

Long range technology for internet of things: review, challenges, and future directions

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ABSTRACT

New networking issues are presented by the increasing need for a wide variety of applications, which has spurred the creation of a new internet of things (IoT) paradigm, such as long range (LoRa). The LoRa protocol uses a patented kind of spread spectrum modulation to provide low-power, long-range communication. In this paper, we provide a comprehensive review of LoRa-IoT in terms of IoT applications, LoRa class, security and privacy requirements, and the evolution of LoRa technology. This review analysis and compares long range wide area network (LoRaWAN) to wireless technology (e.g., Bluetooth, LoRa, 5G, Sigfox, long term evolution-M (LTE-M), Wi-Fi, Z-wave, Zigbee) and provides a list of environment simulators (e.g., OMNeT++, MATLAB, ns-3, SimPy) to carry out experiment for LoRa-IoT. Finally, this review does not only review literature recently studied for LoRa-IoT but also discusses challenges and future directions.

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1. INTRODUCTION

Significant internet of things (IoT) expansion in recent decades has led to an explosion of applications in the smart city [1], industrial [2], and farming [3]. IoT uses short-range wireless standards (Zigbee, Bluetooth) and cellular technology (e.g., 4G, 5G) [4]. These outdated wireless technologies are constrained by communication range and energy consumption for tens of billions of IoT devices. Long range (LoRa) and energy-efficient communication demands have inspired low power wide area networks (LPWANs) as a new IoT paradigm, which fills the gap of traditional wireless communication technologies. LoRa's open-source privilege (running in the unlicensed sub-GHz ISM band) and low-cost commercial-off-the-shelf (COTS) devices indicate considerable potential in industrial and research communities.

LoRa is based on the unique spread spectrum modulation technology chirp spread spectrum (CSS), which is highly resistant to interference and noise. This modulation method, together with the great sensitivity offered by LoRa, makes it possible to receive the potentially weak signals at exceptionally low energy consumption, significantly improving the connection budget to support a large coverage area [5], [6]. Based on LoRa, long range wide area network (LoRaWAN) defines the standard star-topology network architecture and

the protocol used for bidirectional communication between nodes. There are already 163 LoRaWAN network operators in 177 countries [7], deploying LoRa networks for a wide variety of use cases that call for widespread, low-latency rollout [8].

Since LoRa's inception, numerous studies have been presented on it as a result of its widespread use and bright future potential. Therefore, this finding has prompted a number of survey publications [9] on LoRa in the last six years. Particularly, early studies [10], [11] provided overviews of LoRa, focusing on introductory background and fundamentals, laying the groundwork for subsequent investigation. Only a tiny percentage focused on narrow topics like testbed [12], simulator [13], security [14], and mesh topology [15]. The LoRa network has recently been the subject of several exhaustive survey proposals [9], [16].

The rest of this manuscript is provided as follows. Section 2 reviews the literature review in detail. Section 3 shows the explanation of long range technology for the internet of things (LoRa-IoT). Section 4 compares LoRaWAN with previous wireless technology. Section 5 provides a list of simulators used for LoRa-IoT. Section 6 discusses challenging and future work. Lastly, we conclude this paper in section 7.

2. LITERATURE REVIEW

Numerous researchers have been focusing on various topics over the last few years to comprehend the performance, features, and other practical concerns for the adoption of LoRa technology in a variety of disciplines. Receiver sensitivity, network coverage, network capacity, and scalability are additional factors that must be taken into account while implementing the LoRa technology. These are in addition to advanced physical layer and medium access control protocols.

Wang *et al.* [40] described an adaptive data acquisition-based massive landslide intelligent sensing monitoring technique. A detailed introduction to the hardware, software, and general structure design of the intelligent sensing monitoring technology was provided. Rapid perception of environmental changes and adjustments to the deformation factors of landslide disaster bodies were made possible by technology. The adaptive data collecting approach is well suited to capturing unusual alterations in the disaster bodies' monitoring parameters.

The LoRa Semtech SX1272 transceiver was examined in [41] to test its communication abilities and energy consumption patterns. Various unique communication features of this transceiver were found that might be used in the deployment of this technology. Bor *et al.* [41] proposes LoRa-Blink as a new physical layer protocol that facilitates multi-hop communications.

