - Some of The Examples For Mamdani Fuzzy Inference Rule

1.	If (T=S) & (DV=S) & (QL=S) = (P=Min)
2.	If (T=M) & (DV= M) & (QL= M) = (P= Avg)
3.	If (T=H) & (DV= H) & (QL= H) = (P=Min)
4.	If (DV=Le) & (T=Le) & (QL=Le) = (P=Min)
5.	If (DV=Av) & (T=Av) & (QL=Av) = (P=Min)
6.	If (DV=Mo) & (T= Mo) & (QL= Mo) = (P=Min)
7.	If (QL=Lo) & (DV= Lo) & (T= Lo) = (P=Min)
8.	If (QL=Mid) & (DV= Mid) & (T= Mid o) = (P=Min)
9.	If (QL=S) & (DV= S) & (T= S) = (P=Min)

4. Results and Discussions

In this study proposes a novel methodology called RPL-PG (Routing Protocol for Low-Power and Lossy Networks Priority Generation). The study involves setting up a simulated environment using appropriate tools, such as MATLAB. The study evaluates and compares performance measures, such as Packet Loss Ratio, Packet Delivery Ratio (PDR), E2E Delay, and Network Throughput. The effectiveness of the provided model is evaluated from many angles.

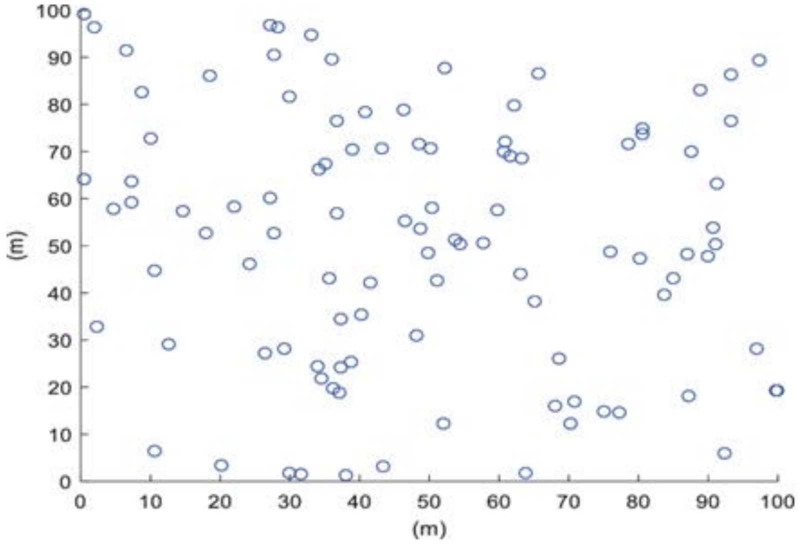

Fig. 6. Deployment Of Nodes

The simulation time is set to 1000 seconds to capture a sufficient duration for data collection and analysis. In this simulated environment, the nodes communicate with each other using a transmission range of 50 meters, ensuring connectivity within the facility. The deployment area is defined as 100m x 100m, reflecting the physical space of the smart manufacturing facility in which nodes are deployed as shown in figure 6.

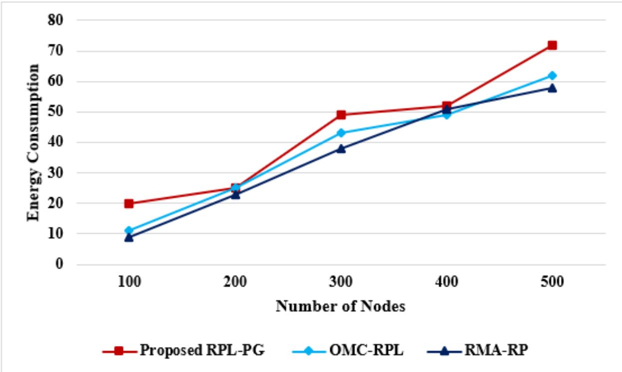

Fig. 7. Comparison Of Energy Consumption

Figure 7 illustrates the Comparison of Energy Consumption the overall amount of power used by the device to transmit the packet is known as power consumption. The energy consumption is shown in equation (3),

$E_c = \sum_{x=1}^{N} E_{x,P}$

Here, $E_{x,P}$ is a representation of Network X's overall energy consumption, after P rounds of collecting information, and N stands for the number of networks. Figure 10. Depicts the comparison of energy consumption with existing techniques.

