

# Optimized LoRaWAN Architectures: Enhancing Energy Efficiency and Long-Range Connectivity in IoT Networks for Sustainable, Low-Power Solutions and Future Integrations with Edge Computing and 5G

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## Abstract

The Internet of Things (IoT) has expanded rapidly, allowing for a network of sensors and gadgets to collect and share information to make people's lives easier and more convenient. As the Internet of Things (IoT) grows, however, energy efficiency becomes a major issue, especially for portable and wireless gadgets. Low-power, long-range communication capabilities are needed, and Long-Range Wide Area Network (LoRaWAN) has emerged as a viable solution to meet this need. This study provides an in-depth analysis of the LoRaWAN-based, low-power Internet of Things. The suggested network architecture is optimized for low power consumption and high connectivity for numerous Internet of Things (IoT) use cases. This low-power Internet of Things network relies on LoRaWAN gateways, end devices, and a server to function. LoRaWAN is a technology that enables the low-power, long-range transmission of data packets. The results show that the optimized case and non-optimized case have a delivery ratio of 0.85 to 0.73 from node 100 to 500. LoRaWAN significantly reduces energy usage compared to conventional IoT connectivity alternatives, making it a fantastic option for battery-powered devices in far-flung or limited-resource locations. Finally, the adoption of LoRaWAN provides a viable solution to address the energy efficiency concerns in IoT networks, hence allowing for sustainable, long-lasting IoT installations and enabling a wide variety of new applications within the IoT ecosystem. Furthermore, addresses the potential applications of this technology in the future, including upgrades and integration with other technologies like edge computing and 5G networks.

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## 1. Introduction

The Internet of Things (IoT) is a branch of computer engineering and science that has been providing numerous useful tools and approaches for dealing with contemporary issues [1]. Therefore, the growth of the Internet of Things market causes a rise in interest. Solutions based on technologies that enable long-distance wireless connectivity are at the heart of the Internet of Things' design concept [2]. Many protocols and technologies, including LoRa, NB-IoT, Sigfox, Weightless, NB-Fi, etc., make up Low-Power Wide Area Networks (LPWANs), which are one of the future developments in the Internet of Things [3]. LoRa [4] is a cutting-edge Internet of Things (IoT) technology that permits long-range connections while maintaining extremely low energy usage. The Long-Range (LoRa) System is a

modification of the Chirp Spread Spectrum (CSS) modulation system [5]. LoRa is attempting to address several difficulties, including facility monitoring, energy usage tracking in buildings, etc. For IoT applications, LoRa has emerged as a crucial component [6]. The LoRa Wide Area Network (WAN) is a state-of-the-art communication infrastructure built specifically to make it easier to deploy and manage IoT gadgets. Data transfer is optimized by the Lora WAN architecture, allowing for multiple devices to connect at once with minimal impact on power usage [7].

### 1.1 Introduction to IoT and its Significance

Fifth generation (5G) wireless networks have revolutionized the Internet of Things and enabled many new capabilities and uses. It helps integrate devices into a communication network [8]. Given its rapid expansion in recent years, it's vital to understand everything it can about this cutting-edge technology and study its numerous prospective uses [9]. Introducing human-inanimate interaction. Main strength: new effect. Widespread IoT adoption requires low-cost sensors, fast, error-tolerant data transmission, powerful algorithms, and many applications. The IoT is employed in smart cities, housing, healthcare, and more [10]. This online approach is great for data management and information sharing by linking everything to the network [11]. Figure 1 depicts the application of IoT.

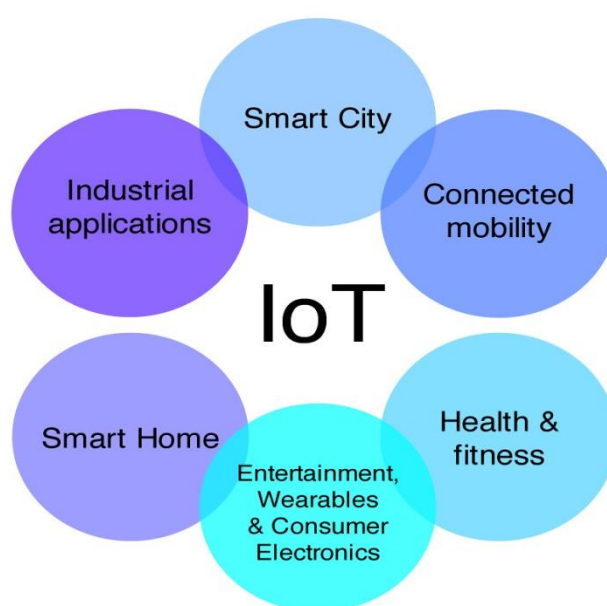


Figure 1: Applications of the IoT.