The goal of Augustin *et al.* [42] is to identify the issue relating to the network capacity constraint by evaluating receiver sensitivity. According to Augustin *et al.* [42], different received signal strength indications (RSSI) for various spreading factors were evaluated and compared in order to assess receiver sensitivity. It is also clear from the result that greater spreading factors must be chosen in order to expand the network coverage area.

By conducting simulations and experiments, Bor *et al.* [41] focused on the network scalability aspect when adopting LoRaWAN and highlighted the elements that limit network scalability as duty cycle, sub-band subdivision, and transmitter count. The duty cycle, on the other hand, restricts the size of the network, as was demonstrated by [43] by mathematical modeling. It also conducted network quality research by sending packets between a large number of endpoints, concluding that collisions constitute the primary constraint on network capacity.

Research by Mikhaylov *et al.* [44], first considered a single LoRaWAN end device to assess its uplink throughput and transmission duration, and then numerous end devices were connected to a single LoRaWAN base station to observe the data traffic conditions while taking various application scenarios into consideration. Depending on the distance from the base station, one base station can support a variety of end devices. The adaptability of LoRaWAN technology to internetwork interference was tested in Mikhaylov *et al.* [45]. According to Mikhaylov *et al.* [45], greater data rates are more susceptible to interference than lower data rates, while LoRa-modulated data rates are less susceptible than FSK-modulated ones.

Magrin *et al.* [46] suggested technique for modelling LoRa links and utilising the ns-3 simulator to assess the performance of LoRa networks. According to simulation data, a gateway connected to 104 devices across a LoRa network has a throughput that is higher than that of ALOHA-based networks. The network is also scalable, dependable, and has a 95% packet success rate. The effectiveness of LoRa technology in both indoor and outdoor settings Wixted *et al.* [47]. A location was chosen within Glasgow's core business district

(CBD), which features glass skyscrapers, sandstone structures with up to seven stories, flat river plains, and hills that rise to a height of 50 metres.

Druagulinescu *et al.* [48] examined the development of LPWANs and the internet of medical things, highlighting both its benefits and shortcomings. This article also suggested brand-new LoRa-based medical IoT designs for home healthcare and hospital services. Islam *et al.* [49] suggested a flexible architecture for home automation that makes use of Bluetooth connectivity, LoRaWAN, and server-based LoRa gateway in addition to other communication technologies. The many household appliance types are successfully controlled by this integrated system, which also maintains intelligent management of all the electrical components.

Prade *et al.* [50] introduced multi-LoRa, a multi-radio and multi-hop LoRa communication architecture that will improve the service and coverage for widespread IoT deployment in rural areas. For the purpose of physically implementing the multi-LoRa architecture, we provide a hardware prototype. The findings demonstrate that multi-LoRa significantly reduces the challenges associated with multi-hop LoRa communication for large-scale IoT implementation. Comparing several multi-LoRa setups on a small-scale physical testbed and a large-scale simulation environment, multi-LoRa lowered the delay by 60% and the packet loss by 2.9%.

3. LONG RANGE TECHNOLOGY FOR INTERNET OF THINGS

3.1. Internet of things

3.1.1. Overview

The IoT is a network of interconnected computing devices, appliances, buildings, vehicles, and other items that enables them to exchange data and coordinate their operations in ways that improve service delivery and simplify user lives in previously unimaginable ways. Sensors, actuators, smart phones, and other similar devices are all examples of intelligent things. Smart homes, smart cities, smart agriculture, smart retail, smart healthcare, are just a few of the many possible IoT applications. In 1999, while at the auto-ID center, Kevin Ashton first proposed the concept of the IoT radio frequency identification (RFID). These days, there are more internet-connected things than people. As many as 20 million internet-enabled gadgets will populate the planet by 2020, according to a recent study.

