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# **A comprehensive systematic review of progressive applications of LoRa and LoRaWAN networks in the internet of things**

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**Abstract:** The internet of things (IoT) is a fast-expanding trend that combines cutting-edge communication technologies to transform commonplace objects into intelligent, networked gadgets. This movement is rapidly expanding. This paves the way for developing intelligent processes with applications across industries like monitoring and optimisation. LoRa has been promoted as a potential choice for the backbone of the internet of things due to its long range, low power consumption and low bit rate. Using LoRa over a single wireless hop, messages are transmitted from end devices to a central network server via gateways connected to the internet, which act as transparent bridges. This article provides in-depth information about LoRa networks and the technology's specifications. It also discusses the magnitude of projected growth trends and the challenges inherent in deploying LoRa-based networks. In addition, the paper is coupled with perceptive remarks and thought-provoking suggestions for future research endeavours. The study was conducted to encourage more research towards expanding the LoRa network and make it suitable for a more widespread deployment.

**Keywords:** LoRa; long range wide area network; LoRaWAN; internet of things; IoT.

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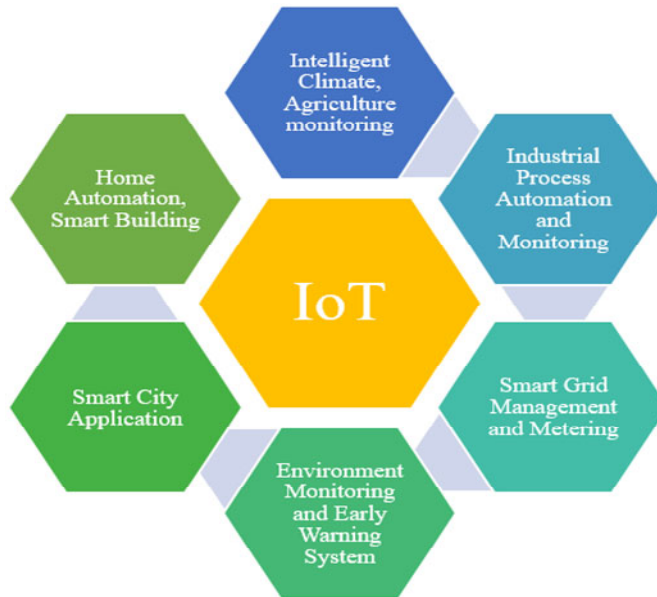
## 1 Introduction

The internet of things (IoT) indicates a network of computers, electronic gadgets, physical objects, living things, and other people or animals that have been given unique identifiers. Indeed, the information can be transferred through a system by utilising wireless connections; this does not require a personal computer or human involvement in any way (Adam et al., 2017). IoT confers cognitive abilities to inanimate objects, allowing them to communicate with one another to give out information and make decisions. As a result of the IoT, these items are evolving from simple to intelligent devices (Al-Fuqaha et al., 2015). LoRa is the newest innovation in IoT connectivity, and it operates on the network protocol called long range wide area network (LoRaWAN). LoRa technology is based on spread spectrum modulation (SSM), which enables the transport of data and information across greater distances at a more cost-effective exchange rate than competing developments (Lavric and Popa, 2017). Longer battery life with compact size, low cost with minimal onsite maintenance, and fully operable indoors and outdoors are the prerequisites of wireless IoT systems. As we prepare for the golden age of the IoT, it will be feasible to link many sensors thanks to a technology called LoRa that has a low power consumption.

LoRa systems have seen significant adoption in various applications across various industries, including education. IoT networks use low-power wide area networks

(LPWANs) because of their excellent communication range, low energy consumption, and low cost. Its flexibility makes it a fantastic choice for various IoT projects (Zhang et al., 2014). There is a variety of IoT applications that make use of LoRa, including smart grids (Barriquello et al., 2017), intelligent meters (Cheng et al., 2018), smart lights (Tung et al., 2019; Muthanna et al., 2018), smart cities (Premasankar et al., 2020; Andrade and Yoo, 2019), water purity (Ngom et al., 2019), intelligent agriculture (Miles et al., 2020; Nagpure et al., 2019), and monitoring of soil and temperatures (Saleh et al., 2021; Purnomo et al., 2021).

**Figure 1** LoRa-LoRaWAN technology enabled IoT application (see online version for colours)



As a result of the increased size of the coverage zone, a metropolitan area implementing LoRa can cover a greater coverage area. Table 1 compares and contrasts the many gadgets that can give a group of sensors access to a network. This comparison is shown in Table 1. Table 1 considers several factors: low data rate, wide range, low cost and low power use. LPWAN technology is preferred for connecting low-power devices that send small amounts of data over a long distance.

**Table 1** Existing wireless protocols comparison

|                          | <i>Bluetooth</i> | <i>BLE</i> | <i>ZigBee</i> | <i>WiFi</i> | <i>Cellular</i> | <i>LPWAN</i> |
|--------------------------|------------------|------------|---------------|-------------|-----------------|--------------|
| Long range (> 10 KM)     | No               | No         | No            | No          | Yes             | Yes          |
| Low data rate (< 5 kbps) | Yes              | Yes        | Yes           | No          | No              | Yes          |
| Low power                | Yes              | Yes        | Yes           | No          | No              | Yes          |
| Low cost                 | Yes              | Yes        | Yes           | Yes         | No              | Yes          |

The LoRa protocol is an up-to-date technology currently available, running in the non-licensed spectrum below 1 GHz. This makes it an attractive option for network communication that spans enormous distances. LoRa is a private SSM system, which

means it is a version of chirp spread spectrum (CSS) that trades off data capacity for sensitivity. This trade-off allows LoRa to communicate with a more significant number of devices. This system functions within a specified frequency range and makes as effective use of the spectrum as is humanly possible.