Large-scale to improve IoT intelligence, symmetry, and asymmetry. Application of IoT includes aquatic quality analytics, bee colony monitoring, precise agriculture, data communication balancing, smart traffic management, spatiotemporal prediction, and intelligent engineering. To demonstrate their usefulness to future platforms, researchers are exploring IoT [13]. IoT offers the benefit of merging the real and virtual worlds represented by the internet [14]. The IoT paradigm connects anything, anywhere, and everyone. This tech connects people and resources and simplifies tasks [15]. Connection and data sharing are IoT's goals. People always carry smartphones, automobiles, medical equipment, and office devices [16]. Additionally, Radio Frequency Identification (RFID) pioneered several additional technologies; including sensors, smart devices, and actuators [17]. IoT benefits include M2M [18] and V2V [19] communications [20].

#### 1.1.1 The increasing role of IoT in various industries

IoT has altered numerous company areas by connecting everyday devices to the internet, sharing, and analyzing data. Many industries have increased communication as a result. Analyzing the Internet of Things' expansion in various industries:

**i. Healthcare:** IoT accelerates healthcare automation. The Healthcare Internet of Things collects medical data. IoT interests Hospital IoT. The Internet of Things enhances healthcare and life [21]. Medical sensors and equipment are networked, making patient data easier to retrieve. Remote patient

monitoring, disease and recovery prediction, diagnostic and therapy standardization, and mobility are possible with this data [22].

- **Remote Patient Monitoring:** Remote patient monitoring, or telemonitoring, aims to improve medical care by electronically transferring health data [23]. Telemonitoring is valuable, however, there have been no meta-analyses of clinical study's various contributing aspects [24].
- **Smart Healthcare Facilities:** With wearables, the IoT, and mobile Internet, "smart healthcare" platforms can speed up health record entry and make communication and cooperation simpler between individuals, organizations, and institutions. Informed medical treatment requires collaboration between clinics, hospitals, and schools [25].

**ii. Energy Management:** The energy management layer forecasts and manages energy usage, while the cloud server connects consumers to smart grids [26]. Cloud servers collect, process, and send household and industrial energy needs to grid stations [27]. The authors created a price-based Demand Response (DR) program for IoT-enabled households to manage energy use. Systems like the energy management controller (EMC) use automatic controllers in clients' houses to optimize energy use [28]. Energy management involves complex distribution networks, households/buildings, and other elements [29].

**iii. Transportation and Logistics:** Logistics and transport industry benefits of IoT technology. IoT architecture and usefulness in solving complex challenges are explored. Internet of Things applications in transportation [30]. The IoT solves engineering problems at the system level using cutting-edge technology. The IoT is the physical manifestation of purpose-driven information and communication networks. No matter the application, IoT has few nano- and micro-sized electro-mechanical sensing instruments [31]. A growing number of industries, including transportation and logistics (T&L), recognize the importance of sensors and their industrial applications as the Internet of Things (IoT) grows in popularity [32].

**iv. Smart Cities:** Residents of smart cities have superior amenities to their ancestors. They have everything to run real-time physical things and give citizens intelligent data in transportation, healthcare, smart buildings, public safety, parking, traffic, agriculture, and more. Smart city apps acquire sensitive data. At several design layers, security and privacy issues may arise. Thus, throughout application development, privacy and security must be considered [33].

## 1.2 Long Range Wide Area Network (LoRa WAN)

The low-power, long-range LoRaWAN communications enhance IoT applications. Densifying LoRaWAN for IoT is difficult. Smart devices and urban gateways can disrupt channel transmissions. IoT applications have transformed society [34]. Rise of LoRa and LoRaWAN. A proprietary radio-frequency modulation, LoRa is for LPWAN wireless WAN networks. A low-power, long-range LoRa communication uses CSS modulation. It's the LoRa Alliance's open network layer. LoRa Alliance notes that LoRa radio is the physical layer of LoRaWAN's top layers and network architecture [35].

Star-of-stars LoRaWAN architecture includes IoT devices, gateways, a network server, and an application server [36]. LoRaWAN is largely a single-hop multi-channel for IoT device-gateway communication. Gateways provide IoT messages to the application server via radio connections over IP networks. Upward communication between network servers and IoT devices [37]. Coexistence in LoRaWAN boosts IoT device and application deployment. IoT devices sending data to the gateway share a channel, causing interference and poor performance [38].

### 1.2.1 Architecture of LoRaWAN

LoRaWAN has network servers, gateways, and end nodes in a star-of-stars topology. GWs act as mediators between end nodes and the network server, using LoRa modulation for node-to-communication with adaptive data rates and channels. The network server receives data frames from end nodes and routes them throughout the network using Internet Protocol (IP) technology to manage gateways (GWs) [39]. Figure 2 provides an overview of the LoRaWAN architecture.

