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Synergistic Integration of LPWAN technology and Edge Computing: Enhancing IoT Applications for Real-time Analytics and Low-Latency

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Abstract

The integration of Low-Power Wide Area Network (LPWAN) and Edge Computing presents a promising approach for enhancing Internet of Things (IoT) applications, specifically by enabling real-time analytics and low-latency processing. This research paper aims to investigate the synergistic integration of LPWAN and Edge Computing and its impact on IoT applications. Through a thorough analysis of existing literature, case studies, and experimental evaluations, the study explores the benefits, challenges, and implementation strategies associated with this integration. The findings emphasize the potential for improved performance, scalability, and efficiency in IoT deployments. Valuable insights and recommendations are provided to effectively leverage the synergies between LPWAN and Edge Computing, unlocking the full potential of real-time analytics and low-latency processing in IoT applications.

Keywords: LPWAN, Edge Computing, IoT applications, real-time analytics, low-latency

Introduction

The growth of Internet of Things (IoT) devices has revolutionized various industries, generating vast amounts of data that require efficient handling and processing. To obtain full potential of IoT applications, there is a need for seamless connectivity and real-time analytics capabilities. In this context, the integration of Low-Power Wide Area Network (LPWAN) with Edge Computing has emerged as a compelling solution. LPWAN technologies provide long-range, low-power connectivity, while Edge Computing brings computational power and analytics closer to the data source. IoT applications can benefit greatly from the combination of LPWAN and Edge Computing. Organisations may increase data processing rates, decrease latency, and improve scalability by combining the extensive coverage and energy efficiency of LPWAN with the localised processing and real-time analytics capabilities of Edge Computing. In applications like industrial automation, smart cities, and remote asset monitoring, where real-time decision-making and low-latency reaction times are essential, this connection is especially beneficial. Over the past ten years, LPWAN have undergone substantial research, leading to the development of numerous LPWAN-related protocols [1]-[5]. With respect to the big data produced by the exponentially growing number of connected devices, new computational paradigms, such edge computing, have been used to create system architectures [6].

There are several difficulties when LPWAN and Edge Computing are combined, though. These include managing resource allocation at the edge, tackling the complexities of heterogeneous networks, protecting data security and privacy, and streamlining data transfer between LPWAN devices and edge servers. It takes careful design, strong architectures, and effective protocols to overcome these obstacles. This research paper focuses on exploring the integration of LPWAN with Edge Computing and its implications for IoT applications.

The significance of integrating LPWAN and Edge Computing for IoT applications

- Real-time analytics: By bringing computation closer to the edge devices, LPWAN and Edge Computing integration enable real-time data analysis and decision-making.
- Low-latency processing: By lowering latency through data processing at the edge, time-sensitive applications may respond faster and take action when it is needed.
- Scalability and bandwidth optimization: The integration of LPWAN with Edge Computing enables distributed data processing, improving both scalability and bandwidth efficiency.
- Reduced network traffic and cost: Edge processing reduces unnecessary data transmission, minimizing network traffic and associated costs.
- Improved reliability and resilience: The integration enhances reliability by enabling edge devices to continue processing data even during network disruptions, ensuring uninterrupted operation.

There are still a number of gaps and restrictions that need to be filled in the integration of LPWAN and Edge Computing for IoT applications. The necessity for standardization to guarantee interoperability between various LPWAN technologies and Edge Computing frameworks is one of these. Data integrity and authentication are also significant areas of study for security and privacy issues. Furthermore, ensuring cost-effectiveness while installing the integrated system and optimizing resource allocation in edge devices with limited resources present difficulties. The successful implementation and utilization of LPWAN and Edge Computing integration in IoT applications will be facilitated by streamlining system design, establishing assessment criteria, and addressing these gaps.

LOW POWER WIDE AREA NETWORKS

The field of Internet of Things (IoT) applications has seen a substantial traction in Low-Power Wide Area Network (LPWAN) technologies. The various LPWAN technologies, such as LoRaWAN, NB-IoT, and Sigfox, are discussed in this section, with an emphasis on their key traits, advantages, and application cases. The emphasis is on how LPWAN offers long-range, low-power communication, making it a great option for Internet of Things (IoT) devices across a variety of industries.