In LoRa, the relationship existing between the needed data, the chirp rate, the symbol rate, and the bit rate are as follows (Purnomo et al., 2022): considering that the following assertions are correct, we can deduce that  $R_b$  is the bit rate as:

$$R_b = SF = \frac{1}{\frac{2^{SF}}{BW}} \text{ bits/sec}$$

Abbreviations refer to both the spread factor and the modulation bandwidth (BW). Spreading factor (SF) stands for spread factor, while the modulation BW is called BW (Hz). The rest of the paper is laid out as Section 2 introduces LoRa technology and specifications. Section 3 discusses related work, and Section 4 exonerates constraints in LoRa technology. LoRa's developmental trend is talked about in Section 5. Finally, the concluding remark is given in Section 6.

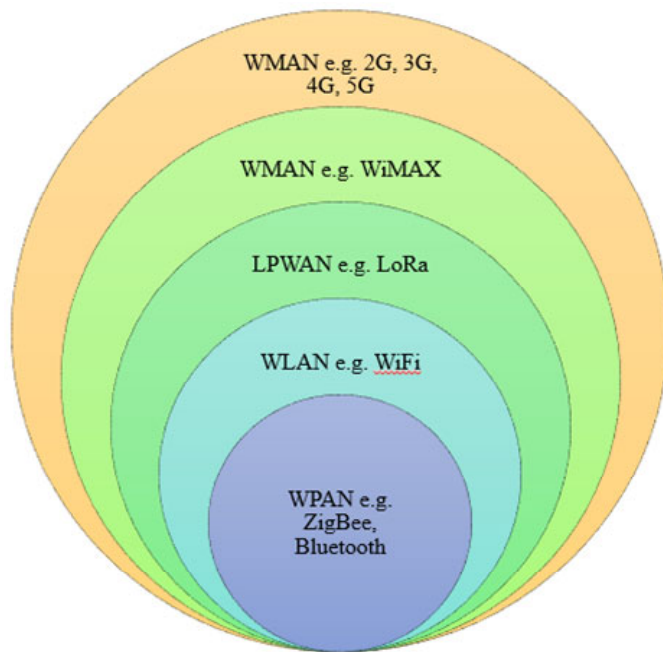
## 2 LoRa technology

### 2.1 Overview

The technologies that use the LoRa protocol are becoming an increasingly important component of the IoT (Haxhibeqiri et al., 2018). LoRa has been widely applied in various industries, including agriculture, healthcare, renewable energy and industrial processes. It is also used in applications that might take time to be obvious, such as detecting position based on relative signal strength indicator (RSSI) (Sadowski and Spachos, 2018). As a direct result of our work, it has been implemented in the underground mining industry to detonate explosives and communications (Branch et al., 2020).

Supported by LoRa Alliance, LoRa was developed by Semtech to establish long distance wireless communication (Augustin et al., 2016). It was named after the company that developed the method. As can be seen in Figure 2, it is situated in a LPWAN, which is a component of a wireless metropolitan area network (WMAN). LoRa's low data rate and long distance capabilities make it an excellent choice for providing wireless network services to devices powered by batteries with long battery life. LoRa's low data rate is also suitable for use in low-power environments.

LoRa is a radio access CSS modulation technology that operates in the sub-GHz industrial, scientific and medical (ISM) band, providing a long-range, low-power, bidirectional connectivity platform for the IoT channels. CSS technology utilises a broad spectrum of carrier frequencies in order to transmit a signal with a limited BW into the outer space. Furthermore, the chirp spectrum exhibits immunity to the detrimental effects of multipath fading, a prevalent issue encountered by numerous low-power devices. In order to enhance its sensitivity, LoRa employs the forward error correction (FEC) technique in conjunction with CSS modulation.

**Figure 2** Wireless networks overview (see online version for colours)

It is feasible to use LoRa modulation on a wide range of frequencies that are a part of the unlicensed ISM spectrum. The 169 MHz, 433 MHz, 868 MHz, and 915 MHz are only a few examples of this category. Because of this, no new licenses are required, making it possible to deploy it and ensuring that it can be used elsewhere (LoRa Alliance Technical Committee Regional Parameters Workgroup, 2020). This makes it practical to deploy it and makes it possible to use it elsewhere. Table 2 depicts the allocated frequency bands for LoRa technology across the globe.

**Table 2** LoRa frequencies in various regions

| <i>Regions</i> | <i>Frequency bands (MHz)</i> |
|----------------|------------------------------|
| Asia           | 923                          |
| USA            | 902–928                      |
| India          | 865–867                      |
| Europe         | 863–870                      |
| North America  | 902–928                      |
| Australia      | 915–928                      |
| South Korea    | 920–923                      |

As LoRa utilises several SFs for modulating a signal on a short band communication channel (i.e., 500 kHz, 250 kHz and 125 kHz), the LoRa modulation technique could be categorised as a type of CDMA. This kind of communication has improved resistance to interferences and fading in its transmissions, making it a more desirable option. Nodes situated closer to a gateway station will have a higher data rate than nodes situated further from the gateway. The further apart nodes must spend more of their communication

connection budget. This, in turn, causes a decrease in the data rate by increasing the SF. The dependency of signal-to-noise ratio on LoRa features is exonerated in Table 3.