3.1.2. IoT applications

As can be seen in Figure 1, IoT has many potential uses in many different domains, including the domestic sphere, medical care, manufacturing, commerce, transportation, security, and more. As an example of IoT's usefulness, consider the following:

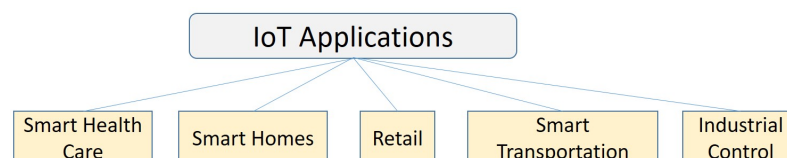


Figure 1. Applications of IoT

- Smart health care: patients, especially the elderly who need round-the-clock care, will benefit from the integration of IoT features into medical devices because it will enhance the quality of the services they receive. The IoT can be put to use in a variety of settings, including hospital and home care for the elderly, monitoring of medication and vaccine storage refrigerators, and patient monitoring [17]–[19].
- Smart homes: in the future, our homes will be “smart,” meaning that we’ll be able to control all of our appliances from our computers and phones. Smart metres allow us to monitor not only energy use but also temperature [20], [21].
- Smart transportation: the IoT is used to track the location of goods in large storage facilities or ports, to ensure that goods are shipped in pristine condition, and to monitor the paths taken by particularly valuable or sensitive items (such as gold and pharmaceuticals) [22], [23].
- Retail: product tracking and temperature monitoring are two additional uses for the IoT. It can be used to tailor product recommendations to individual customers and automate the process of replenishing stock in a store’s shelves and storage facilities [24]–[26].

- Industrial control: the IoT is used in manufacturing settings for air quality monitoring, temperature tracking, ozone detection, and emergency alerts [27]–[29].

3.2. Long range technology

3.2.1. Overview

When it comes to wireless networking, the IoT is the cutting edge, and LPWAN is the technology that made it possible. LoRa, a proprietary technology developed by Semtech in 2012, is the newest LPWAN [30]. With LoRa, there are two distinct layers involved: i) the physical layer, which employs the CSS modulation technique [31] and ii) the media access control layer, which employs a protocol (LoRaWAN). That's because it's built with CSS technology. LoRa technology supports multiple bandwidths, including 125, 250, and 500 kHz [32]. The chirp signals' frequencies shift over time, but the phase between neighboring symbols remains fixed. The receiver is better able to decode the signal with an attenuation level 19.5 dB below the noise signal if the chirp signals' rates of frequency variation are low [33], as shown in Figure 2.

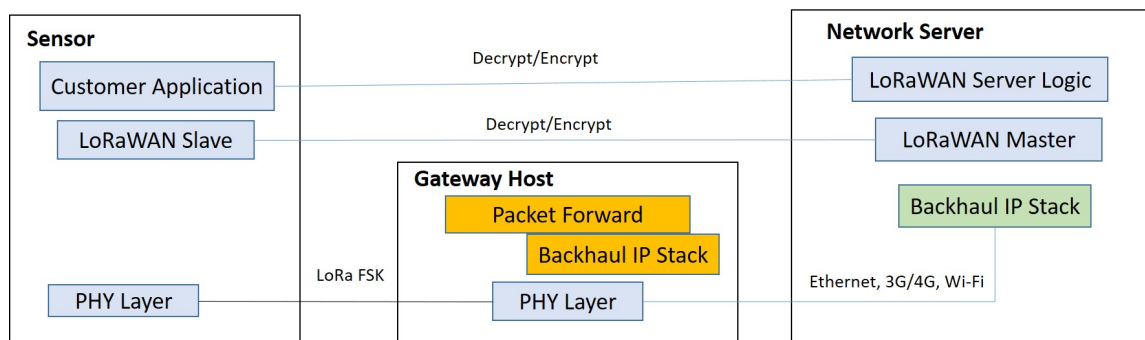


Figure 2. Layer of LoRa network diagram

3.2.2. LoRa class

LoRa WAN's safety is ensured by the IEEE 802.15.4 protocol. A unique app key [34] is generated for each LoRaWAN device. As shown in Table 1, LoRaWAN can be broken down into three distinct categories. These classes are provided as follows:

- Class A: LoRa class A devices are employed in numerous low-powered sensor networks because they are more energy efficient and can withstand longer periods of latency.
- Class B: allows for beacon-time synchronization. Also linked to low-power gadgets, but end nodes can learn about the listening window thanks to beacons.
- Class C: has a high number of available reception slots but minimal latency time. These are two-way, but they require an additional power source.