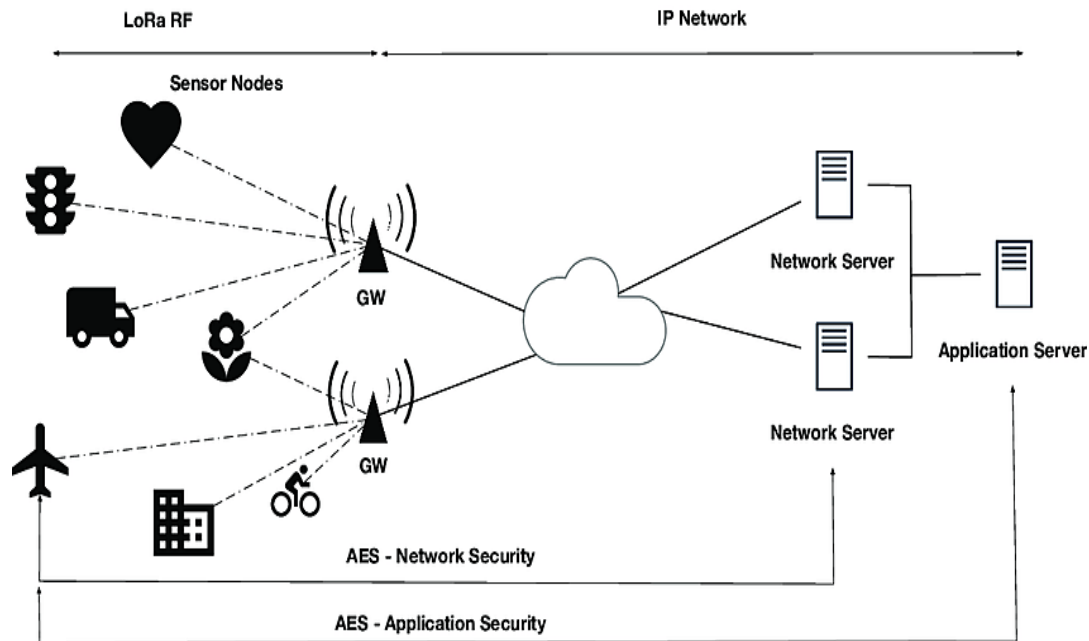


Figure 2: Architecture of LoRaWAN [40]

LoRaWAN works to improve medium management and network congestion as a Media Access Control (MAC) layer protocol.

### 1.2.2 Relevance of LoRa WAN in IoT Deployments

LoRaWAN is a form of wireless communication optimized for low-power Internet of Things (IoT) deployments across vast distances. For many IoT implementations, it has become increasingly important and popular such as:

- **Long Range:** LoRa is a relatively new wireless technology that enables long-range communication for low-power IoT devices [41]. LoRa's ability to reliably carry low-volume data over long distances in a wide variety of deployment scenarios has made it a leader in the Low Power Wide Area Network (LPWAN) space [42].
- **Low Power Consumption:** LoRaWAN's power savings are great. Environmental sensors and asset tracking in remote regions can run on a single battery for years. Sleeping reduces power usage instead of optimizing hardware. Sleeping gadgets use less power than active ones [43].
- **Low Cost:** Using LoRaWAN to link Internet of Things devices is a frugal option. As a result of its low power consumption and cheap hardware components, running costs are minimal. The current situation calls for solutions that are both low-cost and long-coverage areas to establish a landslide monitoring system for a specific regional level [44].

## 2. Literature Review

A review of the literature reveals that many authors have attempted this method and published their results.

Anwar et al [57] presented an NS-step-side ADR (NS-side ADR) utilizing a Gaussian filter and received power to allocate SF and TP effectively. The proposed ADR was shown to be effective in reducing convergence time and energy usage in simulations. Researchers also found that the suggested ADR effectively improves the packet delivery ratio by lowering the rate at which packets are lost in transit. In addition, the suggested ADR may be readily incorporated at the NS as part of regular maintenance because it operates on the NS side. Because of its rapid convergence time, high packet delivery ratio, and low power consumption, authors think the proposed ADR can be used by mobile IoT end devices. Al-Gumaei et al [58] introduced a new game-theoretic framework for LoRaWAN called Best Equal LoRa (BE-LoRa), to improve both packet delivery rates and bit-per-Joule efficiencies simultaneously. The ratio of throughput to transmit power characterizes a LoRa node's utility function. Numerical and simulated findings reveal that the packet delivery ratio and energy efficiency of the proposed BE-

LoRa power allocation algorithm are significantly higher than those of the ADR method of legacy LoRaWAN. In extremely dense networks, for instance, BE-LoRa can increase the delivery ratio by 17.44% while decreasing power consumption by 46% in comparison to LoRaWAN ADR. Asvial et al [59] address the issue of bottlenecks in the IoT network, To maximize the efficacy of available resources during routing processes, this study suggests a physarum routing algorithm with adaptive power control (PRA-APC). The results show that PRA-APC outperforms alternative physarum routing methods such as Pre-Packed Insolvency Resolution Process and RS- Parallel Redundancy Protocol (P-iRP and RS-PRP) in terms of throughput, network longevity, and delay between hops. Limbasiya et al [60] introduce MComIoV, a new secure and low-power message-passing system based on elliptic curve cryptography (ECC) and one-way hash functions. The experimental findings show the effectiveness in terms of computing time, storage space, price, communication complexity, and power usage.