**Table 3** SF for LoRa communication over a channel of 125 KHz

| <i>SF</i> | <i>Chips/symbol</i> | <i>SNR limit (dB)</i> | <i>Data rate (bps)</i> |
|-----------|---------------------|-----------------------|------------------------|
| 7         | 128                 | −7.5                  | 5,469                  |
| 8         | 256                 | −10                   | 3,125                  |
| 9         | 512                 | −12.5                 | 1,758                  |
| 10        | 1,024               | −15                   | 977                    |
| 11        | 2,048               | −17.5                 | 537                    |
| 12        | 4,096               | −20                   | 293                    |

*Source:* Marchese et al. (2020)

**Table 4** Transmission characteristics for various SF and BW

| <i>SF</i> | <i>BW</i> | <i>Time-on-air (msec)</i> | <i>Data rate</i> | <i>Sensitivity</i> |
|-----------|-----------|---------------------------|------------------|--------------------|
|           |           |                           | <i>(kbps)</i>    | <i>(dBm)</i>       |
| 7         | 125       | 44.29                     | 5.47             | −123               |
| 7         | 250       | 22.14                     | 10.94            | −120               |
| 7         | 500       | 11.07                     | 21.88            | −117               |
| 8         | 125       | 88.58                     | 3.13             | −126               |
| 8         | 250       | 44.29                     | 6.25             | −123               |
| 8         | 500       | 22.14                     | 12.5             | −120               |
| 9         | 125       | 144.38                    | 1.76             | −129               |
| 9         | 250       | 72.19                     | 3.52             | −126               |
| 9         | 500       | 36.01                     | 7.03             | −123               |
| 10        | 125       | 288.77                    | 0.98             | −132               |
| 10        | 250       | 144.38                    | 1.95             | −129               |
| 10        | 500       | 72.19                     | 3.91             | −126               |
| 11        | 125       | 577.54                    | 0.54             | −134.5             |
| 11        | 250       | 288.77                    | 1.07             | −131.5             |
| 11        | 500       | 144.38                    | 2.15             | −128.5             |
| 12        | 125       | 1,155.07                  | 0.29             | −137               |
| 12        | 250       | 577.54                    | 0.59             | −134               |
| 12        | 500       | 288.77                    | 1.17             | −131               |

*Source:* SX1272 LoRa Calculator (<https://www.semtech.com/search/results?keywords=calculator%2A>)

The modulation of data transmission speed is influenced by the SF, which subsequently governs the chirp rate. Lower SFs lead to faster chirps, resulting in a higher data transmission rate. The range of LoRa broadcasts is shortened as a result of reduced processing gain and increased data rate while employing lower SFs. The network has the capability to modify the data rate for individual end devices by altering the SF, hence

influencing the coverage range. Table 4 presents the outcomes of different combinations of BW and SF, which were computed using the Semtech SX1272 LoRa Calculator.

Network protocol LoRaWAN was developed on top of the physical and connection layers (LoRa Alliance, 2015). End devices that derive their power from rechargeable batteries are ideal candidates for use with LoRaWAN because the network was intended to work with them. LoRaWAN is a network that offers encryption services, serving as an internet gateway, and outlines a network of star of stars where each star has a LoRa gateway. It also operates as a gateway to other LoRaWAN networks. End devices that utilise unlicensed radio spectrum resources in the ISM band use a variety of channels and data rates (Centenaro et al., 2016). This is because the FCC does not regulate the ISM band.

Other applications may be allowed access to the internet by the LoRa gateway through protocols such as message queue telemetry transport (MQTT), or access may be granted to other apps by utilising an API such as RESTful (Message Queuing Telemetry Transport, <https://mqtt.org/>). Within LoRaWAN networks, control and contention management are handled using a basic protocol called ALOHA. Although ALOHA is only functional at low data rates, low data rates are typical for the applications that comprise the vast bulk of LoRaWAN's use cases. Figure 3 illustrates the presence of both LoRa and LoRaWAN technologies.

**Figure 3** LoRa and LoRaWAN technology stack (see online version for colours)



## 2.2 LPWAN technologies

Table 5 highlights and compares the various LPWAN systems in light of a wide variety of criteria. This allows for the selection of a technology based on the needs of a specific IoT application and its intended use. NB-IoT, Telensa, and SigFox do not support private network deployment, whereas LoRa and RPMA can be employed as private networks for the required application. Similarly, NB-IoT, Telensa, and SigFox support the adaptive data rate. Furthermore, LoRa and RPMA can minimise time on air and energy

requirements by using adaptive data rates depending on the separation distance between the gateway and node. As can be seen from the comparison, LoRa excels over RPMA in various respects, including data payload size, link symmetry and reduced power utilisation.

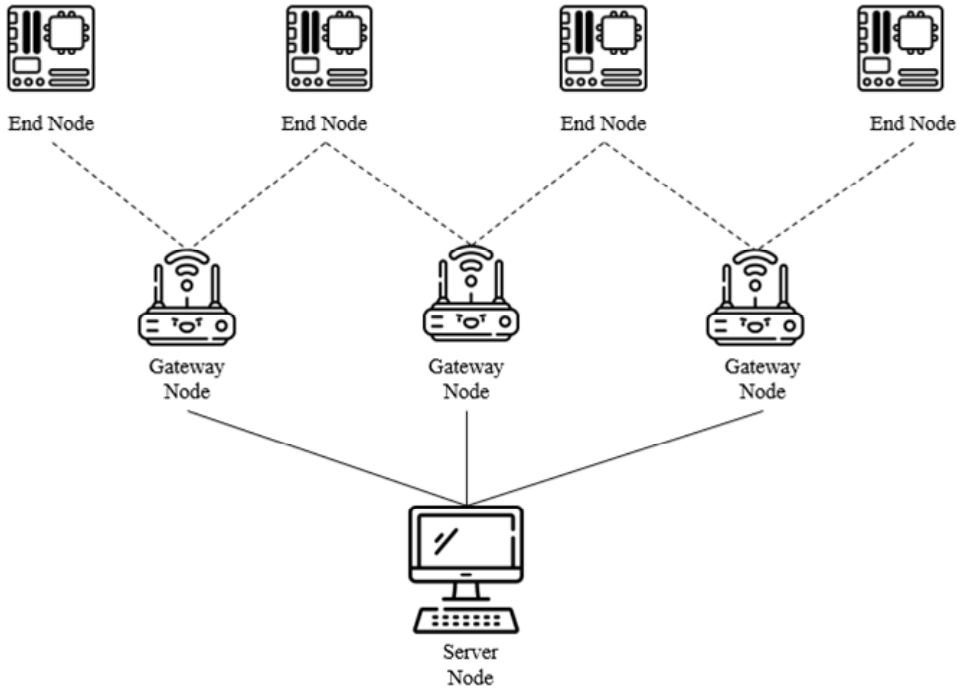
**Table 5** Analysis and comparison of LPWAN technologies