Table 1. Network simulators in LoRa technology

Class A	Class B	Class C
Battery powered	Low latency	Low latency
The server can communicate with the end device at a predetermined window	The server can communicate at set intervals	End devices are always getting
Small payload	Small payload	Small payload
Communication is started by the end devices	Ping slots	Communications may be started by the server
Bidirectional	Bidirectional with receive slots	Bidirectional
Unicast	Unicast and multicast	Unicast and multicast

3.2.3. Evolution of LoRa technology

This part provides a good understanding of the development of LoRa technology. A new perspective for the research community is provided. The four parts are described as follows:

- Communication: many efforts have been made to improve the throughput, range, scalability, and energy consumption of LoRa systems.

- Analysis: LoRa performance testing studies seek to research and analyze LoRa bandwidth utilization in diverse situations, which may also serve LoRa communication, security, and its enabled applications works.
- Security: transceiver cybersecurity is delicate but vital, getting significant attention in vulnerabilities and countermeasures, along with PHY layer security approaches.
- Enabled applications: wide adoption of LoRa networks has inspired a variety of applications, including backscatter, sensing, and mobile network integration.

4. ANALYSIS OF LORAWAN IN CONTRAST TO PREVIOUS TECHNOLOGY

Technology has advanced to the point where many different options are available for use in IoT implementations. Each technological advancement comes with its own set of benefits and drawbacks. Every IoT use case requires a different technology [35]. As shown in Figure 3, the wireless technologies and LoRaWAN are compared as follows.

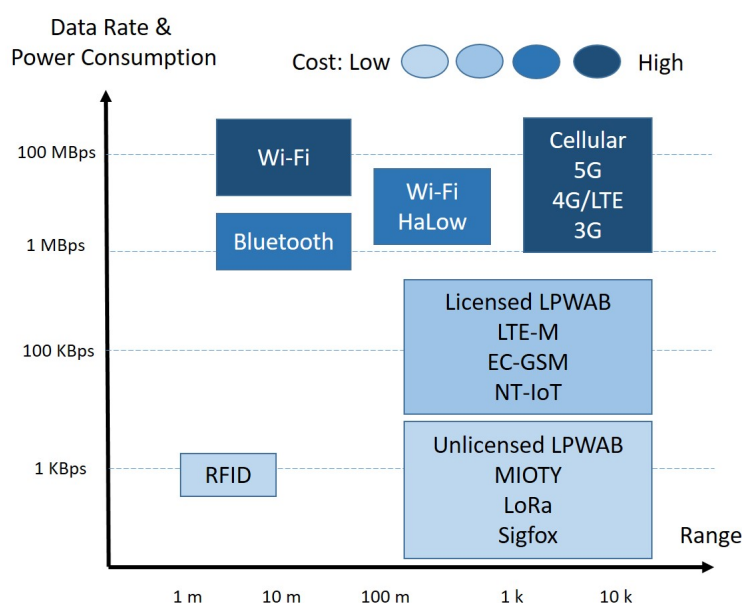


Figure 3. Comparison between LoRaWAN and other wireless technologies

4.1. LoRaWAN versus Bluetooth wireless technologies

Both LoRa and Bluetooth can be considered important contributors to the IoT. Actually, they could all be easily combined into one for enhanced performance. With the exception of Bluetooth low energy, Bluetooth uses more power than LoRa even though it is less power-hungry than Wi-Fi and LTE. Its shorter range than LoRa makes it well-suited for nearby devices.

4.2. LoRaWAN versus LoRa wireless technologies

Despite their differences, most people use these terms interchangeably. It all works its way down to the layer of the telecom device where the network makes contact. LoRa is a radio wave carrier signal that communicates with the hardware of a device. A LoRa modem allows you to convert data into wirelessly transmittable signals. LoRa is similar to other networks (Wi-Fi and Bluetooth), but it excels in two key areas: communication range and receiver sensitivity.

4.3. LoRaWAN versus 5G wireless technologies

Even though 5G is superior, LoRaWAN is being used as a stopgap until it can be fully replaced by 5G. In a perfect world, 5G would allow for the transmission of more data at a higher rate and with less interference. However, 5G won't be a practical option until the necessary infrastructure is set up, which will take time and money.

