A Review of LoRaWAN and its Application in Forest Remote Monitoring System

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Abstract—**Recently, the Internet of Things (IoT) has become a rapidly growing communication technology phenomenon. The long-range wide area network (LoRaWAN) has garnered considerable attention from the research community due to its low cost and power consumption and its long transmission range. LoRaWAN has been used in many applications, including smart agriculture, monitoring systems, and data communication. This paper reviews the use of a LoRaWAN-based remote monitoring system. This paper starts with an overview of LoRaWAN's history, features, and protocols. The LoRaWAN system's architecture, network models, and quality of service are then discussed in detail. Finally, the present research on using LoRaWAN-based remote monitoring systems in forests and orchards is presented, including a description of the research method and its limitations.**

Index Terms—**Communication technology, Internet of things, LoRaWAN, Remote monitoring system.**

I. INTRODUCTION

HUNDREDS of billions of dollars are spent each year on low-power sensors and other battery-supplied devices for use in smart agriculture, smart cities, intelligent industrial control applications, smart metering systems, and intelligent street lighting [1]. Such applications require wireless networks capable of covering large areas, such as buildings, farms, entire cities, or forests [2]. Thus, a network's communication range cover anywhere from hundreds of meters to several kilometres. Additional major concerns include energy efficiency and power usage.

Since the onset of the Fourth Industrial Revolution in Malaysia, numerous works have been dedicated to developing low-power wide-area network (LPWAN) standards [3]. Fig. 1 and Fig. 2 compare LPWAN standards to other standards in terms of energy efficiency, terminal and connection costs, data throughput, and range. Current networking systems, such as Bluetooth, ZigBee, and wireless fidelity (WiFi), are only useful for short-range communication and consume considerable amounts of power. As a result, the mesh network topology is used by ZigBee and various communication standards, such as the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 to enhance network coverage. However, nodes cannot be spaced much more than 100 m apart [4]. Satellites have a wide range of coverage, but they are expensive and lack energy efficiency. Cellular networks have a high data rate but cannot provide seamless coverage like satellites can. Meanwhile, LPWAN technology is suitable for connecting devices that deliver modest amounts of data over great distances while preserving battery life. Table I shows the different types of LPWAN protocols available in the market.

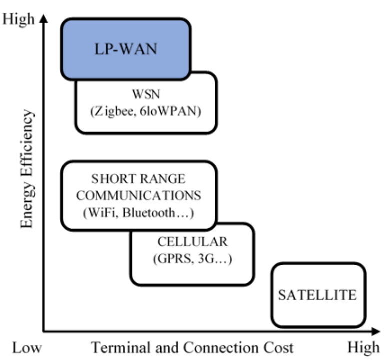

Fig. 1. Rankings of LPWANs and other wireless communication standards in terms of their energy efficiency and terminal and connection costs [5].

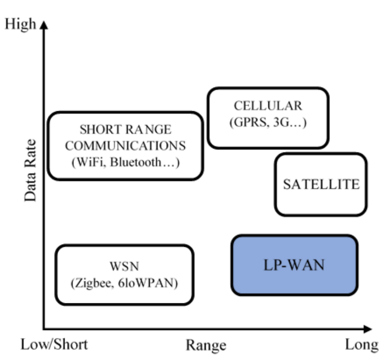

Fig. 2. Rankings of LPWANs and other wireless communication standards in terms of their data rate and range *[5]*.

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TABLE I
THE FEATURES OF LORAWAN AND OTHER LPWAN PROTOCOLS [6]

Feature	LoRaWAN	NB-IOT	LTE-M	Sigfox	WiSUN
Licensed spectrum	No	Yes	Yes	No	No
Cost efficiency	Yes	No	No	Yes	Yes
Power efficiency	Very High	Very High	Medium	Very High	Very High
Range (km)	15 – 45 (flat area)	<15 (outdoor)	< 11 (outdoor)	40 (rural) 10 (urban)	4
Data rate (bps)	0.3-50 k (DL/UL)	<170 k (DL) <250 k (UL)	<10 M (DL) <5 M (UL)	100 (DL/UL)	<300 k (DL/UL)
Bandwidth (Hz)	<500 k	180 k	1.4-20 M	200 k	<1 G