In [61], authors analysed that a user's current activity and the wearable device's battery life can be used to inform an energy-efficient technique for LoRa networks. The system has been tested through simulations using various mobility models and with one or more wearable devices. The simulation findings show that the energy consumption may be reduced in several different node mobility models without affecting the network's delivery ratio, which is crucial given that LoRa packets are utilized for the geolocation of the missing individual. Farhad et al [62] allocated the best SF to IoT-enabled mobile EDs for each uplink transmission, authors provide a mobility-aware resource (SF) assignment technique (M-ASFA) that considers the signal strength at the gateway. The simulation results demonstrate that the proposed M-ASFA system actively responds to the mobility of the Enforcement Directorate (EDs) to allocate the SF to mobile EDs. By being proactive, the suggested technique reduces the impact of interference, retransmissions, and packet loss, making it superior to LoRaWAN-based ADR in terms of packet success ratio. The authors in [63] explored that how scaling and gateway densification affect system dependability while accounting for the capture effect. For LoRaWAN networks with numerous gateways, the authors offer an optimization problem to determine the distribution of nodes at varying spreading factors (SF). The suggested technique enhances the network's throughput and packet delivery ratio, as demonstrated by simulation results, which show that it greatly outperforms the state-of-the-art algorithms. El Rachkidy et al [64] stated a study that effectively interprets several superimposed LoRa signals, researchers at the University of Washington have suggested a unique beacon-based MAC protocol based on a collision resolution mechanism. The suggested decoding method capitalizes on the one-of-a-kind properties of the LoRa physical layer as well as the little discordance between the layered signals. The Cyclic Redundancy Check (CRC) is already available in each frame, and the research shows how it may be used to improve the decoding performance of the collision resolution approach. The suggested Cognitive Radio-Medium Access Control (CR-MAC) protocol is shown to significantly enhance system throughput and energy efficiency in simulations when compared to the standard LoRaWAN protocol. Delay reduction is a difficult problem to solve in 5G wireless communication networks, but the proposed protocol makes it possible. Kousias et al [65] stated that with a dataset made up of LoRaWAN traces gathered in the city of Antwerp, Belgium, researchers investigated the efficacy of the device-side ADR method in a variety of mobility circumstances. As the mobility of the ED grows, the benefits of ADR diminish, suggesting there is room for additional enhancement and optimization.

### **3. Problem Formulation**

#### **3.1 Energy Efficiency in IoT Networks**

Increasing energy efficiency across heterogeneous IoT networks has been a major research challenge, but the Green Internet of Things (G-IoT) is emerging as a promising new area of study [45]. IoT technologies, which provide pervasive sensing and computing, have grown fast in recent decades. The IoT is being researched as its commercial and industrial uses grow. Energy efficiency is one of the most important issues of research in green IIoT due to the finite resource's potential impact on system lifespans and the massive sensors, gadgets, and machines' constant power requirement [46].

#### **3.2 Energy Conservation Techniques in Communication Protocols**

In the case of wireless and battery-operated devices, energy efficiency is of paramount importance in the development of communication protocols. Some common methods used by communication protocols to reduce power consumption are:

**3.2.1 Low-Power Modes:** Device inactivity can last minutes. When not delivering or receiving data, communication protocols can use low-power modes. This reduces standby power. The energy harvesting paradigm is likely to spread due to downsizing and ultra-low power [47].

**3.2.2 Power Management:** Power management methods optimize radio and processor use. This comprises real-time power and data transmission adjustments to meet changing communication needs. A power management system coupled to a Wireless Sensor Network (WSN) node can power it with environmental energy [48].

**3.2.3 Adaptive Data Rate:** Adaptive Data Rate (ADR) optimizes LoRaWAN data throughput, airtime, and power. Signal strength may affect data rate in communication systems. In strong signals, faster data transfer at higher data rates is possible, but in weak signals, lower data rates with more dependability save energy. ADR is essential to LoRaWAN. This method saves energy and boosts throughput by altering the data rate for each LoRaWAN end node dependent on the connection budget [49][50].

