International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Review of Computer Engineering Studies
Vol. 9, No. 2, June, 2022, pp. 71-78
Journal homepage: http://iieta.org/journals/rces

Low Power Wide Area Network Technologies: Open Problems, Challenges, and Potential Applications

Muhammad Sani Danladi*, Muhammet Baykara

Department of Software Engineering, Faculty of Technology, Fırat University, Elazığ 23119, Turkey

Corresponding Author Email: 191137130@firat.edu.tr

https://doi.org/10.18280/rces.090205

Received: 19 April 2022
Accepted: 6 June 2022

Keywords:
data transmission, internet of things, long-range, LPWAN, wireless networks

ABSTRACT

Nowadays, the number of internet of things (IoT) connected devices continues to increase exponentially. However, the core underlying wireless network technologies that enable IoT devices to achieve such growth and wide applications face numerous challenging deployment requirements such as operating range, power consumption, and cost. Low-power wide-area network (LPWAN) technologies enable long-distance, low-power, and low data transmission at a low cost. These new wireless technologies shape the IoT ecosystem due to their wide applications. This study aims to review the various features and analyze the performances of the leading LPWANs, namely LoRa, SigFox, NB-IoT, and Weightless. Initially, precise descriptions of their underlying technologies and various applications were provided. Then, several challenges facing the LPWANs and potential solutions were outlined. Finally, the study analyzed their performance against several specifications, including frequency range, Bandwidth, Modulation, and so on. The outcome shows that these technologies are more efficient than the short and medium-range IoT technologies, particularly regarding power, range, and cost. The study's findings are hoped to provide a guide and eliminate LPWAN technology selection issues.

1. INTRODUCTION

The evolution of the IoT, which began decades ago, strives to build a global infrastructure by utilizing smart devices. These devices are often manufactured with processing capability, built-in memory, and networking support and are deployed for automated and sophisticated applications that significantly minimize human interventions [1]. The devices connect using wireless communication protocols to execute user-defined programs that solve problems in vast domains of human lives. Their applications can be found in numerous projects ranging from home automation [2], livestock monitoring [3], landslides monitoring [4], railway level crossing [5], smart energy metering [6], and so on. According to a new report published by Statista, as shown in Figure 1, the number of global IoT devices is projected to triple from 8.74 billion in 2020, with China leading with about 3.17 billion devices, to higher than 25.4 billion in the year 2030 [7]. Also, the IoT global market was worth a whopping 389 billion U.S. dollars by 2020. It is estimated to reach above a trillion U.S. dollars by 2030, as reported by the same company.

Nonetheless, the core underlying wireless network technologies that enable IoT devices to achieve such prominence in growth, wide application, and worldwide recognition are confronted with numerous challenging deployment requirements such as operating range, power consumption, cost, and the likes [8]. Wireless technologies like Wi-Fi, Bluetooth, ZigBee, Wireless USB, etc., are incredibly famous for transmitting a substantial amount of data at a very high speed but trading cost, power consumption, and transmission range. For example, Wi-Fi, a generic name for all devices based on the IEEE 802.11 standard and its derivatives, can only transmit within 50 to 100 meters, depending on the device manufacturers' frequency band [9]. Due to the above mention, extra access points are required to connect the available remote network nodes for long-range deployment, resulting in an increased overhead cost.

Furthermore, because the unlicensed frequency band has minimal oversight, most short-range wireless networks suffer from eavesdropping and electromagnetic interference from other services running on the same spectrum, not to mention its high energy consumption demand. Bluetooth and ZigBee, however, despite their affordable cost and availability, are generally known for their highly short-range transmission and undeniable low data size [10]. In this era of intense worldwide IT competition, a highly affordable technology capable of transmitting these devices' data over very long distances while using a small amount of power becomes necessary. To appropriately realize the fast-growing IoT industry's goal, connect every device to the internet to increase efficiency, automation, and real-time machine-to-machine communication.

Low-Power Wide-Area Network technologies are the recent wireless network technologies that provide long-range, low power, low data, and in many cases, affordable solutions to IoT devices. LPWANs comprise numerous technologies such as NB-IoT, LoRa, and SigFox that operate in licensed and unlicensed frequency bands. They can transmit data covering a pretty long range and pass through several obstacles like buildings using just battery-operated power devices [11].

This paper aims to provide adequate background knowledge of the leading LPWAN technologies and features regarding their applications and challenges. In addition, their various features were analyzed by comparing them side by side.