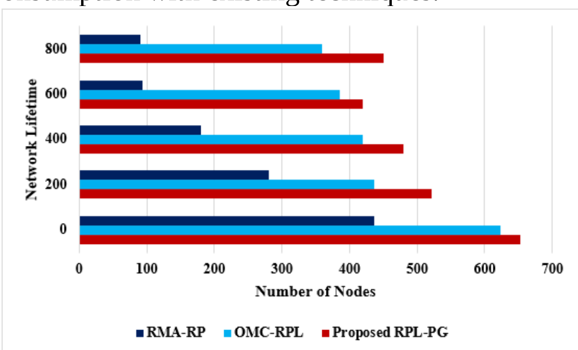

Fig. 8. Comparison of Network Lifetime

A network's lifetime is the amount of time it is operational and able to carry out specific tasks. It is the amount of time left until the initial device or monitoring cluster in a system runs out of power. Figure 8 compares the network longevity with existing methods. It is described as the length of time sensor networks in a WSN devote to sensing.

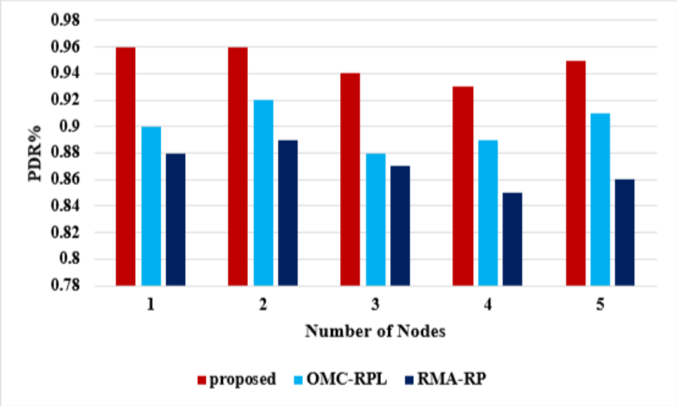

Fig. 9. PDR% Versus The Number Of Nodes

The proposed methodology ensures their preferential treatment and timely delivery, resulting in a higher PDR. This prioritization ensures that emergency packets receive preferential treatment, reducing the chances of packet loss and improving the overall PDR. The limited routing mechanisms of AERP and QoSIoT struggle to handle the increased traffic and find optimal paths for data transmission. As a result, some packets may experience delays, congestion, or even loss, leading to lower PDR values as shown in figure 9.

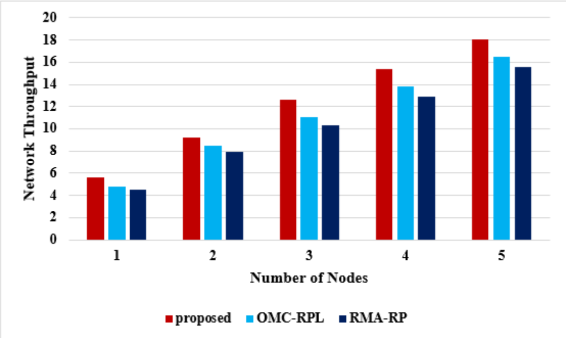

Fig.10. Network Throughput Vs Number Of Nodes

The quantity of data sent through a network in an allotted period of time is denoted as network throughput. The network may encounter higher traffic and potential bottlenecks as the number of nodes rises. The integration of RPL in R3E-RPL optimizes the routing paths for regular data packets. This optimization improves the efficiency of data transmission, reducing bottlenecks and enhancing network throughput compared to the existing protocols as shown in figure 10.