### 3.3 Adaptive Data Rate and Battery Life Extension

ADR is essential for LoRaWAN. As part of LoRaWAN, the ADR system changes end node data rates and TP to save power and boost throughput. LoRaWAN's data rate is adjustable, making gateways easy. ADR greatly boosts network capacity since SFs send orthogonal, simultaneous data packets [51]. LoRaWAN increases PDR by managing end-node transmission settings with ADR. Data flows from the gateway to the end node via ADR. The ADR algorithm restricts end node data rate and transmission power based on the Underwriters Laboratories (UL) message's link budget estimation and the maximum signal-to-noise ratio (SNR) needed for accurate data packet decoding at the current data rate. Network-managed ADR or Static ADR is maintained by the NS for fixed-end nodes based on UL packet history. Channel attenuation prevents network-based ADR for mobile end nodes. Mobile end nodes perform blind ADR. LoRaWAN gateways process messages from many channels using adaptive modulation and multiple-channel modem transceivers. Spread spectrum technology divides signals orthogonally by assigning SFs [52].

Data rate management benefits. LoRaWAN ADR adjusts transmission settings for performance and battery longevity. Adjust the LoRa terminal node data rate and TP. Data capacity, arrival time, and power grow with ADR. Optimize LoRaWAN end node data rate with SF. Use the ADR wisely because SF increases collision risk and lowers throughput. ADR originally supported fixed-end nodes and steady radio channels. Historical terminal node performance impacts ADR data rate [53]. So, heating demand, battery current, and life are connected. Heating power considerably impacts battery life and system performance [54].

Power-saving IoT communication methods require ADR. Based on signal quality, gateway distance, and network congestion, ADR modifies transmission data rate. Radio bandwidth optimization reduces data transmission power [55]. Devices last longer in harsh environments by reducing data transfer. Since battery replacement is impractical or expensive in remote environmental sensors and long-term asset monitoring systems, this adaptive strategy keeps IoT devices connected and conserves power [56].

## 4. Research Methodology

The problem is to design an energy efficient IoT network using Long Range Wide Area Network (Lora WAN). It involves evaluating the coverage area based on specific use cases and requirements, analyzing data rate needs considering data volume and quality of service, optimizing power consumption through energy-efficient components and power management techniques, conducting signal propagation analysis to identify weak coverage areas, optimizing node placement based on power requirements and signal factors, assessing signal strength and adjusting gateway and node placement accordingly, analyzing power availability and exploring additional power sources, utilizing Radio frequency (RF) signal analysis for node placement optimization, implementing Bloom filters for data aggregation and compression, incorporating adaptive data rate algorithms to optimize energy consumption, and implementing Role-Based Access Control (RBAC)-based authentication for secure access control.

#### 4.1 Low-power Microcontroller

A low-power microcontroller model is used in this simulation to simulate the behavior of energy-efficient devices in a LoRaWAN network. The simulation runs in discrete time increments, which simulate times in which the microcontroller switches between active and sleep mode. An adaptive power control method estimates the appropriate transmission power level based on received signal strength indicator (RSSI) and signal-to-noise ratio (SNR) data when the device wakes up. The microcontroller is then responsible for data gathering, processing, and transmission. Transmission time, power level, and microcontroller energy characteristics are used to calculate power consumption in active mode. To save energy, the microcontroller then goes into sleep mode. This cyclic process is repeated throughout the simulation, demonstrating how the microcontroller optimizes power usage while meeting communication needs in a LoRaWAN configuration [67].

#### 4.2 Adaptive power control

The adaptive power control method is responsible for dynamically modifying the transmission power levels inside individual nodes of the LoRaWAN network simulation. The optimization of energy consumption and communication dependability is achieved by the utilization of received signal strength indicator (RSSI) and signal-to-noise ratio (SNR) measurements. The program makes intelligent decisions on whether to boost or reduce the transmission power by comparing these numbers to specified criteria [68].

#### 4.3 Proposed architecture

The given procedure describes the essential stages involved in simulating the operation of a LoRaWAN (Long Range Wide Area Network) node in a network environment. It begins with the initialization of node parameters, such as ID, duration of simulation, and communication settings.