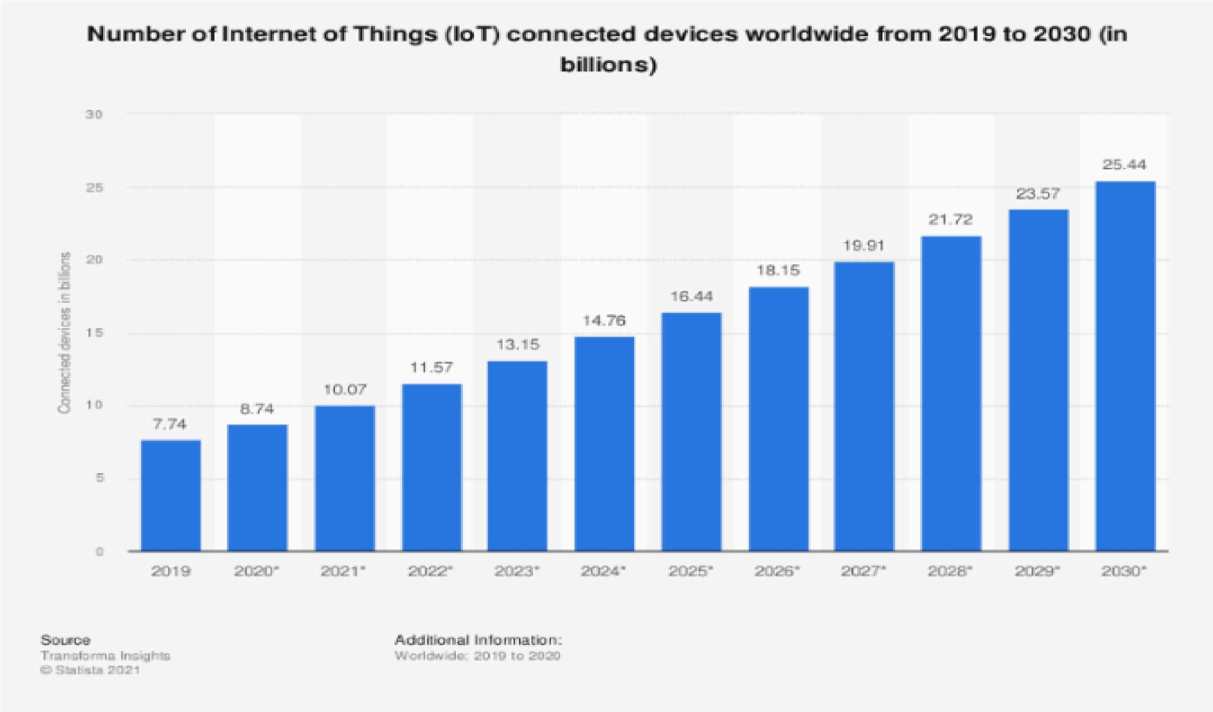

Figure 1. Worldwide IoT-connected device forecast from 2019 to 2030 [7]

The rest of the paper is as follows: Chapter 2 provides important project implementations using LPWANs. A description of the leading LPWAN technologies and their applications is provided in Chapter 3. Chapter 4 described LPWANs challenges and possible solutions. Chapter 5 concludes the study.

2. LPWANS PROJECT IMPLEMENTATIONS

This section presents recent works that employed LPWAN technologies to implement several important IoT projects. Philip and Singh [12] implemented an algorithm that controls the transmission power of a GPS-based LoRa end device, immensely decreasing the power consumption rate. They varied the end device's transmission power to the distance between the transmitter and receiver and deployed it in the water quality monitoring system, saving about 40% of energy. Moreover, they performed a statistical distribution variability study regarding the path loss exponent and discovered that Johnson SB is the best option. However, their work's major drawback is the assumption that the GPS module is always turned on for its continuous operation. Home automation is another vital aspect of our lives today. Smart devices such as TVs, refrigerators, air conditioners, etc., are constantly evolving to connect to the internet. These led to techniques to ensure automated and continuous operations, minimizing human intervention. Khmas et al. [13] developed an energy-efficient smart home prototype using SigFox and LoRa. They further integrated different online IoT web platforms with Python frameworks for improved user interactions. Nonetheless, due to such integration, they witness excessive time and resource consumption in implementing the system.

Prasanna et al. [14] proposed another impressive work designed to intelligently control industrial power with LoRa. The suggested system initially identified an employee based on their ID card details at entry with a LoRa end node made with Raspberry Pi and a surveillance camera. This information is then transmitted to the distribution box controller with the help of an LPS8 LoRaWAN gateway, where components like air conditioners and other devices are controlled. The proposed system significantly reduced energy consumption. Niles et al. [15] presented another impressive research work. Their system investigated the use of LPWAN technologies to detect and observe analytes with LoRa. They utilized a small size, weight, and power sensor's electrochemical ability, controlled remotely (or automatically) with a vehicle to transmit the detected chemical concentration to the internet of things network through a LoRa gateway. The proposed system proved valuable as the prototype is widely employed for testing by numerous researchers in the field, majorly due to its low power consumption. Due to the multiple sensor nodes required by the system for proper execution, they were pretty confronted with end nodes and gateway configuration and distribution challenges in avoiding data loss, collision, and other issues. Also, Deng et al. [16] proposed a system that monitors soil conditions like temperature, moisture, and chloride ion level with an RFID sensor and LoRa. The system used a patrol car embedded with the RFID sensor to collect data in a farmland monitoring center and transmit the data to the cloud platform with a LoRa gateway. They recorded a success rate of 90% with above 10 Km^2 coverage. However, the short-range RFID sensor (maximum distance of 1.3 m) necessitates a patrol car, making the system costly.