The long-range wide area network (LoRaWAN), Sigfox, narrow bandwidth Internet of Things (NB-IoT), long-term evolution (LTE), category M1 (LTE-M), and wireless smart utility network (WiSUN) are the examples of LPWAN protocols. According to Table I, the LoRaWAN is more suitable than the other protocols regarding its free licensed spectrum and in terms of energy efficiency. The LoRaWAN was created to enable long-distance communication between devices at a low data rate by allowing demodulation for a signal of an extremely low strength [7-10]. At low data rates, LoRa tolerates interference from signals with amplitudes that are 16 dB higher than the power of the actual LoRa signal being received [11]. LTE-M and NB-IoT have an advantage over other protocols due to their usage of licenced spectra. However, these two LPWAN protocols are much more expensive than the others. In addition, quality of service (QoS) is essential for meeting users' requirements and beyond. Retransmission times affect the coverage and QoS; specifically, longer retransmission times are associated with greater coverage areas and a higher QoS. In LoRaWANs, Sigfox, and WiSUN, the networks are linked to several gateways, enabling these networks to select the highest-quality message among all messages received by the gateways.

A real-time monitoring system can provide vital insights into critical processes and valuable catchment data [12]. According to [13], without real-time monitoring, the distance between the animal and the shepherd cannot be virtually reduced, nor can the exact animals' positions be accurately identified. The properties of LoRaWAN such as low power, long range and high reliability make it suitable for real time monitoring of IoT devices [14]. Furthermore, most studies have been conducted in open urban areas, while only a few studies have considered agricultural areas and forests [15]. Hence, this review focused on monitoring applications in remote, dense rural areas, such as orchards and forests, where internet connections are weak or lacking. In [16] [17], both types of research were conducted to quickly detect forest fires, thus preventing delays in extinguishing them due to slow communication and alerts signalling the early signs of fire. Potential solutions for early fire detection could be conceived through the IoT, as forest fires have become a severe problem in recent years.

This paper discusses the technology and network architecture of long-range (LoRa) communication systems, as well as various issues and challenges that have arisen when using LoRaWAN technology. This paper also describes the details underlying LoRaWANs and all possible network topology models. The parameters and characteristics influencing the QoS of LoRaWAN are also explained. The paper's focus then shifts to monitoring applications in remote and rural areas such as forests and orchards.

In the following section (Section II), the LoRaWAN system and network architecture are explained in detail. Then, in Section III, a review of the latest development of forest monitoring systems using LoRaWAN is discussed. The paper closes with Section VI, which offers our conclusions.

II. LORAWAN SYSTEM AND NETWORK ARCHITECTURE

The LoRa was first proposed and launched in 2015 by SemTech Corporation as part of a system that included the LoRa physical layer [18]. The LoRa Alliance is currently developing the standard for LoRaWAN, a media access control (MAC) protocol used in wide-area networks (WANs). While the LoRaWAN is an open technology, specific LPWAN solutions are primarily proprietary. A LoraWAN transmits data at speeds of 0.25-12.5 kbps over radio frequency bands of 169, 443, 868, and 915 MHz (depending on the radio frequency band used [19]) to connect low-power gadgets to Internet-connected applications through long-range wireless connections.

The architecture of the LoRa system comprises several components (Fig. 3). The first component is the end device, which is responsible for sensing control. The second component is the LoRa gateway, which accepts signals from the LoRa end devices and forwards them to the backhaul system. A typical LoRaWAN design consists of several nodes and a gateway that communicates with a network server that implements a standard protocol for disseminating heterogeneous protocol routing packets [20] [21]. Standard IP connections are used to connect gateways to a server. The network server's administration of the entire network is the third component. The fourth and final component is the application server, which allows a remote computer to control the operations of an end device or to gather data from it.