- LoRaWAN: Long Range Wide Area Network makes use of chirp spread spectrum modulation. It has a great range that enables IoT devices to communicate over distances of many kilometres, even in populated areas. LoRaWAN offers IoT applications cost-effective deployment choices because it uses unlicensed spectrum. It is suited for a variety of use applications, including smart agriculture, asset tracking, and smart cities, because to its low power consumption and scalability [2].
- NB-IoT: Narrowband IoT is a 3GPP-standard cellular LPWAN technology. It uses licenced spectrum, enhancing security and dependability. Deep indoor coverage and increased battery life made by NB-IoT make it perfect for applications like smart metering, industrial monitoring, and logistics that need dependable connectivity in difficult settings.
- Sigfox: Another LPWAN solution that uses unlicensed spectrum is Sigfox. It makes use of ultra-narrowband technology, which offers outstanding energy economy and long-distance communication. Sigfox is best suited for low-cost, low-data-rate applications including supply chain management, asset tracking, and environmental monitoring [3].

- **LPWAN Benefits for IoT Connectivity**
- Long-range coverage: LPWAN makes it possible to communicate across great distances, expanding the potential of IoT applications.
- Low power usage: LPWAN devices can run for years on batteries, reducing the requirement for routine maintenance or a power source.
- Cost-effectiveness: When compared to conventional cellular networks, LPWAN technologies offer affordable connectivity solutions.
- Scalability: LPWAN networks are suited for extensive IoT installations since they can support a high number of devices.