Peer-to-peer, short for (P2P), is a method of communication where individual parties have equal capacity and can prompt a communication session without constraint by any other party. It is termed decentralized communication and has many advantages, including anonymous routing, extensive parallel computing, etc., in contrast to Server/Client communication [17]. Madaan et al. [18] suggested an Sx1278 LoRa module to develop a P2P communication operating with a Raspberry Pi desktop environment with a GUI. Also, they suggested using the Advanced Encryption Standards (AES) algorithm that worked based on the principle of serialization in transmitting packets to enhance the reliability and security of the system.

Finally, they tested their system's reliability with pyLora, a LoRa extended Python data transmission module. Self-regulating street lightning (SL) systems are an integral component of smart cities. A real-time, energy-saving, and intelligent metering system provides incredible solutions by lowering costs and significantly reducing the waste of resources. Sanchez-Sutil and Cano-Ortega [19] developed a LoRa-based low-energy monitoring and control SL installation system to address this issue. The approach constituted a gateway, operation and monitoring, illumination measuring devices, and an SL regulation algorithm for the system automation. Artificial Bee Colony (ABC) optimization technique, a fast and reliable optimization algorithm, was employed to control the lighting level. Using Firebase, the sensor data was transmitted to the cloud effectively.

3. LEADING LPWANS AND THEIR APPLICATIONS

This section presents detailed explanations regarding the leading LPWAN technologies such as LoRa, SigFox, NB-IoT, etc. The companies that own these technologies function differently, and each has its mode of operations, regulations, and distribution across the globe. Moreover, the section presents various areas of preferred applications and the limitations of the LPWANs.

3.1 LoRa and LoRaWAN

Long-Range, short for LoRa, is Semtech's radio frequency modulation technique that allows extreme long-range data transmission for low-power and wide-area network (LPWANs) technologies. LoRa is the physical (PHY) layer established based on the Chirp Spread Spectrum (CSS) modulation that provides the transceiver modules with high sensitivity and robustness against noise and interference. LoRa operates in a fixed bandwidth channel of 125 or 500 kHz for uplink channels and 500 kHz for downlink channels, resulting in a trade-off between sensitivity and data rate. Lora's further use of orthogonal spreading factors permits the network to extend the battery life of connected end devices by creating adaptive power and data rate optimizations for each end device [20]. A regular, fully supported eight-channel LoRa gateway can accommodate a payload ranging from 11 to 242 bytes in size from up to 60,000 end devices when sending sensor data in an hour window for about 5 km in the urban setting and at least 15 km in rural settings. As shown in Figure 2, LoRa provides the physical layer for the radio transceivers to transmit the modulated signals. However, LoRaWAN provides the medium access control (MAC) layer protocol, depicting how the end devices effectively communicate with the gateways (base stations). They are created on top of LoRa and are managed by the LoRa Alliance company.

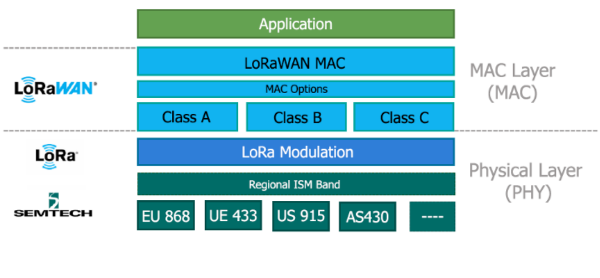

Figure 2. LoRaWAN protocol stack [20]

The MAC layer in LoRaWAN facilitates communication between LoRa end devices and the gateways, which further sends the sensor data to the cloud. LoRaWAN utilizes the star topology, meaning that end devices can only communicate with the gateways and not with one another [21]. At the same time, numerous gateways can be linked to the network servers, where the application servers can further be created for users to observe and control the status of the payloads. There are three classes of operation in LoRaWAN, as seen in Figure 2 and are explained below:

- **Class A:** Devices in this category are the most energy-efficient due to their constant sleeping mode. They are only active upon noticing changes in the sensors' value for transmitting an uplink message. Also, the server can only send a downlink message at this short window.
- **Class B:** Like in Class A, devices in this class also consume less energy. However, besides receiving a new sensor value, they can be scheduled to wake up, which provides a downlink message window.
- **Class C:** This category is energy inefficient as the devices always listen to downlink messages. They are not listening to the downlink only when sending an uplink message.

LoRaWAN has a vast range of suitable applications for both outdoor and indoor use. Their long-range communications ability also allows them to be deployed in urban and rural areas to assist in various applications. These applications include smart agriculture, smart cities, smart buildings, smart homes, smart environment, smart utilities and metering, industrial IoT (IIoT), smart supply chain and logistics, and many more [22].

3.2 SigFox

SigFox is a multimillion-euro company founded by two French individuals, Ludovic Le Moan and Christophe Fourtet, in 2010 with an initial plan of connecting every physical object to the internet [23]. The idea is to create an IoT ecosystem with low-power and long-range devices capable of transmitting small data for end-to-end connectivity. The standby and dedicated radio-based networks provide a somewhat inexpensive and highly reliable connection among these devices and sensors with a minimal power consumption over great distances [24]. Sig-Fox belongs to the non-free narrow-band LPWAN protocol group that utilizes the unlicensed ISM frequency band for various applications. SigFox provides more efficient and secured packet exchange, lower bandwidth, and decreased power consumption while transmitting sensor data across the network compared to different LPWANs, such as NB-IoT and LoRa.