| <i>Technology</i>    | <i>LoRa</i>                                 | <i>RPMA</i> | <i>NB-IoT</i> | <i>SigFox</i>                    | <i>Telensa</i>                  |
|----------------------|---------------------------------------------|-------------|---------------|----------------------------------|---------------------------------|
| Frequency band       | 868 MHz,<br>433 MHz,<br>915 MHz,<br>430 MHz | 2.4 GHz     | 900 MHz       | 868 MHz,<br>902 MHz              | 868 MHz,<br>915 MHz,<br>430 MHz |
| Bandwidth            | 125, 250,<br>500 kHz                        | 1 MHz       | 180 kHz       | 1.5 kHz                          | 100 kHz                         |
| Adaptive data rate   | Yes                                         | Yes         | No            | No                               | No                              |
| Range                | 5 km–50 km                                  | 15 km–50 km | 1 km–40 km    | 3 km–50 km                       | 3 km–15 km                      |
| Data payload (bytes) | 250                                         | 64          | 13            | 12                               | 65                              |
| Security             | AES 128 b                                   | AES 256 b   | L2            | No or encryption at higher level | Yes                             |
| Power(Tx) dBm        | 21                                          | 21          | 35            | 24                               | 14                              |
| Topology             | Star of stars                               | Tree/star   | Star          | Star                             | Tree/star                       |
| Power usage          | Very low                                    | High        | Low           | Low                              | Low                             |
| Link-symmetry        | Yes                                         | No          | No            | No                               | No                              |
| Private network      | Yes                                         | Yes         | No            | No                               | No                              |
| Expenditure          | Extremely low                               | Low         | Reasonable    | Reasonable                       | High                            |

### 2.3 LoRa network architecture

Standard LoRa networks have the star-of-stars topology, as shown in Figure 4. This configuration uses three distinct types of nodes.

The following is a rundown of the major components that, when put together, make up a LoRaWAN network: LoRa is the protocol used for communication between end devices and gateways, which are then connected to the LoRaWAN network. Gateways route raw LoRaWAN frames from devices to a network server using a backhaul interface with a bigger capacity, commonly an Ethernet or 3G connection. This is accomplished by employing a backhaul interface with a larger capacity. As a direct result of this fact, gateways are essentially nothing more than relays or protocol converters that function in both directions. The network server decodes the packets received from devices and brings packets to be transmitted back to the devices. The available LoRa end devices are categorised by looking at the downlink scheduling.

**Figure 4** Architecture of a basic LoRa network

### 3 Related work

In this section, recent review papers relevant to the study have been discussed.

The activities on LoRa-based platforms are the focus of this study (Gkotsiopoulos et al., 2021), which looks at those activities. Their mode of functioning is broken down and classified according to the degree of technological advancement they have attained. Most of this study is dedicated to discussing a variety of key performance metrics that notably stand out. These variables can be broken down into five basic categories: the features of the physical layer, the characteristics of the installation and the equipment, the transmission parameters of the end device, the specifications for the LoRa MAC, and the requirements for the application. Each of these categories can be further subdivided into further subcategories as needed. Using the RSSI as a comparative metric, the researchers summarise the study on LoRa signal disruptions in this publication (Antoine-Santoni et al., 2022). Previous investigations were conducted in this field. In the second step of the process, we isolate the most important factors so that we may evaluate them in light of the information that was gathered inside the innovative framework of the Smart Village of Cozzano. This project is a scientific endeavour to develop electronic tools to preserve and keep an eye on the natural world. The analysis of the LoRa networks presented in Sundaram et al. (2020) presents a complete discussion of the technical obstacles involved with installing the LoRa networks and the solutions that are now accessible.

Saari et al. (2018) proposes a strategy for organising research articles on a wide variety of topics by using the categories that have been supplied. This study sheds light on the most recent breakthroughs in LoRa research and the numerous application cases that have been investigated. In addition, this study sheds light on the many application instances studied. In conclusion, this research will present academics and practitioners with some ideas on how they may make the most of the advantages supplied by technologies based on LoRa in creating IoT systems and solutions. These ideas will help them make the most of the advantages offered by technologies based on LoRa in developing IoT systems and solutions. This advice will centre on how they make the most of the opportunities presented by these technologies to their advantage.

Sarker et al. (2019) investigate a variety of application fields for LoRa and their linked activities. In addition, they discuss possible chances for improvement and factors that are related to these application fields. In addition, to improve the overall performance of applications based on IoT, we have built a generic architecture capable of combining edge computing capabilities. This was done to raise the overall performance. Devalal and Karthikeyan (2018), which compares LoRa to other IoT technologies currently in use, discusses the benefits that LoRa possesses over those other technologies. In addition to that, it talks about the characteristics that are associated with the LoRa protocol. The open-grade security provided by the LoRaWAN standard is used to connect to the IoT. Table 6 summarises and compares the relevant work of LoRa and LoRAWAN technology.