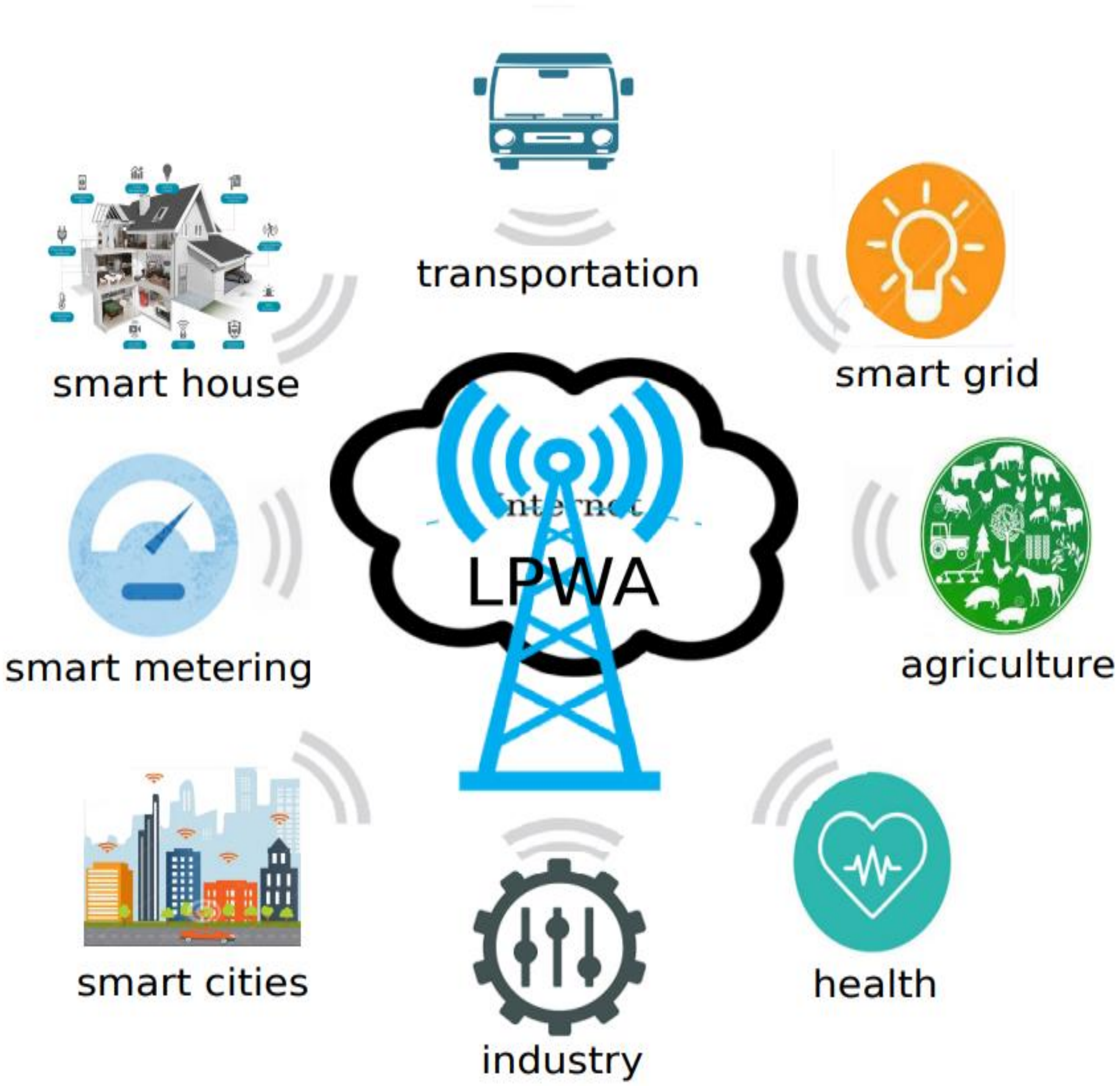

Figure 1: Use cases of LPWAN technologies [9]

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LPWAN Technology	Range	Data Rate	Power Consumption	Use Cases
LoRaWAN	Long	Low	Low	Smart cities, asset tracking, environmental monitoring
NB-IoT	Moderate	Moderate	Low	Smart metering, industrial monitoring, agriculture
Sigfox	Global	Low	Ultra-low	Asset tracking, supply chain management, security
Weightless	Long	High	Low	Smart cities, industrial automation, transportation
LTE-M	Wide	High	Moderate	Smart agriculture, healthcare, asset tracking

Table 1: Comparison of different LPWAN technologies

EDGE COMPUTING

Edge computing is the decentralised processing and data storing that takes place at or close to the network edge. It tries to lessen reliance on centralised cloud infrastructure, network traffic, and latency. Edge nodes, edge analytics, and edge devices are important ideas. Edge nodes are computational units that process and analyse data at the edge, whereas edge devices are IoT devices or sensors that generate data. Edge analytics includes making decisions and conducting data analysis closer to the data source.