Furthermore, SigFox allows devices and their nearest gateway to connect in a star topology. The gateway then sends the sensor data from these devices to the cloud infrastructure, which users can access via a secure link. After which, different protocols such as MQ Telemetry Transport (MQTT), Hypertext Transfer Protocol (HTTP), etc., can be employed to initiate a communication between the cloud infrastructure and the running application servers. Figure 3 depicts the SigFox network's architecture, which is a visualization of these explanations. Essential features to consider for using a SigFox as an LPWAN IoT solution include an uplink message capacity of about 140 per day, each with a payload of 12 and 8 bytes, for uplink and downlink, respectively. There is also a data rate of about 100 and 600 bytes per second (Bps) for uplink and downlink with roughly 6 seconds for data transmission requirements [25]. Below is a brief description of the four basic protocol stacks that are found in SigFox:

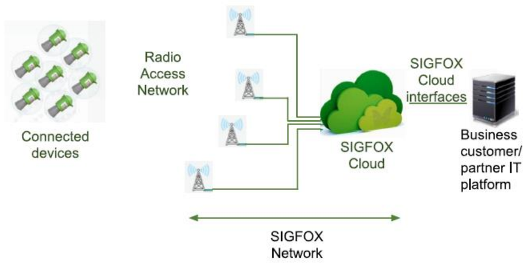

Figure 3. The architecture of the SigFox network [9]

- **PHY Layer:** In this layer, the ultra-narrow band transceivers enable the transmission of about 100 Hz data over 192 kHz bandwidth. The uplink and downlink messages are transmitted using different modulation techniques: Differential Binary Phase-Shift Keying (DBPSK) and Gaussian Frequency Shift Keying (GFSK). Hence, the long-range, between 10 to 50 km, communication distance in SigFox is summarized in Table 1.
- **MAC Layer:** The MAC layer in SigFox uses the pure Aloha channel access method, which heavily employs the Random Frequency and Time Division Multiple Access (RFTDMA).
- **Frame Layer:** The frame layer permits radio frames to be developed, usually initiated at the Application Layer. The sequence number of individual data is inserted in the data transmission process.
- **Application Layer:** The application layer enables end-users to access and control several functionalities such as sensor data messages, updates, and other vital web services. Figure 3 shows the architecture of a Sigfox network.

Due to the proprietary condition of SigFox, there is extreme device coverage resulting from the slow modulation technique adoption. The above decision makes them suitable for applications where a small amount of data must be sent over long distances. These applications include gas tank remote monitoring, street lighting, smart parking, risk management, connected dumpster, etc. [26].

3.3 NB-IoT

Narrowband IoT (NB-IoT) was among the three new technologies launched by the third generation partnership group (3GPP) in June 2006 to enable low power and bandwidth solutions for the M2M IoT communications. It is precisely contained in the LTE-Advanced Pro description document Release 13, the others being Machine Type Communication (MTC) and Extended Coverage GSM (EC-GSM) [9]. NB-IoT utilizes the extensive ecosystem present in the Long-Term Evolution (LTE) to provide low-power IoT applications with low bandwidth ranging from 180 to 200 kHz, a data rate of up to 250 kbps, and latency ranging from 1.6 to 10 seconds [27]. Moreover, due to this integration into the LTE standard, numerous qualities of the LTE were improved to contribute to reduced energy consumption, cost, and broader coverage. These improved features, shown in Figure 4, can also include using distinct cell searching processes, changing random access techniques, exploiting different bandwidths, etc. Other trade-offs in latency, frequency spectrum efficiency, and data rate had to be adopted to facilitate these qualities in NB-IoT technologies. NB-IoT operates in the licensed frequency band with a Quadrature Phase Shift Keying (QPSK) modulation for the radio transceivers. More on the summary of NB-IoT features can be found in Table 1 under its header.

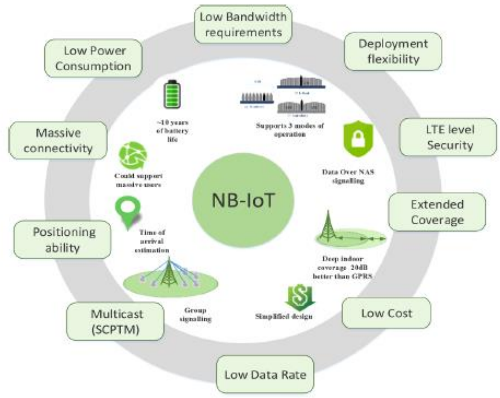

Figure 4. Features of the NB-IoT [28]

5G is a new generation of network technology where data speed, reliable network, improved user experience, and more have been prioritized. Providing a 5G atmosphere, known as 5G new radio (5G NR) for NB-IoT, intend to produce outstanding, low-throughput devices connectivity worldwide. Figure 4 illustrates the features of NB-IoT technology.