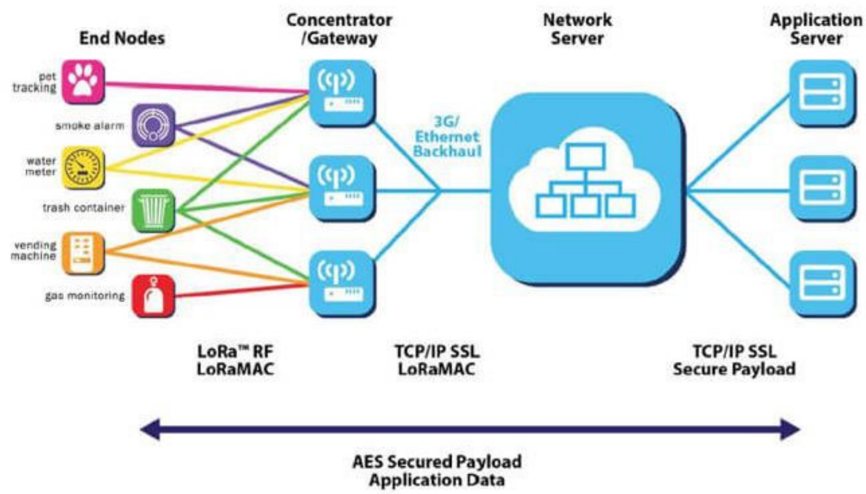

Fig. 3. LoRaWAN system architecture [22].

A. LoRaWAN Protocol Stack and End Device Classes

Fig. 4 shows the LoRaWAN protocol stack [23]. The topmost layer is the application layer, and the bottommost layer is the physical layer. The chirp spread spectrum transmission method is used by the LoRaWAN physical layer. The LoRa Alliance defines the data link layer as a layer between two devices. Three categories of end devices can be used with LoRaWAN, and the mechanism employed by the protocol is a pure ALOHA medium access control mechanism [24].

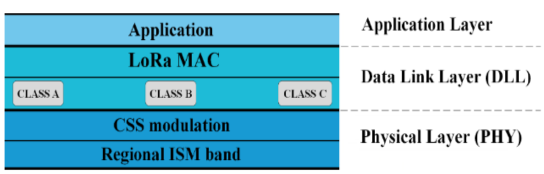

Fig. 4. LoRaWAN Protocol Stack [23].

LoRaWANs support end devices from three classes (labelled as class A, B, and C) to ensure the diverse requirements of applications are met [25]. LoRa end devices are typically classified as class A devices with power-saving capabilities unless specifically classified as class B or Class C. The manner in which packets are sent from the gateway to the device is the most significant factor that distinguishes the three modes of operation (Fig. 5).

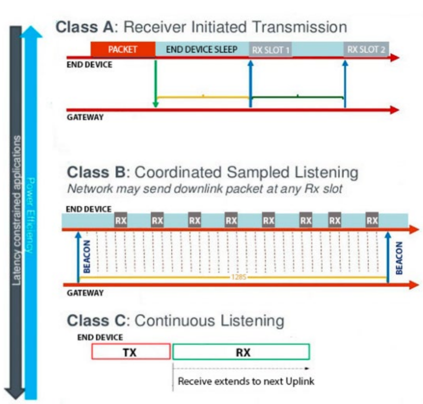

Fig. 5. Operation of Three Different LoRaWAN Classes [26].

Class A is the most power-efficient transmission mode, as it comprises two short downlinks that follow each uplink transmission's receive window. In order to conserve energy, class A devices conserve energy by powering down after the receive windows have closed. The receive windows of class A devices are not the only ones that are opened; additional receive windows are opened by class B devices at predefined intervals. The receive windows can be synced with the gateway by sending beacons to the receiving devices. Finally, class C devices are not typically powered by batteries, meaning they can keep their radios in receive mode indefinitely. As such, they can send data to a device instantly without waiting for a receive window to open.

B. LoRa Parameters

Table II provides the configuration values, requirements, and limitations required to achieve a favourable QoS. LoRa parameters such as bandwidth (BW), carrier frequency (CF), coding rate (CR), spreading factor (SF), and transmission power are discussed. LoRa transceivers work with CFs ranging from 137-1020 MHz (in 61-Hz intervals). However, this frequency may be restricted—specifically, to the range of 860-1020 MHz, depending on which particular LoRa chip is applied [27]. A larger BW enables higher data rates but reduces the Time-On-Air (TOA) and sensitivity [5]. Meanwhile, reducing the BW increases sensitivity but decreases the data bit rate.