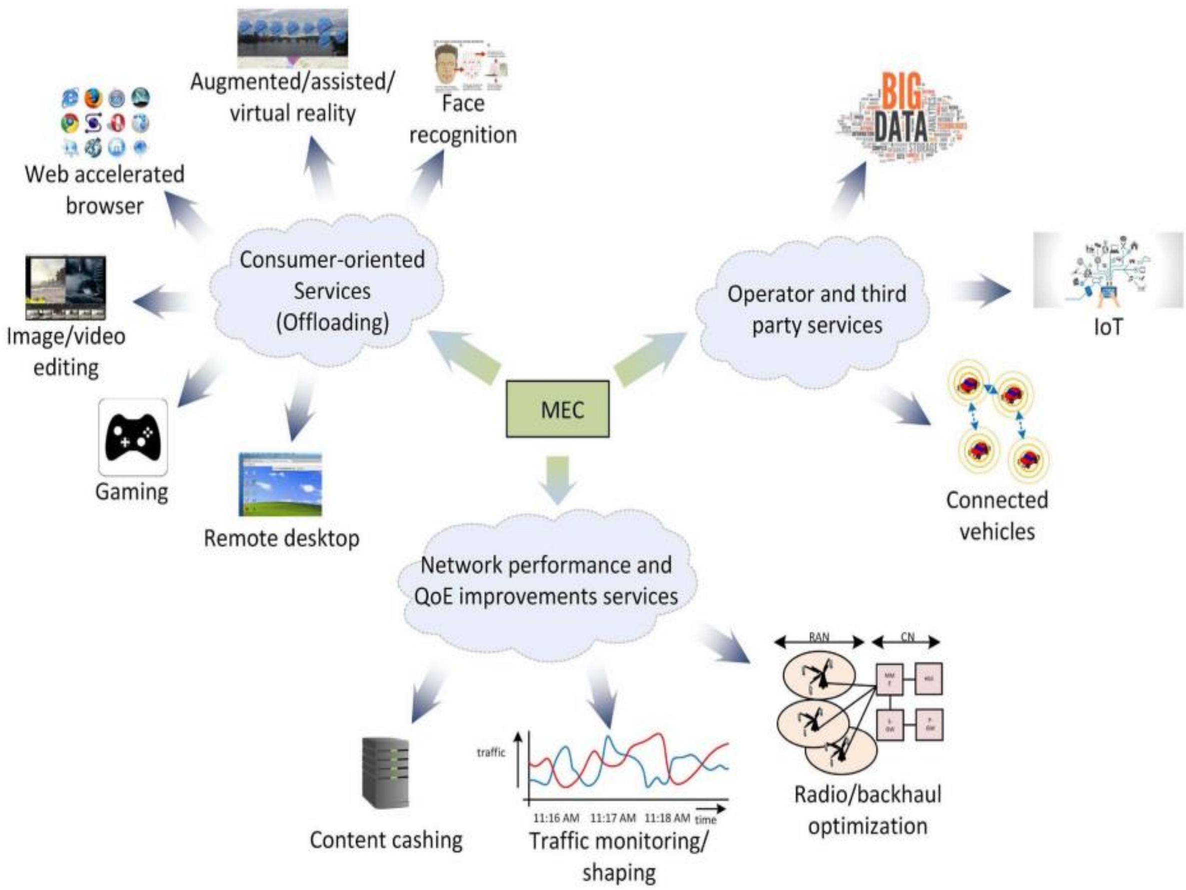

Figure 2: Used Cases of MEC Architecture [8]

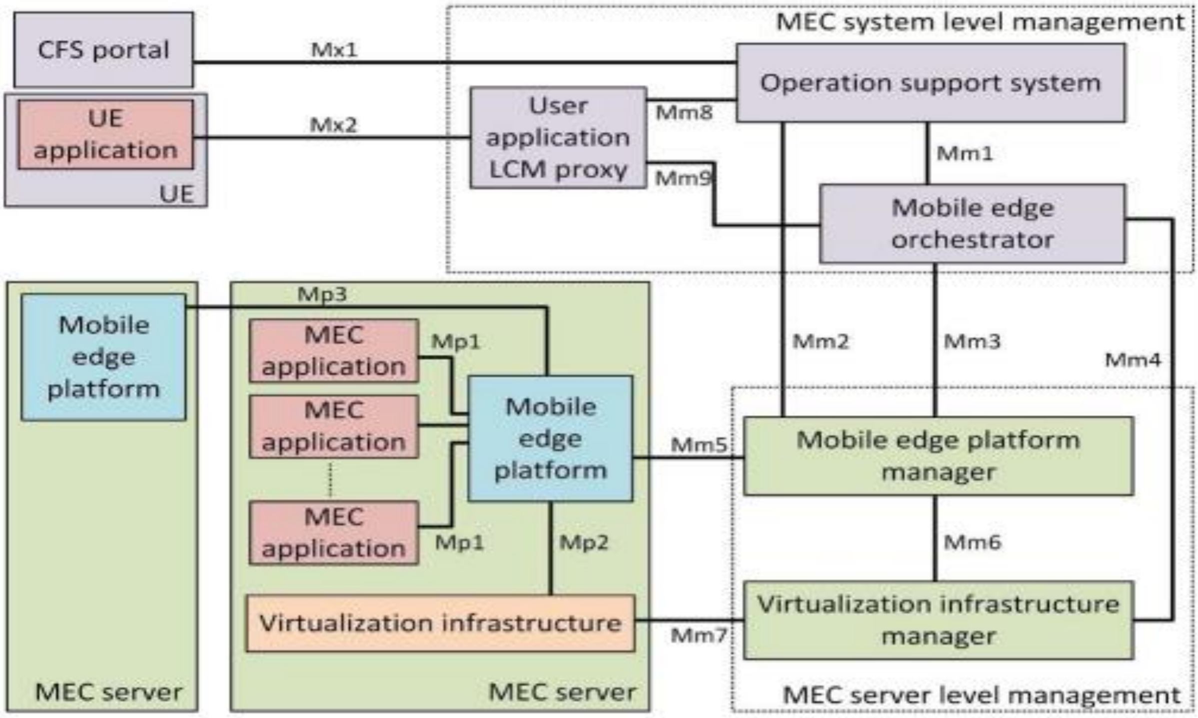

Figure 3: Mobile edge computing reference architecture [8]

❖ **Advantages of Edge Computing**

- Reduced latency: Edge Computing reduces the latency associated with delivering data to distant cloud servers by processing data closer to the edge devices. Faster response times are made possible by this, making it perfect for time-sensitive applications like industrial automation and driverless vehicles.
- Real-time analytics: By processing data locally, edge computing enables real-time data analysis and decision-making. As a result, operational efficiency is increased, and real-time analytics are made possible for a variety of applications.
- Bandwidth optimisation: By performing data filtering and aggregation at the edge, edge computing lowers the amount of data transported to the cloud. Through this optimisation, network traffic is decreased, capacity utilisation is increased, and data transfer costs are decreased.