NB-IoT technology is employed in numerous IoT applications that significantly solve many problems in human lives. These applications include smart appliances, smoke alarm systems, highway and street light Monitoring, kids and pets tracking devices, waste management, and so on [28].

3.4 Weightless

Weightless Alliance, earlier known as Weightless SIG (Special Interest Group), established in 2008, remains the sole LPWAN open-standard that operates in the sub-GHz unlicensed frequency spectrum, providing efficient IoT connectivity. Five different groups, such as ARM, Accenture, M2COMM, Sony-Europe, and Telensa, are the companies that support the Weightless LPWAN [29]. Weightless comprises a set of three LPWAN technologies, namely Weightless-W, Weightless-N, and Weightless-P, that work differently. The series of Weightless began with the Weightless-W, designed to operate on the TV band's unused white space radio frequency spectrum. In this adoption, numerous feature requirements such as modulation, packet size, and SF have resulted in many constraints and overhead costs in the overall technology management.

However, two-way communication with data rates varying from 1 kbps to 10Mbps has been achieved in the Weightless-W. Also, the battery's performance of these end devices is limited to three (3) years, with about a 5 km range between them and base stations depending on whether there are obstacles. To accelerate its competitive position with opposition technologies in the run for low cost, low power, and long-range IoT device connectivity, Weightless-N adopted a low-cost technology identical to SigFox. Weightless-N uses a Differential Phase Shift Keying (DPSK) modulation technique to transmit about 100 bps via the ISM frequency bands but only in one direction (making it send uplink messages only). These changes have considerably improved the Weightless-N by making the end devices have over ten (10) years of battery life and long-range with a more affordable price [30]. Eventually, the most recent Weightless-P open standard was developed. Weightless-P uses a narrow-band channel to provide a true-bidirectional data transmission for uplink and downlink, operating in licensed and unlicensed ISM frequency bands. These features significantly improved the Weightless-P's overall performance and, in a short time, attracted a large number of the market to the group. Figure 5 gives a general structure of Weightless network architecture.

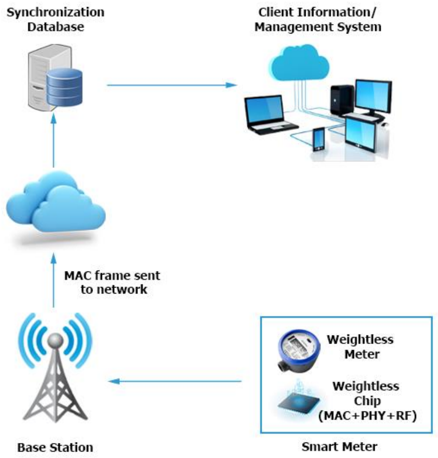

Figure 5. Structure of weightless network architecture [31]

These impressive outcomes led Weightless SIP to focus more on it and later renamed it to just "Weightless." Weightless has a data transmission rate ranging from 200 bps to 100 Kbps transmission power control for uplink and downlink with time-synchronization in base stations for an efficient resource schedule. Weightless also has low latency and forward error correction (FEC), resulting in a fast networking ability. Gaussian Minimum Shift Keying (GMSK) and Offset-Quadrature Phase Shift Keying (OQPSK) modulation techniques employed by Weightless have minimized energy consumption to a great extent. Weightless can transmit sensor data for up to 2 km in urban areas in terms of range with AES-128/256 encryption for improved security along with other valuable features, as summarized in Table 1. There is also device interoperability between various Weightless technology manufacturers [32]. The vital area that Weightless focused on is the advanced metering infrastructure (AMI), with approximately 250,000 end-connected devices that are projected to reach above 600,000 by the end of 2021. The company also records daily meter messages of about 27 million with an average size of roughly 40 bytes.

4. LPWANS CHALLENGES AND POSSIBLE SOLUTIONS

The LPWAN technologies constantly evolve and expand daily, with new companies joining the IoT ecosystem. These improvements have led to competition in the continuous manufacture of low-power, low-cost, and long-range devices in huge quantities. Despite the necessary effort to ensure that every device in the physical environment is connected to the internet, several trade-offs have to be made. Some of these trade-offs result in adding potential challenges in the long run. Therefore, this section provides brief details regarding some challenges in the LPWAN technology atmosphere.

4.1 Low data rate support

The LPWANs plan is to provide transmission of small-size data over long-range, thereby preserving the energy consumption of these devices. This approach is excellent for IoT devices as they don't usually require extensive data usage. Also, several IoT devices are only expected to detect changes in their environment without focusing much on the time and speed of sensor data transmission (with an average data rate of between 1 to 100 kbps). However, numerous evolving technologies like aerial imaging for farming and video streaming of high-quality sensor data may force the LPWAN companies to strategize to capture such needs in the IoT ecosystem. Hence, LPWANs should develop new plans that will make such provisions in the future should the need arise [33].