In LoRa, the SF can be fixed anywhere between 6 and 12 [28]. SF's effect on energy consumption is stronger than its ability to increase transmission power, which extends the communication range. As a result, energy consumption can be lowered without harming the communication range by modifying the SF. Also, increasing the SF causes the signal-to-noise ratio (SNR) to increase (along with the data bit rate and sensitivity of communication), while the TOA is decreased; this process is also suitable for long-distance transmission [5] [29]. When a device is positioned far away from the gateway, the device must utilise a big SF (e.g. SF11 or SF12) to ensure its broadcasts are received, which implies longer transmission times, greater contention (more collisions), and higher energy

TABLE II

LORAWAN PARAMETERS, CONFIGURATION VALUES, REQUIREMENT AND LIMITATION TO ACHIEVE GOOD QOS PERFORMANCE [15] [30]

Parameter	Definition	Configuration Value	Requirement	Limitation
Carrier frequency	Central transmission frequency.	137-1020 MHz (in 61-Hz intervals).	Frequently deployed in ISM bands (EU: 868 and 433 MHz, USA: 915 and 433 MHz)	Frequency may be limited from 860-1020 MHz, depending on the particular LoRa chip[27]
Bandwidth	Range of frequencies available for transmission.	Typically 125, 250, and 500 kHz	A higher bandwidth is necessary for high-speed data transmission (1 kHz = 1 kbps).	Reduces the range and sensitivity of communication.
Spreading factor	Symbol rate-to-chip rate proportion.	6, 7, 8, 9, 10, 11, or 12	Increased SF results improves the communication range, radiosensitivity, and signal-to-noise ratio.	Increases energy consumption.
Coding rate	Useful payload to total data bit ratio, which includes the additional parity bits for forward error correction.	4/5, 4/6, 4/7, or 4/8	Decoding errors and interference bursts are better protected against when higher significant coding rates are used.	Longer packets require more power.
Transmission power	The amount of power required to send a specific data packet.	Signal power from -4-20 dBm	Increased transmission power improves the signal-to-noise ratio.	High energy expenditure.

consumption. For example, a device that transmits using SF11 consumes approximately 10 times as much energy as a device that transmits using SF7 [31].

LoRa corrects the error in received data via forward error correction [28]. LoRa's robust interference protection necessitates a higher CR, which increases the TOA and energy use. Also, the user can manipulate how much energy is used to transmit a particular data packet. The transmission power was set to the maximum amount permitted by the regulations followed in most testbeds [32]. However, the maximum power does not need to be used, as less transmission power is required by nodes located close to the gateway. Thus, the battery life of the gateway can be extended by reducing the amount of power supplied to these nodes.

C. QoS of LoRaWAN

Communication reliability and energy consumption are critical characteristics of battery-powered wireless IoT systems [33 34]. The reliability performance metrics evaluated in LoRaWAN networks include the SNR, received signal strength indicator (RSSI), and packet loss [32]. The SNR is a ratio denoting the power of a signal in relation to the amount of noise. When the SNR is above 0 dB, the signal is stronger than the noise [35]. This ratio can be improved by increasing the spreading factor, but this prolongs the transmission time [36]. If the SNR value is low, problems could arise with the connection between the end device and the gateway. Fortunately, many methods have been developed for improving the performance of LoRaWAN networks, including increasing the receiver's sensitivity, improving the transmit power, achieving a clear line-of-sight, increasing antenna height, and reducing the distance between the gateway and the end device [6].

The RSSI value indicates the gateway's coverage range and the communication signal strength [32]. Previous research on LoRa configurations for forests proposed using SF10, with a CR of 4/5 and a BW of 250 kHz [17]. RSSI values lower than -136 dBm are not acceptable, as they are considered either entirely or partially lost. Table III displays the RSSI values obtained in a forest environment at various distances (as presented in [17]).