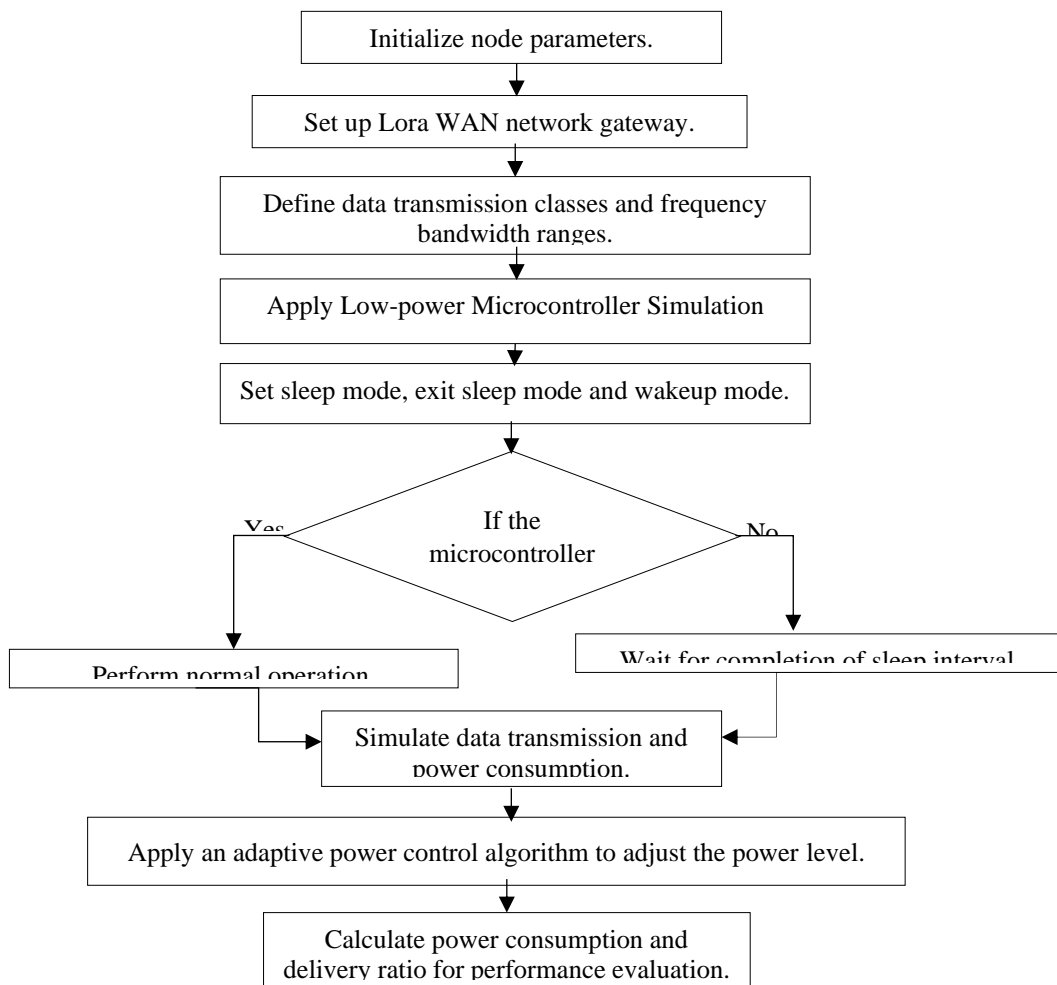


Figure 1: Proposed architectural flowchart.

Parameters are configured for a virtual LoRaWAN gateway, and data transmission classes with associated frequency bandwidth ranges are defined. The simulation then includes the behaviour of a low-power microcontroller within each node, such as slumber and wake modes. Nodes capture and process data for transmission while considering power consumption during active operation. Utilizing factors such as gateway distance and signal quality, an adaptive power control algorithm optimizes transmission power levels. In order to assess the network's efficacy, performance evaluation concludes with an assessment of power consumption and delivery ratios. Figure 3 shows the flowchart of the proposed architecture.

#### 4.4 Proposed Algorithm

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**Start**

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##### **Step 1: Initialize Node Parameters**

Initialize node parameters like node ID, number of nodes (NUM\_NODES), simulation duration (SIM\_DURATION), spreading factor (SF), and gateway range (GATEWAY\_RANGE).

##### **Step 2: Setup Lora WAN Network Gateway**

Initialize a virtual Lora WAN gateway in the simulation environment.

Configure the gateway parameters like frequency channels and receive windows.

##### **Step 3: Define Data Transmission Classes and Frequency Bandwidth Ranges**

Define different data transmission classes (e.g., A, B) with associated frequency bandwidth ranges for uplink and downlink communication.

```
DT_CLASS_A = DataTransmissionClass ("Class A", BANDWIDTH_RANGE_A)
DT_CLASS_B = DataTransmissionClass ("Class B", BANDWIDTH_RANGE_B)
BANDWIDTH_RANGE_A = (860e6, 870e6) # Example bandwidth range A in Hz,
BANDWIDTH_RANGE_B = (900e6, 910e6) # Example bandwidth range B in Hz,
```

##### **Step 4: Apply Low-Power Microcontroller Simulation**

Simulate the behaviour of a low-power microcontroller within each node.

Implement sleep mode, exit sleep mode, and wakeup mode functionalities.

```
class LowPowerMicrocontroller:
```

```
def __init__(self):
self.active = True

def enter_sleep_mode(self):
self.active = False
print("Entering Sleep Mode...")

def wake_up(self):
print("Waking Up...")
```

##### **Step 5: Node Operation**

If the microcontroller is active, perform normal operations like data collection, data processing, and preparing for transmission.

If the microcontroller is in sleep mode, wait for the completion of the sleep interval.

### Step 6: Simulate Data Transmission and Power Consumption

Simulate data transmission from active nodes to the gateway based on the selected data transmission class and frequency bandwidth.