❖ **Edge Computing Architectures and Technologies**

- Fog computing: Fog computing provides resources for data processing, storage, and analytics by extending the cloud computing paradigm to the network edge. It seeks to assist real-time data analysis and decision-making and low-latency applications.
- Mobile Edge Computing (MEC): MEC incorporates computing resources within the framework of the mobile network. As a result, latency is reduced and novel edge-based use cases are made possible. It permits the execution of applications and services at the mobile network's edge [8].
- Edge AI: Edge AI combines capabilities of Artificial Intelligence (AI) with Edge Computing. It allows for the execution of AI models and data processing at the edge, boosting the effectiveness of AI-driven applications and enabling intelligent decision-making in real-time.

Integration of LPWAN and Edge Computing

In IoT applications, LPWAN and Edge Computing demonstrate synergistic properties that make them very complementary. Long-range, low-power connectivity offered by LPWAN makes it possible for IoT devices and the network infrastructure to communicate without interruption. Contrarily, edge computing enables real-time analytics and low-latency processing by bringing computation and data processing closer to the edge devices. The combination of LPWAN with Edge Computing builds on each technology's advantages and creates a robust and effective IoT ecosystem.

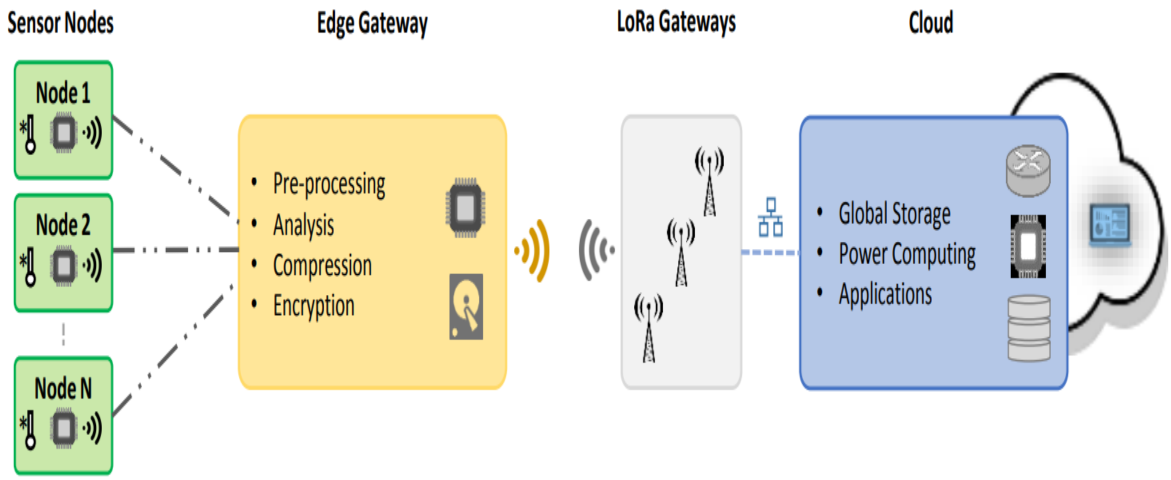

Figure 4: Architecture with integration of Edge Computing [7]

The additional layer of Edge-assisted gateway proposed the architecture. In more detail, sensor nodes can gather various data and send it to an Edge-assisted gateway through Bluetooth Low Energy (BLE), nRF, or IPv6 via Low-Power Wireless Personal Area Networks (6LoWPAN). The Edge-assisted gateway frequently has high-computation hardware, is permanently installed, and runs on socket power or a sizable battery [7]. As a result, the Edge-assisted gateway may run complicated algorithms while continuing to function for a long time. These protocols have a theoretical maximum data rate of 250 kbps and a practical maximum of 150 kbps [10]-[11], while using only about 70 mW of electricity. Therefore, these are appropriate for high data rate applications like ECG monitoring. Extra hardware modules (such as nRF, 6LoWPAN, or BLE) can be introduced into one or more Edge-assisted gateways, depending on the application, when the number of sensor nodes considerably rises. Wi-fi can be utilised as the primary wireless communication method between sensor nodes and Edge gateways in situations where an application demands an extraordinarily high data rate, such as video streaming. However, this leads to a rise in the energy use of sensor nodes.