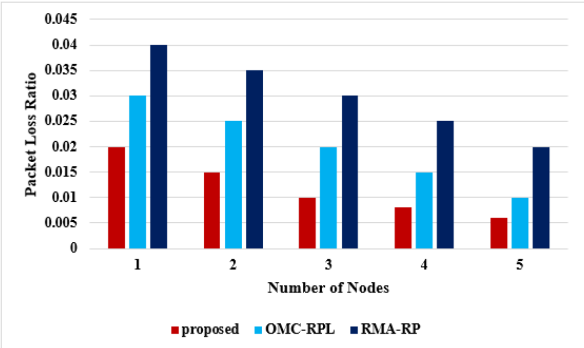

Fig.11. Packet Loss Ratio Versus Number Of Nodes

Packet Loss Ratio (PLR) measures the percentage of lost or dropped packets in a network transmission. By assigning higher priority levels to emergency packets, R3E-RPL ensures that these time-sensitive messages are transmitted with minimal loss, reducing the packet loss ratio as shown in figure 11.

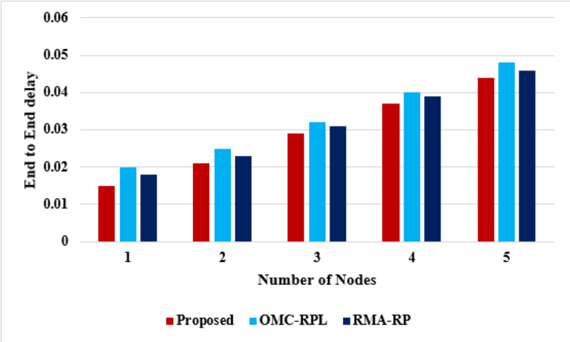

Fig. 12. E2E Delay Versus Number Of Nodes

A performance statistic called E2E delay calculates how long it takes a packet of data in a network to travel between a particular node to the next. The network may encounter more congestion and longer routing paths as the number of nodes rises, leading to potential delays. Analyzing E2E delay with different numbers of nodes helps assess the influence of network size on the timeliness of data delivery. In Figure 12 illustrates the E2E delay versus Number of nodes.

Table 3 - Comparison Between Proposed and The Existing Methods

Authors	Methods	Accuracy (%)
[36] Alishahi, M.,	OMC-RPL	38
[38] Farag, H.,	RMA-RP	35.8
Proposed	RPL-PG	43.6

Table 3 compares proposed method with other existing methods. The proposed RPL-PG achieves 43.6 % of Energy Consumption, that is better than the existing method.

5. Conclusion

In this section proposed a novel methodology called RPL-PG (Routing Protocol for Low-Power and Lossy Networks Priority Generation). Initially sensors like Temperature, Humidity, Vibration, Proximity, Gas and Current Monitoring Sensors are used for smart manufacturing. Consequently, Destination Oriented Directed Acyclic Graph (DODAG) is used for RPL configuration. Based on selected RPL configuration the priority is generated using assign priority count and priority-based queuing. Finally, Fuzzy rules are used to select the RPL path and then update the DODAG finally reached the destination. The study involves setting up a simulated environment using appropriate tools, such as MATLAB. Experimental findings evaluate and compares performance measures, such as Energy Consumption, Network Life Time, Packet Loss Ratio, Packet Delivery Ratio (PDR), E2E Delay, and Network Throughput. The Energy Consumption of the proposed RPL-PG method achieves 43.6 % lower than 38 % and 35.8 % in terms of OMC-RPL and RMA-RP respectively. In the future, RPL-PG can be developed to enable mobile network scenarios and expanded to provide routing to multiple sinks

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