4.4. LoRaWAN versus Sigfox wireless technologies

Explaining the differences between LoRa and Wi-Fi can be challenging, so let's start at the beginning. Low power consumption, high bandwidth, and extended range are all desirable qualities in a network, but only two can be present at once. While Wi-Fi has the potential to offer the fastest data transfer rates, it also has significant limitations in terms of battery life and wireless range. Most networks aren't reliable enough for widely dispersed IoT gadgets because their range drops below 15 metres after that.

4.5. LoRaWAN versus LTE-M wireless technologies

Like other forms of cellular technology, long term evolution-M (LTE-M) has long since become established. The network's data throughput is high, but its battery life isn't up to par. In addition, LTE-M is difficult to roll out, making it inappropriate for rapid deployment initiatives.

4.6. LoRaWAN versus Wi-Fi wireless technologies

Comparing LoRa and Wi-Fi can be difficult to explain, so let's start at the beginning. You can only have two of the following three features in a network type: low power consumption, high bandwidth, and long range. Wi-Fi may be the best option when it comes to data transfer rates, but it has serious drawbacks when it comes to battery life and wireless coverage. The inability of most networks to function beyond 15 metres makes them unsuitable for dispersed IoT devices.

4.7. LoRaWAN versus Z-wave wireless technologies

Both Z-wave and Zigbee are low-power communications that transfer data over short and medium. Over short and medium distances using a mesh protocol. LoRa, on the other hand, uses a star network topology in which each node talks to a single gateway.

4.8. LoRaWAN versus Zigbee wireless technologies

LoRaWAN's primary selling point is its low-cost, long-range, and low-power sensing. LoRaWAN's making a formidable competitor to Zigbee. A key distinction between LoRa and Zigbee is that the former employs a star network topology and the latter a mesh one.

5. SIMULATORS

Through the replication of communication exchanges in networks, a simulator of network is a virtual device used to investigate system-level or link-level performance. The definition of the network configuration (such as the propagation, parameters, and topology models), event simulation (such as downlink and uplink), and performance assessment are the typical components. When large-scale testbeds are not available or are impractical to employ, simulations are frequently utilised to evaluate theoretical models. Current well-liked LoRa network simulators are shown in Table 2, along with the capabilities they offer. The description of network simulators is listed as follows.

Table 2. Network simulators in LoRa technology

Environment	Simulator	Year	Developer
OMNeT++	FLoRa	2018	Slabicki <i>et al.</i> [36]
MATLAB	LoRaWANSim	2021	Marini <i>et al.</i> [37]
ns-3	LoRaWAN	2020	Finnegan <i>et al.</i> [38]
SimPy	LoRaWANFREE	2019	Abdelfadeel <i>et al.</i> [39]

- OMNeT++: for OMNeT++ end-to-end LoRa simulations, Slabicki *et al.* [36] created FLoRa. Then, in order to manage link parameters dynamically for scalable and effective network operations, Slabicki *et al.* [36] build and test the adaptive data rate (ADR) mechanism included with LoRa. However, this proposal does not support the features of class C and SF quasi-orthogonality in the LoRa network. While the rest of the features (such as topology configuration, parameters configuration, MAC command, bi-directional traffic, propagation model, duty cycle, and node's energy consumption) are fully supported.
- MATLAB: for the sake of completeness, Marini *et al.* [37] introduced LoRaWANSim in the MATLAB environment, a current simulator that defines the LoRaWAN network behavior with regard to PHY, MAC, and network features. All the features (such as class C, SF quasi-orthogonality, topology configuration, parameters configuration, MAC command, bi-directional traffic, propagation model, duty cycle, and node's energy consumption) are fully supported.

- ns-3: by integrating ADR into the LoRaWAN module in ns-3, Finnegan *et al.* [38] expand its functionality and make it possible to simulate authentic LoRaWAN networks as well as incorporate the latest improvements. However, this proposed does not support the class C feature in LoRa network. While the rest of the features (such as SF quasi-orthogonality, topology configuration, parameters configuration, MAC command, bi-directional traffic, propagation model, duty cycle, and node's energy consumption) are fully supported.
- SimPy: Abdelfadeel *et al.* [39] suggested LoRaWANFREE, a precise scheduling system for dependable and economical data collecting. By providing synchronised bulk data transmission, FREE takes advantage of applications that do not have strict criteria for data delivery delays. However, this proposed does not support the class C feature in LoRa network. While the rest of the features (such as SF quasi-orthogonality, topology configuration, parameters configuration, MAC command, bi-directional traffic, propagation model, duty cycle, and node's energy consumption) are fully supported.