4.2 Massive end device deployment

It is widely known that billions of IoT devices are connected to the internet. The number is projected to triple in the not-distant future. Although such statistics incorporate every device, including those based on short and middle-range devices, the share of the LPWAN technologies is increasing exponentially. Therefore, data are being shared randomly among these devices, resulting in a substantial potential problem in the future. Another thing to note is that devices are not evenly distributed globally. Some regions like the densely populated urban settlements tend to have more device connections and become the center of attraction for such conceivable problems. Therefore, LPWAN technologies must look into these issues and provide adaptable and well-managed data transmission strategies [9].

Table 1. Summary of key specifications in leading LPWANs [9, 34]

	LoRaWAN	SigFox	NB-IoT	Weightless-P
Frequency Range	433/780/868/915 MHz ISM Band	865-924MHz	LTE/GSM	Sub-1 GHz Band
Bandwidth	7.8 – 500 kHz	100 Hz	128 – 200 kHz GSM Band	12.5 kHz
Modulation	CSS	BPSK (UL), GFSK (DL)	QPSK	GMSK/OQPSK
Frequency Band	Unlicensed	Unlicensed	Licensed	Unlicensed
Base Station Capacity	> 1,000,000	> 1,000,000	> 52,000	Unlimited
Packet Size	19 – 250 B	12 B (DL) – 8 B(UL)	16 – 2536 b	5 – 260B, 131 – 514B
Range	2 - 5 km (Urban), 10 – 15 km (Rural)	3 – 10 km (Urban), 20 – 50 km (Rural)	≤ 100 km	2 – 5 km (Urban), ~ 25 km (Rural)
Security	AES 128	AES 128	3GPP 128 – 256 b	AES 128 – 256
Battery Span	10 yrs.	10 yrs.	10 yrs.	3 – 8 yrs.

4.3 LPWANs device interoperability

Due to the adoption of different underlying technologies by LPWANs and other wireless forms of device connection, interoperability amongst the general group of IoT devices remains questionable. However, if these technology giants can come together and develop a robust strategy that will ensure future coexistence, the IoT industry will become unstoppable. Currently, there is little or no concern for such an approach. The majority of the companies focus more on improving their products and services for massive deployment. Another thing is that merging such technologies will not be an easy task due to several reasons like competition, potential disputes, regulations, and so on [9].

4.4 Real-time communication

Several LPWANs are designed to accommodate varying applications that are robust and flexible. Some of these devices would require real-time monitoring in various applications, ranging from healthcare management, where patients' lives are on the line, to heavy industrial condition monitoring, where low latency delay time and improved reliability are crucial. Real-time communication is also necessary for emergency monitoring like intelligent parking, data center power monitoring, etc. Many LPWANs that adopt the sub-1GHz bands are equipped with less than 1% of the general duty in most cases and are incredibly faced with such problems. Therefore, it is expected that appropriate measures are taken to tackle challenges of this nature [33].

4.5 Interference

Generally, interference is a primary challenge in RF and cellular data transmission. Radio waves transmitting data in the same frequency spectrum tend to collide. Interferences may come from transceivers of the same LPWANs or neighboring technologies. Such collision results in poor sensor data value reception [35]. The unlicensed ISM bands are dedicated to industrial, scientific, and medical operations. However, it is open to any individual, provided the regional guidelines and regulations are followed. Many LPWANs such as SigFox, LoRa, and Weightless operate in these sub-GHz bands and are likely to experience more interferences in the future when the number of connectivity shoots. Therefore, regulating bodies are expected to provide an avenue for proper spectrum tracking and management for future solutions.

4.6 Bidirectional transmission

Due to the high acceptance rate gained by LPWANs, the IoT ecosystem is projected to be filled with different robust applications from these technologies. Most of which support uplink and downlink bidirectional data transmission. However, LPWANs like LoRa, SigFox, etc., have insufficient bandwidth for downlink messages [36]. Another research demonstrated a great tendency of downlink messages to compromise the uplink performance due to the transmission window's nature [37]. In the future, where massive LPWANs connectivity and deployment are expected, solutions regarding these challenges will be of utmost importance. In light of the abovementioned issues, the leading LPWAN technologies should adopt a strategy based on multiple service priorities for improved performance. When greatly prioritized and adequately implemented, LPWANs will provide impressive and robust IoT device implementations with a fully bidirectional ability.

4.7 Data security

Security is an essential aspect of every wireless data transmission to provide integrity, confidentiality, and availability of the transmitted data. LPWANs send sensor data through the air in many stages before reaching the end-user, exposing them to potential hacking and attacks from external forces. Unlike cellular networks, where security challenges are greatly minimized by using every network device's Subscriber Identity Module (SIM) to guarantee safety, LPWANs use straightforward cryptographic techniques with simple key sharing between devices and networks [33]. For instance, for home automation applications, unauthorized access will result in disclosing information that may expose the privacy of many homes or even unwanted control of the home appliance. Another instance is health monitoring; access to such data may cause exposure to patients' sensitive medical information. Due to their massive deployment in many sectors of human lives, security challenges have to be a focal point of LPWANs to avoid damage and discomfort [34].