Calculate power consumption during the transmission process based on the transmission power, data rate, and transmission time.

```
data = "Sensor data from Node {}".format(self.node_id)
power_consumed= random.uniform(0.01,0.1)
# Random power consumption between 0.01 and 0.1 units
self.battery_remaining -= power_consumed
return data,power_consumed
```

### Step 7: Apply Adaptive Power Control

Implement an adaptive power control algorithm to adjust the transmission power level based on factors like distance to the gateway and signal quality.

The algorithm can periodically assess the Received Signal Strength Indicator (RSSI) and Signal-to-Noise Ratio (SNR) to determine the optimal power level.

The rule applied: if the battery is less than 20%, reduce the power level by 5 units,

# If the previous delivery ratio was less than 50%, increase the power level by 5 units,

# Otherwise, keep the current power level

### Step 8: Performance Evaluation

Calculate the power consumption of each node over the simulation duration, considering active operation time and sleep time.

Calculate the delivery ratio by comparing the number of successfully received transmissions at the gateway with the total number of attempted transmissions.

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**End**

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## 5. Simulation Environment and Parameter

After looking over the simulators, settled on the Framework for LoRa (FLoRa) simulator and chose to modify it to meet the needs. The primary justification for this is that FLoRa has included many features found in a complete standard LoRa network. Unlike LoRasim and phylorasimulator, FLoRa's graphical user interface (GUI) is straightforward and easy to use. FLoRa was the ideal solution because of the network's high-quality and powerful graphical user interface. The simulations are compared in Table 1. The table below lists Python-based simulation environment components. First, Python was chosen for its versatility, popularity, and cross-platform support. Since the simulation may run on any Python-supported platform, consumers have additional options. Command-line simulations employ text-based interfaces instead of graphics. User input and output are text-based. Using the code to track energy consumption statistics is useful. This capability is useful for tracking energy use during simulations of energy-efficient systems or battery-powered devices for analysis and optimization. Code documentation makes no mention of community support, such as forums or help desks. General Python programming resources, online Python communities, and forums may help users troubleshoot or ask questions about the code. This simulation requires Python and its ecosystem knowledge.

Table 1: Comparison of simulation environments

Features	Simulation Environment
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<b>Language</b>	The code is written in Python.
<b>Operating System</b>	The code can be run on any operating system that supports Python.
<b>GUI</b>	It's a command-line simulation.
<b>Energy Consumption statistics</b>	The code provides track and record energy consumption if that is a requirement for the simulation.
<b>Community Support</b>	The code does not mention any specific community support, forums, or online resources for assistance. It may need to rely on general Python programming resources for help with this code.

To ensure that the system makes the most of the wearable's capabilities, have calculated the average consumption in each mode and displayed it in Table 2. The described system runs in the ultra-high-frequency (UHF) range, with a frequency bandwidth of 870 MHz to 910 MHz. There are three separate modes of operation that it can perform: sleep, transmit, and receive. When not actively sending or receiving data, the system enters a low-power sleep mode with a power consumption of 0.0125 to 0.0964 W, allowing for efficient standby operation while saving power. This is essential for extending the runtime of the network's devices. When the system is in transmit mode, it sends data across reasonably long distances using a transmission power of 8 dBm to 14 dBm while remaining within the allowed frequency range. This network can have anywhere from 100 to 500 nodes, making it flexible enough to adapt to a wide variety of deployment settings. The system uses a LowPowerMicrocontroller as the power controller to manage power usage efficiently throughout these modes. This microcontroller is critical because it regulates the system's power consumption to maximize efficiency and minimize drain on the network's devices' batteries.

Table 2: Current and power consumption

<b>Parameters</b>	<b>Mode</b>
<b>Modes</b>	Sleep Mode, Transmit Mode, Receive Mode
<b>Frequency Bandwidth</b>	870 million Hz to 910 million Hz
<b>Power consumption range</b>	Between 0.012517640601067234 units $\mu$ W to 0.09641993613656387 units $\mu$ W
<b>Number of nodes</b>	100 to 500
<b>Power Controller</b>	LowPowerMicrocontroller
<b>Transmission Power</b>	8 dBm to 14 dBm

## 6. Results

From the data, the approach reduces the amount of power used by the LoRa nodes. Figure 4 displays the optimized and non-optimized energy usage with the nodes in a stationary mobility model. The

graph below illustrates the power requirements per network node. The proposed mechanism has little effect on the delivery ratio because the curves for the optimized and non-optimized cases are nearly identical for all path loss models. In some circumstances, the number of nodes makes a huge difference.