**Table 6** Summary of relevant work in the field of LoRa and LoRaWAN technology

| <i>Ref.</i>                   | <i>Technology</i> | <i>Comment</i>                                                                                                                      |
|-------------------------------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| Ortiz et al. (2020)           | LoRa              | Experimental and modelling data are used to evaluate LoRa technology for automotive communication.                                  |
| Sundaram et al. (2020)        | LoRa              | Assessment of LoRaWAN's IoT utility.                                                                                                |
| Lavric and Popa (2017)        | LoRa              | LoRa modulation assessment favouring the requirement of IoT.                                                                        |
| Qin et al. (2019)             | LoRa, IoT, NB-IoT | Provides a quick review of LPWAN-enabling technologies.                                                                             |
| Antoine-Santoni et al. (2022) | LoRa/LoRaWAN      | Reviews current developments in energy efficiency, communication range, error correction, and multiple access that pertain to LoRa. |
| Marais et al. (2020)          | LoRaWAN           | Examines the newest LoRaWAN implementation, which is dependent on verified traffic.                                                 |
| Boquet et al. (2021)          | LoRa/LoRaWAN      | Describes the theory behind long range frequency hopping spread spectrum for future use.                                            |
| Ghazali et al. (2021)         | LoRa/LoRaWAN      | Analyses the state of the art in LoRa-based real-time communications for unmanned aerial vehicles.                                  |
| Cheikh et al. (2022)          | LoRaWAN           | It provides an overview of energy efficiency in LoRaWAN networks and suggests future areas of investigation.                        |

In every one of these survey articles, the topic of the wireless networking technology known as LoRa is brought up for discussion. According to the data presented in this

section, the writers of each study address LoRa from the perspective of their research projects. This study also explores the LoRa technology from various viewpoints, such as application requirements, specifications, deployment cost, and challenges that have yet to be addressed in any prior studies mentioned in combination.

## **4 Constraints in LoRa and LoRaWAN technology**

Researchers are looking into the difficulties that are brought up by the use of LoRa communication. The extent to which these issues disrupt the typical functioning of the LoRa system is one way to evaluate the gravity of the situation that has arisen. This section reviews many issues with LoRa networks and provides practical solutions based on recent studies. To overcome some of these challenges, in-depth evaluations of their effect on the LoRaWAN network's capabilities are performed.

### *4.1 Energy consumption*

The incredibly high amount of power that LoRaWAN needs to operate is the one aspect of this technology that stands out as the most problematic. This is a necessary component that must be present to increase the amount of time that cutting-edge technology continues to perform correctly. During the 5 to 10 years that LoRa bridges are expected to have a lifespan (Gao et al., 2020), it is envisaged that they will require very little to no maintenance. One of the most significant issues related to LoRa communication is the quantity of power it requires. In Bouguera et al. (2018), the authors introduced an efficient energy model for sensor nodes that operates on the LoRa/LoRaWAN network. The sensing, MCU, and transmission units evaluated the proposed models to reduce energy loss. The energy consumption of each LoRa node subsystem was modelled independently so that consumption could be compared. The proposed model shows how the sensor's performance changes depending on the hardware and software options. It also shows how different LoRa/LoRaWAN parameter choices and transmission acknowledgment might affect the data transfer. Thus, it is essential to optimise the spread factor, payload size, BW, and coding rate in order to reduce the energy consumption of the final devices.

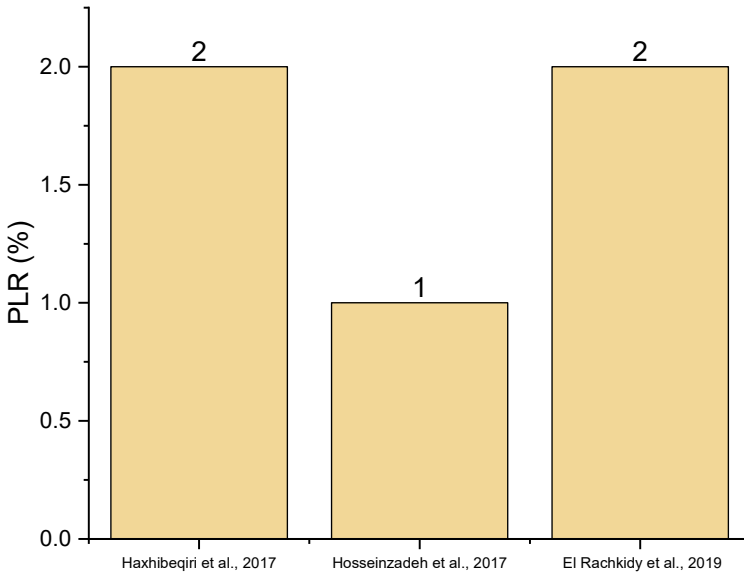
In Casals et al. (2017), a model of the power profile of a LoRaWAN end node is shown. The model accounted for the impact of the BER that remained after bit errors were corrected using FECs. The possibility of collisions is also considered. In Cheong et al. (2017), the authors analysed how long various LoRaWAN terminals lasted on a single charge. Voltage and current drain are initially measured for each end device type. The measurements are used to compare with the end node data sheets. The battery life is then estimated for nearly a decade, considering a wide range of packet sizes, data transfer times, signal strengths, and types of mobile devices. There will probably always be some level of traffic. A report on the power savings achieved via LoRa is provided in Ochoa et al. (2017). Increasing the SF while keeping the transmit power constant has been shown to increase energy consumption more quickly. Therefore, optimising the ADR mechanism requires prioritising an increase in transmit power for a better range over an increase in SF. The power consumption profile of the Semtech SX1272 chip is modelled in Kumar et al. (2023). The estimated battery life at sensing intervals of 1–5 minutes is

1–5 years. Depending on the sensing interval, energy harvesting from renewable sources can double or even triple the battery life from 4 to 12 years.

#### 4.2 Coverage area

The network's reach is affected by the spread factor, the transmit power, channel BW, and the deployment setting of the gateways and end nodes. Much empirical study has been done on coverage outside and from inside to outside. In Petäjärvi et al. (2016), the authors discuss a measuring campaign in Oulu, Finland. The gateway was mounted atop an antenna tower at a height of 24 metres above ground. Despite an RSSI of over 100 dBm, the packet loss ratio (PLR) was 13% at a distance of just 2 km. An archival 2 kilometre range was used for coverage tests in a densely populated urban region with multi-storey structures (Centenaro et al., 2016). In Augustin et al. (2016), a LoRa gateway was put in place on the loft level of a suburban house. With 20% PLR, SF12 coverage might go as far as 2,800 m. LoRa's indoor coverage has been the subject of multiple research (Wixted et al., 2017; Neumann et al., 2016; Petäjärvi et al., 2017; Haxhibeqiri et al., 2017; Hosseinzadeh et al., 2017). With RSSI values greater than 70 dBm, LoRa provides sufficient building coverage (Hosseinzadeh et al., 2017). Under these conditions, any SF can be used for communication. In addition to indoor communication, LoRa can be used with SF7 to enable connectivity in a 34,000 m<sup>2</sup> industrial area (Haxhibeqiri et al., 2017). By using larger SFs, the coverage area can be stretched even further. The abstract of the network performance of LoRaWAN is depicted in Table 7.