6. ISSUES AND OPEN DIRECTIONS

In this paper, this section outlines the difficulties of previously published works and suggests new avenues for study in this field. This section explains LoRa analysis, LoRa communication, LoRa security, and LoRa-enabled applications as follows.

6.1. Challenges

This subsection provides the challenges of LoRa-IoT in detail. The significant challenges are LoRa analysis, LoRa communication, LoRa security, and LoRa-enabled applications. These challenges are described as follows.

- LoRa analysis: understanding LoRa's strengths and weaknesses requires careful analysis of its performance. An important and urgent task for future research is to quantify LoRa performance with the corresponding parameters. There is also space for development in LoRa analysis tools. Existing analytical models are typically generated from quite restrictive assumptions.
- LoRa communication: the coding and demultiplexing at the PHY layer, the MAC protocol, and the node configuration parameters are crucial to the efficacy of LoRa communications. Studies of LoRa communications have primarily focused on improving its efficacy and efficiency.
- LoRa security: given that LoRa is vulnerable to a number of vulnerabilities, security and privacy are of paramount importance as LoRa network growth accelerates. The high power efficiency demand and other LoRa PHY features have revealed novel and potent attacks that are difficult to defend.
- LoRa-enabled applications: numerous works have explored LoRa-enabled application concepts beyond the realm of LoRa networks, exploring backscatter, sensors, and heterogeneous technologies. Although these works have made significant strides and displayed enormous promise in the academic world, they still have a great deal of untapped potential that needs to be explored.

6.2. Future directions

This subsection provides the future directions of LoRa-IoT in detail. The significant challenges are LoRa protocol stack, LoRa network, and AI-empowered LoRa. These directions are described as follows.

- LoRa protocol stack: LoRa is an up-and-coming LPWAN technology, therefore many people have been working on improving its protocol stack, particularly its PHY and MAC layers. The capabilities and promise of the LoRa PHY layer have been shown through applications such as collision disambiguation [51], sensing [52], and backscatter [53]. Adopting deep learning networks [54] can overcome some inherent limitations of LoRa conventional PHY decoding while ensuring the benefits of its weak and collision decoding ability by utilising LoRa PHY packet structure and chirp features in the time and frequency domains, exploiting spatial [55] diversity gain.
- LoRa network: LoRa, in its most basic form, is a method of communication used to set up long-range, low-power wireless sensor networks. Yet, several aspects of network performance, including as throughput, wireless links, energy consumption, capacity, flexibility, and security, merit additional investigation and improvement. So, managed networks can provide services like load balancing, resource allocation, device configuration, auditing, and security. Network aggregation [56], [57] on LoRa networks is one such method that is just beginning to be used for data collection and management. Over-the-air firmware

updates provide insight into network security in addition to other general security methods, and they can be performed on remotely deployed LoRa devices.

- Artificial intelligence (AI)-empowered LoRa: the use of AI is becoming increasingly important in many fields of study and business [58]. Using data-driven deep learning techniques on LoRa signals has led to impressive findings, and novel applications in signal demodulation [54], radio-frequency interference [59], and sensing [60].

7. CONCLUSION

LoRa is an important and promising IoT technology that has been the subject of a growing body of research over the past few decades. This review shows the explanation of LoRa technology for the LoRa-IoT and compares LoRaWAN with previous wireless technology. Meanwhile, this review provides a list of simulators used for LoRa-IoT, reviews the literature review in detail and discusses challenging and future work. We anticipate that this survey will facilitate the identification of research gaps and the subsequent discovery of solutions. In addition, we encourage any and all researchers to delve into this exciting field and help usher in new developments and perspectives.

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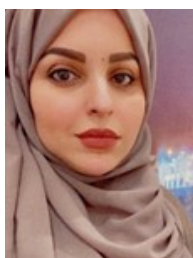
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