TABLE III

RSSI VALUES AT DIFFERENT DISTANCES IN A FOREST ENVIRONMENT FOR SF10, CR 4/5, AND BW 250 KHZ [17]

Distance (m)	Value (dBm)
100	-91
200	-107
300	-127
400	-136

According to [37], the best settings for a tree farm environment are SF9 with a BW of 125 kHz and SF11 with a BW 125kHz. The RSSI readings for these settings are shown in Table IV.

TABLE IV

RSSI VALUES IN A TREE FARM ENVIRONMENT AT DIFFERENT DISTANCES [37]

Distance (m)	Value for SF9 and a BW of 125 kHz (dBm)	Value for SF11 and a BW of 125 kHz (dBm)
100	-76.27	-75.74
150	-77.59	-77.08
200	-90.97	-90.77

Several factors can cause packet loss, including channel attenuation and data collision [29 38]. The formula for packet loss ratio is shown in Equation (1). This metric is obtained by dividing the total number of packets sent (transmitted packets) by the total number of packets not received (dropped packets).

$$Packet\ Loss\ Ratio = \frac{number\ of\ dropped\ packets}{number\ of\ transmitted\ packets} \times 100\% \quad (1)$$

D. LoRaWAN Topology

Fig. 5 illustrates all possible network topologies for bidirectional communication [39]. As the figure shows, a direct network is the most straightforward connection, as it involves direct communication between the node and the gateway. However, when a system involves many nodes, the direct network becomes too expensive to be practical.

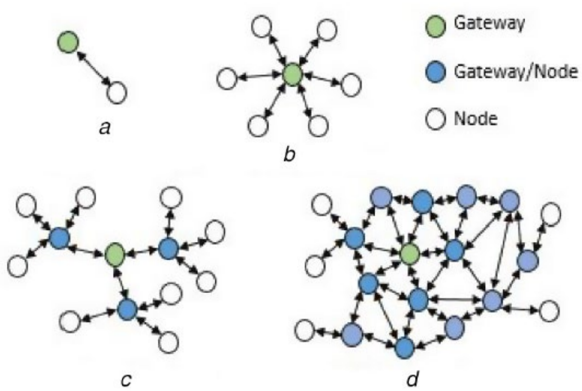

Fig. 5. Possible network topologies for LoRaWAN: (a) direct topology, (b) star topology, (c) cluster topology, and (d) Mesh topology [39].

Fig. 5(b) presents the star topology of LoRaWAN. This method is much less expensive than direct communication because the end devices do not directly communicate with each other; instead, all communication is done through LoRaWAN gateways [40]. The effectiveness of these gateways in sending data to (and receiving data from) the end devices determine how many nodes are utilised. According to IEEE 802.15.4, the LoRaWAN protocol requires a star network. Therefore, deploying a LoRa system for a single large building is cost-effective. Due to improved receiver sensitivity, current LPWAN technologies use a star topology, which enables these networks to cover a more extensive area, makes it easier to manage the network, and lowers the extent to which the end devices require networking firmware [4]. However, the data rates decrease as the coverage area expands.

Fig. 5(c) illustrates the cluster topology, which involves a master gateway and slave gateway (cluster heads). However, this topology's use is limited because no communication takes place between cluster heads. Also, this topology is much more expensive than the star network. Mesh topology (Fig. 5(d)) is a type of multipurpose connectivity. In a mesh topology, the gateway nodes can communicate with one another, as well as with the main gateway. This system's higher cost is compensated for by its ability to encompass a broad area containing many end devices. Multihop communication can extend the area covered by a mesh network topology [41]. Table V summarises the advantages and disadvantages of each topology.

TABLE V
THE ADVANTAGES AND DISADVANTAGES OF LORAWAN NETWORK TOPOLOGIES [39].