**Figure 5** Indoor measurement of PLR (see online version for colours)



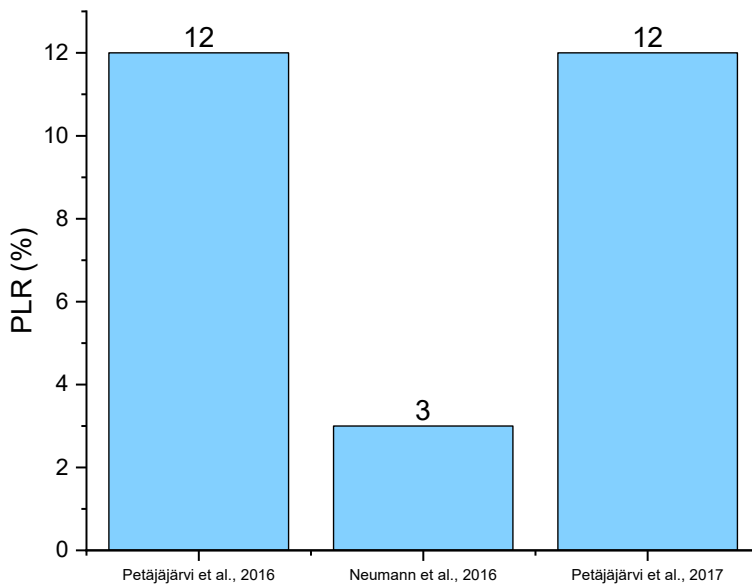
Figures 5 and 6 illustrate the PLR from different investigations for the same gearbox design. Generally, up to a kilometre coverage can be easily achieved in city areas employing SF7. Higher SFs (SF12) should be used for extended coverage beyond 2 km.

The distance from the gateway was ~60 m for indoor measurement, and for case outdoor measurement, it was ~2 km.

**Table 7** Performance evaluation of LoRaWAN deployed setups

| <i>Ref.</i>            | <i>Experimental area</i> | <i>Remarks</i>                                           |
|------------------------|--------------------------|----------------------------------------------------------|
| Bouguera et al. (2018) | Outdoor environment      | Coverage of 2 km distance using SF12<br>RSSI > -90 dBm   |
| Casals et al. (2017)   | Outdoor environment      | Coverage of 2 km distance using SF12                     |
| Cheong et al. (2017)   | Indoor environment       | Coverage of 60 m distance using SF12<br>RSSI > -100 dBm  |
| Ochoa et al. (2017)    | Industrial area          | Coverage of 190 m distance using SF12<br>RSSI > -100 dBm |
| Kumar et al. (2023)    | UG coal mine             | Coverage of 150 m distance                               |

**Figure 6** Outdoor measurement of PLR (see online version for colours)



### 4.3 Security issues

Since the number of LoRa links keeps increasing and LoRa is thought to have several design flaws, privacy, and security are crucial factors. On the other hand, LoRa's physical abilities have made her vulnerable to new, powerful attacks that are hard to protect against. Also, the high power efficiency requirements make it hard to setup effective defences. LoRa and LPWANs in general have a serious security problem because of their devices' limited resources.

El Rachkidy et al. (2019) investigated the critical management techniques deployed in LoRaWAN environments. They provided a safe management architecture predicated on smart contracts and a permission blockchain to bolster LoRaWAN network security and

availability. A prototype of the blockchain-based LoRaWAN architecture was built using open-source software and hardware to evaluate its viability. In Tsai et al. (2020), the authors suggest a two-session S2KG essential generation procedure using join server-related and symmetric key-based links. Message privacy, confidentiality, and reciprocal authentication are all possible with the proposed S2KG method. It protects against replay eavesdropping attempts as well. LoRaWAN communication channels can be made exceedingly secure with the help of a session-key management technique. The study also ignored join server and manufacturer security instead of server-to-server security, which has to be addressed in future studies.

#### 4.4 Scalability

LoRa installations will connect many endpoint devices, each of which can monitor for activity. In addition, the capability of this technology needs to be evaluated before determining whether or not it can be scaled. As a direct consequence of this, studies on the capabilities of LoRaWAN for use in urban deployments and specific port installations have been carried out. According to a study that looked at transmission speed and propagation distance, the maximum bit rate possible is the one that should be used for LoRa implementations that are used in urban settings. Even though the connection speed is slower than the maximum, the terminal occupancy rate in each area does not vary by the provided assumption.