5. CONCLUSIONS

This paper provided essential background knowledge regarding the leading LPWAN technologies. The study first provided an overview of four well-known LPWANs, namely LoRa, SigFox, NB-IoT, and Weightless, discussing their underlying technologies and areas of potential applications. Furthermore, several challenges and possible solutions concerning the general LPWANs were outlined. LoRa is found to be cheap and has a numerous range of suitable applications for both indoors and outdoors, such as smart homes and cities. However, its trade-off between sensitivity and data rate in bandwidth and operation in the unlicensed frequency band results in data size and security challenges. SigFox is bounded by proprietary conditions, making them suitable for applications that require a very long-range transmission of low data, such as gas tank remote monitoring. The adoption of the extensive ecosystem in the LTE by NB-IoT makes it robust and fully secured in providing low-power IoT applications compared to the other technologies. Moreover, weightless remains the only proper open standard in the LPWANs market. It is suitable for advanced metering infrastructure applications with high end-device density and frequent payload requirements. Finally, these four technologies were analyzed by comparing their performances in several specifications such as frequency range, bandwidth, modulation, security, etc.

This concise information will provide a valuable guide and resolve LPWAN technology selection issues, especially in this massive global IoT device deployment era. In the future, an extensive study covering the entire gamut of LPWANs is highly recommended to cover the fast phase by which new companies evolve with ample latest technologies every day. Also, further research regarding the security aspect of LPWANs should be conducted to provide adequate solutions as security is a crucial priority of IoT devices.

REFERENCES

[1] Serpanos, D., Wolf, M. (2017). Internet-of-things (IoT) systems: Architectures, algorithms, methodologies. Springer. https://doi.org/10.1007/978-3-319-69715-4

[2] Islam, R., Rahman, M.W., Rubaiat, R., Hasan, M.M., Reza, M.M., Rahman, M.M. (2021). LoRa and server-based home automation using the internet of things (IoT). Journal of King Saud University-Computer and Information Sciences, 34(6): 3703-3712. https://doi.org/10.1016/j.jksuci.2020.12.020

[3] Germani, L., Mecarelli, V., Baruffa, G., Rugini, L., Frescura, F. (2019). An IoT architecture for continuous livestock monitoring using LoRa LPWAN. Electronics, 8(12): 1435. https://doi.org/10.3390/electronics8121435

[4] Karunarathne, S.M., Dray, M., Popov, L., Butler, M., Pennington, C., Angelopoulos, C.M. (2020). A technological framework for data-driven IoT systems: Application on landslide monitoring. Computer Communications, 154: 298-312. https://doi.org/10.1016/j.comcom.2020.02.076

[5] Naveen, K., Rayala, S. (2021). Automatic railway level crossing using lora technology. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2021.05.704

[6] Kumar, L.A., Indragandhi, V., Selvamathi, R., Vijayakumar, V., Ravi, L., Subramaniyaswamy, V. (2021). Design, power quality analysis, and implementation of smart energy meter using internet of things. Computers & Electrical Engineering, 93: 107203. https://doi.org/10.1016/j.compeleceng.2021.107203

[7] Holst, A. (2021). IoT Connected Devices Worldwide 2019–2030| Statista. 2021. https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/.

[8] Rackley, S. (2007). The future of wireless networking technology. Wireless Networking Technology, 2007: 343. https://doi.org/10.1016/B978-075066788-3/50047-0

[9] Gu, F., Niu, J., Jiang, L., Liu, X., Atiquzzaman, M. (2020). Survey of the low power wide area network technologies. Journal of Network and Computer Applications, 149: 102459. http://dx.doi.org/10.1016/j.jnca.2019.102459

[10] Mekki, K., Bajic, E., Chaxel, F., Meyer, F. (2019). A comparative study of LPWAN technologies for large-scale IoT deployment. ICT Express, 5(1): 1-7. http://dx.doi.org/10.1016/j.icte.2017.12.005

[11] "Lora Developers," "LPWAN Technologies | DEVELOPER PORTAL." https://lora-developers.semtech.com/documentation/tech-papers-and-guides/lpwan-technologies, accessed on Dec. 7, 2021.

[12] Philip, M.S., Singh, P. (2021). Adaptive transmit power control algorithm for dynamic lora nodes in water quality monitoring system. Sustainable Computing: Informatics and Systems, 32: 100613. https://doi.org/10.1016/j.suscom.2021.100613

[13] Khmas, B.F., Aljawahery, A.F., Ibrahim, A.A. (2020). Efficient energy management in smart homes using IOT-based low-power wide-area network (LoRaWAN) protocol. 4th Int. Symp. Multidiscip. Stud. Innov. Technol. ISMSIT 2020-Proc. https://doi.org/10.1109/ISMSIT50672.2020.9254942

[14] Prasanna, K.R., Baranidharan, K., Karthik, G., Seetharaman, R. (2021). Industrial smart power control using LoRa network. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2021.06.369

[15] Niles, K., Ray, J., Niles, K., Maxwell, A., Netchaev, A. (2021). Monitoring for Analytes through LoRa and LoRaWAN Technology. Procedia Computer Science, 185: 152-159. https://doi.org/10.1016/j.procs.2021.05.041

[16] Deng, F., Zuo, P., Wen, K., Wu, X. (2020). Novel soil environment monitoring system based on RFID sensor and LoRa. Computers and Electronics in Agriculture, 169: 105169. https://doi.org/10.1016/j.compag.2019.105169

[17] Linda, R. (2021). "What is peer-to-peer (P2P)? - Definition from WhatIs.com," May 2019. https://www.techtarget.com/searchnetworking/definition/peer-to-peer, accessed on Dec. 22, 2021.