Network Topologies	Advantages	Disadvantages
Direct	• The simplest connection.	• Unreasonably expensive when many nodes are involved.
Star	• Cost-effective. • Better receiver sensitivities. • More straightforward network management. • Less networking firmware required by end devices.	• Direct communication between end devices is not permitted; all communication is carried out via LoRaWAN gateways. • The data rate will decrease with the greater coverage area.
Cluster	• Expandable to the highest bandwidth available	• Limited to some applications. • Higher in cost than the star network.
Mesh	• Capable of covering large areas containing many end devices.	• Expensive

E. LoRaWAN Propagation Models

This section explains the most used propagation models in LoRaWAN. The Okumura-Hata Model, COST-231 Hata Model, Extended-Hata and ITU R 1225. These models can be used by researchers to predict the received signal strength and statistical analysis. Geographical location, frequency, the transmitter and receiver antenna height are the factors that can affect the propagation [42] [43].

1) Okumura-Hata Model

This model was originally developed for NLOS paths in urban environments for frequencies from 150 MHz to 1500 MHz, and its median path loss in urban areas (PL_U) measured in (dB) is defined by [44]:

$$PL_U = 69.55 + 26.16\,log(f) - 13.8\,log(h1) - a(h2) + [44.9 - 6.55\,log(h1)]log(dtr) \quad (2)$$

With frequency f in MHz, h_1 as the gateway antenna height, and h_2 the end device antenna height in m; d_{tr} is the distance between the transmitter (gateway) and the receiver (end device) in km, and ah_2 is the correction factor for the end device antenna height and depends on the area of coverage.

In this study, the formula for rural environments (PL_R), is given by:

$$PL_R = PLU - 4.78[log(f)]2 - 18.33log(f) - 40.98 \quad (3)$$

2) COST-231 Hata Model

This model is an extension of Okumura Hata to cover a higher frequency (500 MHz-2000 MHz) and is mostly used to predict link attenuation in mobile wireless systems. COST- 231 Hata is used in urban, suburban and rural areas [44], and is defined in urban areas (PL_u) by the following formular:

$$PL_U = 46.3 + 33.9log(f) - 13.82log(h_3) - ah_4 + [44.9 - 6.55log(h_3)]log(d_{tr}) + c_0 \tag{4}$$

Whereby, the frequency f is in MHz, d_{tr} is the gateway-end device distance in km, and h_3 is the gateway antenna height in m. The c_0 parameter equals 3 dB urban areas, and 0 dB for suburban and rural areas. The ah_4 parameter for urban areas is given by:

$$ah_4 = 3.2[log\,(11.75h_5)]^2 - 4.97, f > 400 \tag{5}$$

While for suburban and rural areas:

$$ah_4 = (1.1logf - 0.7)\,h_5 - (1.56logf - 0.8) \tag{6}$$

whereby, h_5 is the end device antenna height in m.

3) Extended Hata Model

This model was also developed from the extension of the Okumura-Hata to determine path losses for higher frequency bands (30MHz – 3000 MH) in urban, suburban and rural areas [45] and is given by the following path loss (P_L) formular:

$$P_L = L_0 + L_1 - H_0 - H_1 \tag{7}$$

Where L_0 is the attenuation in the free space given by:

$$L_0 = 92.4 + 20\,log10(d_{tr}) + 20\,log10(f) \tag{8}$$

L_1 is the path loss given by:

$$L_1 = 20.41 + 9.83\,log10(d_{tr}) + 7.894log10(f) + 9.56[log10(f)]^2 \tag{9}$$

H_0 is the gateway height gain factor defined as:

$$H_0 = log10(h_g/200)\,(13.958 + 5.8[log10(d_{tr})]^2) \tag{10}$$

H_1 is the terminal end device height gain factor for medium urban areas defined as:

$$H_1 = [42.57 + 13.7\,log10(f)]\,[log10(h_e) - 0.585] \tag{11}$$

Whereby, the frequency f is in GHz, and d_{tr} is the gateway end device distance in km, h_g is the gateway antenna height and h_e the end device antenna height in meters.

III. Research on Monitoring Systems Using LoRaWANs

LoRaWANs are critical for IoT architectures requiring only small amounts of data to be transmitted and received among various devices and cloud infrastructures. Most disparate application fields can be founded using LPWAN-based architectures, with the Smart City scenario being the most studied application [46]. LPWANs have also been implemented in healthcare monitoring [47], smart energy management [48] , agriculture monitoring applications [49] and peatland monitoring [50]. LoRa has also been shown to be useful in remote areas, for example, in forest and orchard monitoring applications.