Benefits	Description
Low-latency processing	Edge computing makes it possible to analyse data more quickly and close to the point of origin, reduce network latency, and enable real-time or almost real-time analytics.
Real-time analytics	Faster decision-making and response times are made possible by the combination of LPWAN with Edge Computing, which enables instantaneous analysis and insights from IoT data.
Scalability	In order to effectively process and store enormous volumes of data produced by LPWAN-enabled devices, edge computing offers a scalable infrastructure.
Enhanced security and privacy	Sensitive data can be locally analysed and filtered while being processed at the edge, lowering the possibility of data breaches and preserving data privacy.
Improved reliability and availability	High availability and dependability are provided by LPWAN with Edge Computing by reducing reliance on centralised cloud servers. Even in the case of network outages or disruptions, operations can continue thanks to local data processing at the edge..
Efficient resource utilization and cost optimization	Edge computing reduces the requirement for sending massive volumes of data to the cloud by processing data locally to optimise resource utilisation. As a result, bandwidth expenses are decreased, and overall effectiveness is increased.

Table 2: Benefits of integration of LPWAN with Edge Computing

There are several approaches by which we can integrate edge computing with LPWANs:

- LPWAN gateway deployment enables direct communication between LPWAN devices and edge servers by placing the gateways at the edge. Real-time analytics are made possible by this method's localised data collection and processing, which also lowers latency.
- Using Edge Servers-To perform data processing and analytics activities, edge servers are put at the network's edge. Low-latency responses and in-the-moment insights are made possible by LPWAN devices, which send data to the edge servers for immediate processing and analysis.
- Utilising Edge Analytics- At the edge, real-time analysis and decision-making are carried out using edge analytics frameworks. The edge analytics platform receives data from LPWAN devices and applies powerful analytics and machine learning algorithms for quick understanding and response.

Challenges and Considerations

There are numerous advantages for IoT applications when Low-Power Wide Area Network (LPWAN) and Edge Computing are combined. However, this integration also brings with it a number of issues that need to be taken into account.

Network Structure

- designing an optimal network architecture, taking device connectivity and topology into account.
- network load balancing to maintain performance and scalability.

Security:

- protecting data in transit and at rest and securing edge devices.
- putting strong intrusion detection, encryption, and authentication systems in place.

Data Management

- between edge nodes and the cloud, data is gathered, filtered, and synchronised.

- efficient data processing, analytics, and storage from the Internet of Things.

Interoperability:

- LPWAN protocol compatibility with edge hardware and Edge Computing frameworks.
- using open standards and industry-wide guidelines to ensure easy integration.

❖ **Approaches and Solutions**

- Network optimization: It is the process of streamlining network protocols and architecture to improve communication.
- Security frameworks: Implementing authentication, encryption, and detection of intrusions.
- Edge data processing and analytics: Using edge-based frameworks for effective data handling.
- Standardization and interoperability: Supporting open protocols and standards across the industry.

Conclusion

The integration of LPWAN technologies with Edge Computing has demonstrated great potential in enhancing IoT applications by enabling real-time analytics and low-latency processing. Long-range, low-power communication for IoT devices is provided by LPWAN technologies like LoRaWAN, NB-IoT, and Sigfox, making them appropriate for a variety of use cases. However, edge computing enables real-time insights and quick responses by bringing processing and data storage closer to the network edge.

For IoT applications, the combination of LPWAN with Edge Computing has many advantages. Organisations may improve performance, reduce latency, and increase scalability by combining the vast coverage and energy efficiency of LPWAN with the localised data processing and analytics capabilities of Edge Computing. With real-time analytics, low-latency processing, and increased scalability enabled by this integration, IoT applications are improved. It enables businesses to make the most of the potential of their IoT implementations.

Declarations

Author's Contribution

All the author's read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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