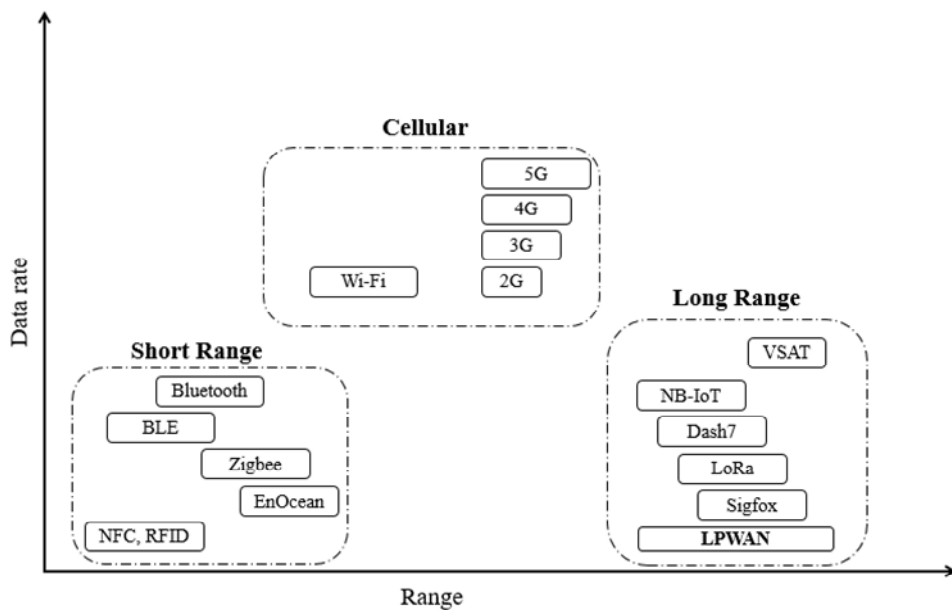
Using a mathematical model of the transmission process, the authors assess the scalability of LoRaWAN networks and describe their findings and model (Bankov et al., 2016). After extensive testing, they determined the network could not support more than 1% of 51-byte frames each second.

In Georgiou and Raza (2017), we see the fruits of a study into LoRaWAN's scalability that uses a stochastic geometry framework. Researchers demonstrated a substantial decrease in expected coverage as the endpoints rose. Theoretical limits on the scalability and throughput of LoRaWAN networks have been the subject of much research (Sanchez-Iborra et al., 2018). Consequences of interference were studied in highly populated LoRaWAN cells. The authors looked on the co-distribution problem that prevents LoRaWAN networks from expanding. These experiments showed that properly configured LoRaWAN networks are necessary to link a sizable number of end devices. The performance of LoRaWAN technology was evaluated in Lavric and Popa (2018) by looking at the likelihood of packet collisions. According to the results, efficiency drops sharply as the number of devices reliant on the ALOHA protocol's communication mechanisms increases. Bor et al. (2016) suggest increasing LoRa scalability by installing more gateways. The authors developed a simulator called LoRaSim, which was written in Python. They left the network with a single gateway, which is bad for scalability given the volume of data being transferred often. Networks with multiple gateways or those with dynamic transmission settings may still be vulnerable to this. According to the research results, the LoRa network's scalability improves if the optimal configuration choices also decrease the ToA.

## 5 Future prospective and direction

The deployment of wireless communication is determined by various factors, including end-node dispersion, scalability, and environmental considerations. Frequently, the utilisation of a hybrid connection is vital in order to enhance production. Figure 7 presents a comparative analysis of different connectivity modules for the IoT, focusing on their data rate and range characteristics. Because LoRa is often used by IoT applications to allow long-range communication, one of the most interesting future study areas for LoRa will be to find ways to integrate LoRa into various systems. This will be one of the most critical study directions because it will be one of the most important ways to use LoRa. Edge computing, 5G networks, and LoRa are just a few of the many other topics that may be discussed concerning these challenges. There are a great many more. But other choices could be taken into account.

**Figure 7** Radio communication technology comparisons



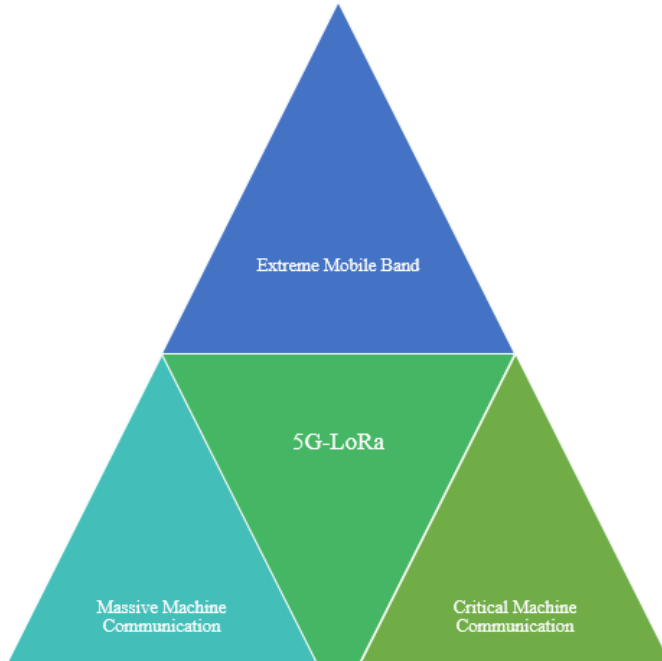
Source: Mekki et al. (2019)

### 5.1 LoRa-5G integration

5G is an excellent choice for apps requiring a high data transfer rate and low latency. The value of the LoRa technology lies in letting devices talk to each other over a long distance. The LoRa technology's ability to cover a large area of communication is an outstanding achievement. Considering everything, it is only a perfect fit for some systems. This could be because of the limitations of the innovation itself or the high cost of chips for new companies. Bluetooth, ZigBee, and WiFi are the most effective ways to send and get info over short distances. The significant reasons for LoRa-5G integration are as follows:

- a It can connect billions of IoT end devices at a density of one million per square kilometre, whereas LoRaWAN can compromise the restrictions of present cellular technologies (Branch et al., 2020).
- b Dual deployment of LPWAN and cellular networks is standard practice among industrial operators, complicating and increasing the cost of models. The potential of the 5G system to act as the backbone connectivity and administration services makes LPWAN implementation far more straightforward, cheaper and more resilient.

**Figure 8** Scope of 5G-LoRA integration (see online version for colours)



LPWAN technologies are expected to supplement 5G networks to accommodate various applications. They operate in unlicensed bands, have minimal power consumption, comprehensive coverage, low costs and are scalable. Adopting a hybrid network with a single management structure and LoRaWAN integration into 5G can significantly reduce the operator's capital and operational costs.