Based on [5], the LoRaWAN protocol is used to transmit images of mangrove forests in the Sabak Bernam District, Malaysia. However, BW limitations are not ideal for transferring high-bit-rate data across image sensors and other devices that require large amounts of data to be transferred. As a result, a new mangrove forest monitoring system was introduced. In this system, the LoRa physical layer of a node-to-node network has image sensor data transferred over it. Then, hexadecimal data are derived by encrypting the sensor's images are encrypted. These data are subsequently grouped into packets that can be transmitted through the LoRa physical layer.

In previous research, temperature and humidity sensors and fire alarms were deployed in a system designed to detect forest fires [17]. Because of the limited internet coverage in the test area, a LoRa mesh network was developed to transmit information in case of a fire. The LoRa gateway was placed 500 m away from the sensor nodes, which was the maximum distance at which data could be sent to and placed in the internet-service area. The system could monitor 10 hectares of the forest using only four LoRa modules.

An experiment was performed in which several parameters were measured from spring to winter [51]. Incorrect models created with impractical sensors can cause poor energy efficiency, location misplacement, and area control failures. First, the measurement platform was designed. Then, the model and the channel transmission characteristics of the LoRa nodes were tested and evaluated. Finally, an energy-harvesting LoRaWAN system was installed. According to the results, the proposed models performed forest environment deployment during the rainy season.

A LoRa technology-based system consisting of a network of nodes and a gateway was developed to determine fire risk in a rural area [16]. The amount of carbon dioxide (CO_2) in the atmosphere was monitored to predict forest fire risk in the study area. The data provided by the nodes were collected and processed on the things network server before being sent to a website for visualisation. The system was run in a naturalistic environment. However, due to the area's vast plant masses, the signal had a lot of dispersion.

Finally, an inexpensive IoT sensor mesh for orchards was developed for measuring parameters from large-scale orchards remotely [52]. The nodes of this mesh are powered by solar energy and have a high level of energy efficiency. Also, the monitored data could be viewed in real-time via a newly developed web interface and mobile application. The setting for the experiments was an olive grove, and various environmental conditions were considered. The system was successfully installed, and it can be concluded that long ranges of communication require high SFs despite the reduced data rate. Table VI summarises the uses of LoRaWAN monitoring systems in remote areas.