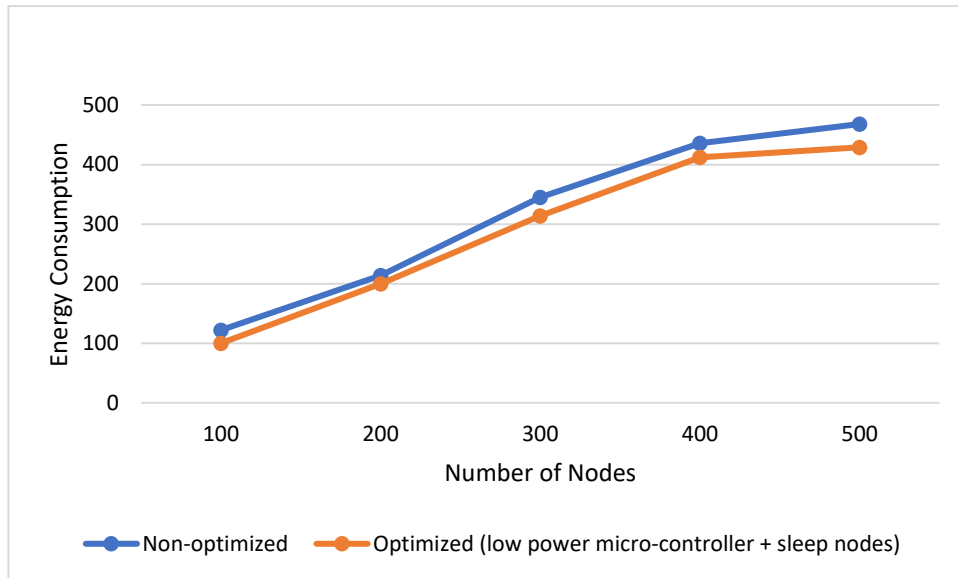


Figure 4: Optimal Case's Energy Consumption

Figure 5 displays the delivery ratio for the three mobility types considered. The percentage of packages delivered as a function of network nodes is depicted in the following figure. At 100 nodes, the optimal case and the non-optimized case have a delivery ratio of 1 to 1, at 200 nodes of 1 to 0.85, at 300 nodes of 1 to 0.75, at 400 nodes, and of 1 to 0.73 at 500 nodes, respectively.

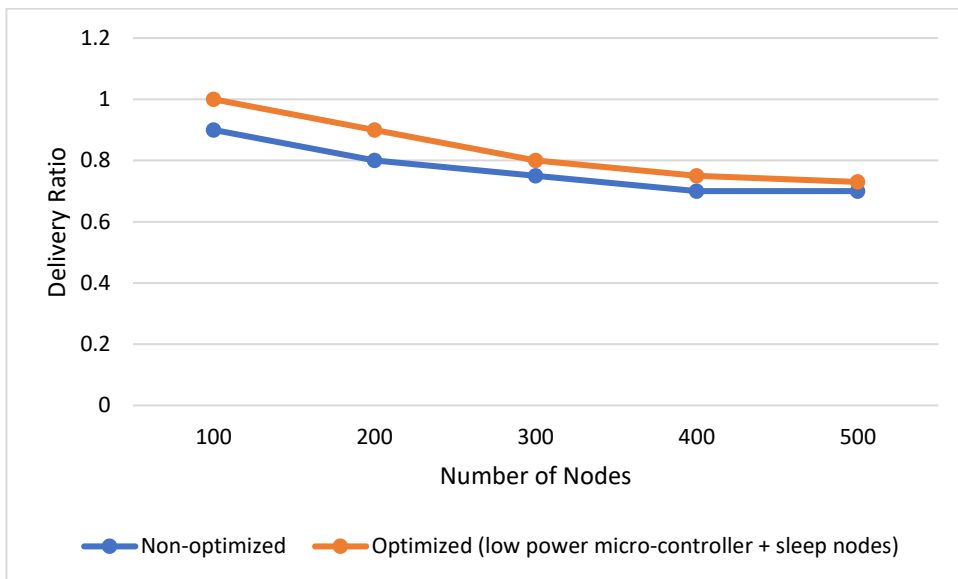


Figure 5: The delivery ratio of all examined cases.

## 6. Conclusion

In conclusion, the study demonstrates how utilizing LoRaWAN technology may be used to build a low-power Internet of Things network. The potential of this technology to transform IoT connectivity and management while also addressing pressing energy needs has been demonstrated. Important features of LoRaWAN, including as its range, power efficiency, and scalability, have been discussed

at length throughout this analysis. By incorporating these elements, IoT networks can not only be made more pervasive but also more resilient and economical. The results show that the method has effectively decreased the power requirements of LoRa nodes. The outcomes show a difference in energy consumption between the optimized and non-optimal scenarios, especially for a model of static mobility. Curves for both examples are similar, indicating that the proposed energy optimization strategy has a remarkably small effect on the delivery ratio across different path loss models. However, the ratio of delivered messages to total messages sent varies greatly depending on the size of the network. The energy efficient IoT network is further validated by this discovery, demonstrating its scalability and resilience. Future work in this area to focus on refining and optimizing energy-saving mechanisms, investigating the incorporation of renewable energy sources, and making use of cutting-edge data analytics and machine learning approaches to further improve the efficacy and sustainability of LoRaWAN-based IoT networks.

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