Mekki et al. (2019) featured a complete examination of LPWAN technologies that can be employed as effective connections for heterogeneous, intelligent, autonomous, and large-scale IoT implementation. Wu et al. (2020) thoroughly investigated the possible characteristics, methodologies, and security hazards of LPWAN. The research focuses on the security problems related to LPWAN and IoT adoption in 5G. The author offered a quick description of the primary enabling technologies in Fujdiak et al. (2020), covering cutting-edge technology for 5G IoT applications. According to Torroglosa-Garcia et al. (2020), the LoRa end device contains the 5G UE's fundamental components, making it capable of 5G communication. In Taneja (2016), multiple intermediate gateways replace LoRaWAN gateways and provide data to the network server over LTE as the backhaul. These gateways can accept the packets from the terminals and then send them on to the

eNodeB. A novel traffic management method was proposed to reduce the load on LTE: picking the optimal eNodeB and gateway for each uplink. Actility (<https://www.actility.com/>) and Simfony (<https://www.simfony.com/>) announced in April 2021 that they will work together to develop a multi-technology IoT platform that may provide MNOs and MVNOs with a single platform to oversee both LoRaWAN and cellular IoT networks.

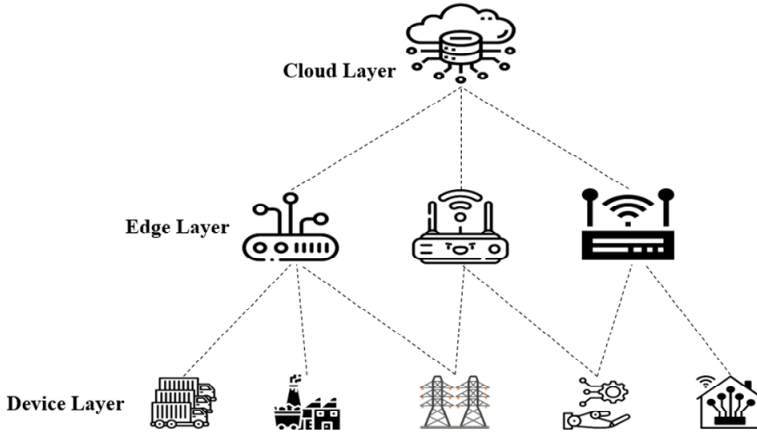
## 5.2 Edge computing with LoRa/LoRaWAN

In the past, cloud computing handled information from many different places. However, because its latency is hard to predict, cloud computing needs help responding in real-time to performance-sensitive and safety-critical apps (Sarker et al., 2019). Edge computing is a new way of thinking about computing that includes moving data processing or storage to the ‘edge’ of a network to free up resources at the central computer. Drăgulinescu et al. (2022), Gia et al. (2019) and Hou et al. (2021) have many papers on LoRa-related edge computing. These studies examine various topics, including medicine, farming, Bitcoin, smart meters, smart cities, artificial intelligence, and many more. In Ferreira et al. (2019), LoRa and Bluetooth worked together to create a low-power intelligent city network. This network was made to collect data on various day-to-day activities, such as the status of different forms of transportation, health information, and so on. The data is made and sent to the LoRa edge gateway using short-range Bluetooth. The data is then sent to the LoRa fog gateway using longer-range LoRa networks. The LoRa edge and fog gateway will do the first processing of the data. The concept of ‘edge-native applications’ that entirely use edge computing capability while maintaining a stable connection is introduced in Satyanarayanan et al. (2019). These custom applications could make use of edge computing’s:

- a scalability in network BW
- b low-latency offload
- c privacy protection
- d resilience in the face of WAN failure.

Figure 9 depicts the fundamental framework of an edge-assisted LoRa application. In addition to typical IoT architecture, the supplied architecture adds a layer of edge-assisted gateways.

Sensor nodes placed at the ground’s surface can collect a wide range of information and relay it to an edge-assisted gateway using either nRF or Bluetooth low energy over LoWPAN. High-computing hardware, a fixed installation, and either wall power or a sizable battery are standard features of the edge-assisted gateway. Therefore, the edge-assisted gateway can run complex algorithms for extended periods without degrading performance. Theoretically, these protocols consume roughly 70 mW of power and have a maximum data rate of 250 kbps (Gia et al., 2015, 2018). Data flattening at edge-assisted gateways can be performed lossily or losslessly, depending on the use case. To make the most of the available BW, data is compressed and filtered before being sent to a LoRa gateway with the help of an edge-assisted gateway (Rahmani et al., 2018). In addition, data can be examined at edge-assisted gateways to extract crucial information before being transmitted to LoRa gateways, thereby conserving BW.

**Figure 9** Basic architecture of IoT-edge computing integration

## 6 Conclusions

LoRa communication standard is well recognised in the field of IoT because to its extensive array of benefits. LoRa has garnered significant attention from the academic community in recent years. Numerous studies have been undertaken as a consequence of this. The widespread use of the IoT has resulted in a rise in the utilisation of LoRa-based applications. LoRa represents a promising novel standard in the realm of cost-effective and energy-efficient wireless communications. LoRa enables enhanced connectivity between IoT devices and the underlying data processing platforms, facilitating more direct linkages. SSM enables broad coverage and enhanced signal penetration across various obstacles, such as buildings. The utilisation of unlicensed frequencies offers numerous applications the opportunity to circumvent the expenses associated with licensing agreements, rendering it a highly appealing option. This article presents a comprehensive analysis of the technical prerequisites that the technology must satisfy, while also offering a detailed exploration of LoRa networks. Moreover, it provides an extensive list of unresolved concerns pertaining to LoRaWAN and proposes many prospective applications for the technology in forthcoming times. The primary objective of this research was to provide a foundation for future endeavours focused on enhancing the performance of LoRa/LoRaWAN networks, with the ultimate goal of facilitating more practical deployments.

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