[18] Madaan, A., Bansal, S., Sahu, A., Kidwai, F. (2020). Peer to Peer Communication in GUI interface using Lora Technology. Procedia Computer Science, 173: 299-304. https://doi.org/10.1016/j.procs.2020.06.035

[19] Sanchez-Sutil, F., Cano-Ortega, A. (2021). Smart regulation and efficiency energy system for street lighting with LoRa LPWAN. Sustainable Cities and Society, 70: 102912. https://doi.org/10.1016/j.scs.2021.102912

[20] Semtech, "LoRa and LoRaWAN," Semtech Tech. Pap., no. December 2019, 1–17, 2020. Available: https://lora-developers.semtech.com/library/tech-papers-and-guides/lora-and-lorawan/, accessed on Dec. 24, 2021.

[21] Saban, M., Aghzout, O., Medus, L.D., Rosado, A. (2021). Experimental analysis of IoT networks based on LoRa/LoRaWAN under indoor and outdoor environments: Performance and Limitations. IFAC-PapersOnLine, 54(4): 159-164. https://doi.org/10.1016/j.ifacol.2021.10.027

[22] "Semtech," "LoRa Applications | Semtech LoRa Technology | Semtech." https://www.semtech.com/lora/lora-applications, accessed on Dec. 26, 2021.

[23] "sigfox," "Our story | Sigfox." https://www.sigfox.com/en/sigfox-story, accessed on Dec. 26, 2021.

[24] "sigfox build," "What is Sigfox? | Sigfox build." https://build.sigfox.com/sigfox#network-overview, accessed on Dec. 26, 2021.

[25] Boccadoro, P., Daniele, V., Di Gennaro, P., Lofù, D., Tedeschi, P. (2022). Water quality prediction on a Sigfox-compliant IoT device: The road ahead of WaterS. Ad Hoc Networks, 126: 102749. https://doi.org/10.1016/j.adhoc.2021.102749

[26] "sigfox application," "5 IoT applications to make our planet great again! | Sigfox." https://www.sigfox.com/en/news/5-iot-applications-make-our-planet-great-again, accessed on Dec. 26, 2021.

[27] "Avsystem," "NB-IoT Overview | What is Narrowband IoT?" https://www.avsystem.com/blog/narrowband-iot/, accessed on Dec. 26, 2021.

[28] Popli, S., Jha, R.K., Jain, S. (2021). A comprehensive survey on Green ICT with 5G-NB-IoT: Towards sustainable planet. Computer Networks, 199: 108433. https://doi.org/10.1016/j.comnet.2021.108433

[29] McClelland, C. (2018). IoT connectivity–comparing

NB-IoT, LTE-M, LoRa, SigFox, and other LPWAN technologies. https://www.iotforall.com/iot-connectivity-comparison-lora-sigfox-rpma-lpwan-technologies, accessed on Dec. 27, 2021.

[30] Sanchez-Iborra, R., Cano, M.D. (2016). State of the art in LP-WAN solutions for industrial IoT services. Sensors, 16(5): 708. https://doi.org/10.3390/s16050708

[31] "rfwireless world," "weightless network overview | weightless system protocol layers." https://www.rfwireless-world.com/Articles/weightless-system-overview.html, accessed on Dec. 7, 2021.

[32] "Weightless Alliance," "Technology | Weightless SIG." https://www.weightless-alliance.org/technology, accessed on Dec. 7, 2021.

[33] Ismail, D., Rahman, M., Saifullah, A. (2018). Low-power wide-area networks: opportunities, challenges, and directions. In Proceedings of the Workshop Program of the 19th International Conference on Distributed Computing and Networking, pp. 1-6. https://doi.org/10.1145/3170521.3170529

[34] Buurman, B., Kamruzzaman, J., Karmakar, G., Islam, S. (2020). Low-power wide-area networks: Design goals, architecture, suitability to use cases and research challenges. IEEE Access, 8: 17179-17220. https://doi.org/10.1109/ACCESS.2020.2968057

[35] "rfwireless world," "Types of Interference in communication-CCI,ACI,EMI,ICI,ISI,light,sound." https://www.rfwireless-world.com/Articles/Interference-basics-and-Interference-types.html, accessed on Dec. 7, 2021.

[36] Di Vincenzo, V., Heusse, M., Tourancheau, B. (2019). Improving downlink scalability in LoRaWAN. In ICC 2019-2019 IEEE International Conference on Communications (ICC), pp. 1-7. https://doi.org/10.1109/ICC.2019.8761157

[37] Mikhaylov, K., Petäjäjärvi, J., Pouttu, A. (2018). Effect of downlink traffic on performance of LoRaWAN LPWA networks: Empirical study. In 2018 IEEE 29th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), pp. 1-6. https://doi.org/10.1109/PIMRC.2018.8580721