TABLE VI
RELATED WORK ON THE MONITORING SYSTEM USING LORAWAN

Source	Environment, Parameter, Performance Analysis, Location	Method Used	Problem/Limitation
Jebril, Sali, Ismail & Rasid, 2018 **[5]**	• Mangrove forest • Image • Packet Loss Rate, Peak Signal-To-Noise Ratio (PSNR) and Structural Similarity (SSIM) • Sabak Bernam, Malaysia	Direct topology was used to transmit images across the LoRa physical layer. The sensor's image is hexadecimal encrypted and grouped into packets that can be transmitted across the LoRa physical layer.	Bandwidth is limited to transmit image data. Dense coconut trees prevented the signal from reaching the receiver.
Adnan, Salam, Arifin & Rizal, 2018 **[17]**	• Seasonal forest • Temperature and humidity • RSSI • Gowa, South Sulawesi, Indonesia	A forest fire detection system based on LoRaWAN was developed by setting up a LoRa mesh network to cover 10 hectares of forest.	The distance across which data was sent using the LoRa module is limited to only 500 m. Additional nodes are required to cover a larger area.
Wu, Guo, Tian & Liu, 2020 **[51]**	• Mixed forest • The diameter of the tree trunk and the leaf area index. • Path loss • The west side of the Zi Jin Shan Mountain in eastern China.	The parameters were measured from spring to winter. First, the measurement platform was designed. Then, the channel transmission characteristics of the LoRa nodes and the model were evaluated and tested. Finally, a LoRaWAN with energy harvesting capabilities was deployed using a star topology.	Models containing practical sensor nodes might be inaccurate, thus resulting in poor energy efficiency.
Sendra, Garcia, Lloret, Bosch & Vega-Rodriguez, 2020 **[16]**	• Temperature, relative humidity, wind speed and CO_2. • RSSI and SNR • Spain	A system based on LoRa technology (consisting of LoRa nodes equipped with sensors) was developed to assess the risk of forest fires and wildfires in rural areas. The things network server was employed to store and process the data sent by the nodes and send them to a website when graphic visualisation is carried out. The system was tested in a natural setting using a star topology.	Large dispersion in the signal occurs because of large plant masses.
Ojo, Adami & Giordano, 2021 **[53]**	• Highly dense forest • Wildlife monitoring • PDR, RSSI and SNR • San Rossore Park in Pisa, Italy	The researchers utilised a gateway embedded with LoRa capabilities that operate in the frequency bands of 433 and 868 MHz, with the gateway placed at a height of 3 m. The prototypes are placed 1.7 m above the ground for wildlife monitoring. Star topology was used.	LoRa is sensitive to the presence of obstacles and reflectors.
Campos, Salinas, Rodas & Araujo, 2019 **[54]**	• Riparian forests • RSSI, SNR and path loss • Cuenca, Ecuador	The study was conducted under various environmental conditions (i.e., urban, semi-urban, and rural) at three rivers with four measurements. SNR and RSSI were utilised to assess this topology's performance.	Trees and shrubs were the greatest obstacles in the rural setting beside the topography.
Casas, Hermosa, Marco, Blanco & Soria, 2021 **[13]**	• Livestock position and activity monitoring • Power consumption, RF performance (PSNR and RSSI) and digital modulation. • Spain	A wearable device utilising a global positioning system and internal sensors was developed. The system also included a low-power wide area network infrastructure that does not require an internet connection to be operated. The device enables animals' positions and actions to be monitored and logged in real-time via adaptive analysis and data compression.	Harsh orography and a lack of communications infrastructure.
Varandas, Faria, gaspar & L. Aguiar, 2020 **[52]**	• Olive orchard • Temperature, humidity and gases. • Transmission power. • Portugal	A LoRaWAN system with a mesh network topology was used to enable remote measurements of parameters in large-scale orchards. Stable communication was tested for a range of approximately 10 km.	A high SF is needed to achieve more extended communication.
Yim, Chung, Cho, Song, Jin, Kim, Ko, Smith & Riegsecker, 2018**[37]**	• Tree farm • Temperature, humidity, solar irradiance and flame. • PDR, RSSI • Unites States of America.	LoRa technology with star topology was deployed in the tree farm with mid-life maple, oak, and pine trees planted in separate rows (each row was 8 m long). The SF, bandwidth, and coding rate were adjusted so that each node had different settings. A frequency of 915 MHz and a transmission power of 13 dBm were applied, and distances were varied.	High SF and CR are needed to secure reliability over large distances.

In summary, after surveying these studies on the use of LoRaWANs for smart agriculture in urban and suburban environments, as well as for forest monitoring, it seems that more studies need to be done on harsh natural landscapes such as dense forest environments. Based on the studies listed in Table VI, the main challenge facing the development of an optimal LoRaWAN network has been the presence of obstacles between the LoRa gateway and the end device. In addition, transferring a data that require large bit rate such as image is very challenging and slow. Hence, creating a real-time monitoring system could be a problem. Most of the studies in Table VI use RSSI and SNR as their performance analysis. Both RSSI and SNR also can be used to calculate performance analysis such as Path Loss. Understanding the factors in the experimental environment, such as demographics, infrastructure, power supply, and the area of the study site, is crucial to overcome this issue.

IV. CONCLUSION

We overviewed a monitoring system using a LoRaWAN, as it provides excellent coverage in forest and orchard monitoring applications. Numerous challenges and considerations must be considered when implementing LoRaWAN technology. A network's long-term performance is influenced by its logical and geographical layout, as well as interference from other networks.

Further research on the capabilities and limitations of LoRaWANs is required. In addition, LoRaWAN testbeds need to be developed, especially in remote areas, to better analyse the performance of LoRaWAN and propose a suitable propagation model for forest environments.

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