2022 IEEE Zooming Innovation in Consumer Technologies Conference (ZINC) | 978-1-6654-8374-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/ZINC55034.2022.9840717

Towards Smart Sensing Systems: A New Approach to Environmental Monitoring Systems by Using LoRaWAN

Junaid Qadir*[1,2], Ismail Butun*[1], Robert Lagerstrom[1], Paolo Gastaldo[2],
and Daniele D. Caviglia[2]
[1] Department of Electrical Engineering and Computer Science, KTH Royal University
of Technology, SE-100 44 Stockholm, Sweden
`(junaidq, butun, robertl)@kth.se`
[2] Department of Electrical, Electronic and Telecommunications Engineering and Naval
Architecture (DITEN), University of Genoa, 16145 Genoa, Italy
`junaid.qadir@edu.unige.it, (paolo.gastaldo,daniele.caviglia)@unige.it`

***Abstract*—The proliferation of monitoring in unpredictable environments has aided the world in solving challenges that were previously thought to be insurmountable. Drastic advancement has been pinpointed in the way we live, work, and play; however, the data odyssey has yet started. From sensing to monitoring, the endless possibility enabled by LoRa, the long-range low power solution has made its mark on the technological world. With the adoption of the LoRaWAN, the long-range low power wide area network has appeared in existence to cope with the constraints associated with the Internet of Things (IoT) infrastructure. This paper presents a practical experiment for sensing the environmental condition using the LoRaWAN solution. The proposed work allows the users to check the environmental effects (temperature, and humidity) online. Furthermore, the signal behavior has been recorded and cross-verified by using MATLAB software implementation.**

***Index Terms*—Sensors, Sensing, IoT, LoRa, LoRaWAN, LPWAN, Monitoring.**

I. INTRODUCTION

A. Trend

Sensing via emerging technology referred to as the Internet of Things (IoT) has introduced revolutionized access to academia and industrial fashion. The paramount significance of IoT has led it to the next generation, and the number of interconnected devices throughout the world will ping the figure of 50 billion in 2023, and twice within the next two years (100 billion-2025) [1]. The total expected IoT revenue will hit a record of USD 19 trillion by the end of 2025. By keeping in view, the above numeral value and revenue, it is witnessed that the IoT technology plays a vital role in our daily life and finds application in various areas; for instance, environmental monitoring, pollution detection, industrial control systems, home automation system, and smart metering [2]. To give these applications a shape, numerous technological flavors are available for developers, for instance, Bluetooth [3], wireless fidelity (Wi-Fi) [4], IEEE 802.15.4 [5], IEEE 802.11 [6], etc. However, another emergent technology called low power wide area network (LPWAN) has stepped into the market. The popularity of LPWAN could be described into three different variants, such as SigFox, narrowband-IoT, and long-range wide area network (LoRaWAN) [7]. However, the former two technologies are beyond the scope of this paper. And we merely consider LoRaWAN for the proposed demonstration as it is a widely accepted solution for IoT infrastructure. LoRaWAN is the upper layer of LoRa that has been designed to connect the devices on local, and national, and now the new version LoRaWAN v1.1 has been settled with a connectivity option for the international level [8]. The network architecture of LoRaWAN consists of nodes, gateways, network, and application servers. However, a modification has been noted with the new version as can be seen in Fig. 1, the join server has been added to the LoRaWAN v1.1 to improve the end-to-end security of the network. The communication between the end device and the gateway could be done by using radio waves. The packet travels from the end device through the radio waves towards the gateway is known as uplink transmission while back to the end device is called downlink transmission. The gateway is further connected with the network server "also known as the brain of the network" via TCP/IP. The network server further extends its communication with the application server by using several types of protocols such as HTTP, MQTT, etc.

B. Motivation

Sensing and monitoring the environmental condition is an essential part of life in the public and private sectors. Environmental effects are composed of several metrics such as temperature, humidity, air quality, pressure, fog, etc. A conventional monitoring station is typically equipped with highly precise sensing equipment. However, such types of systems require huge costs for installation and maintenance. For instance, a monitoring system typically for air quality costs around USD 200 K for installation and USD 30 K for maintenance per year [9]. Therefore, such kinds of systems

---

*Corresponding authors

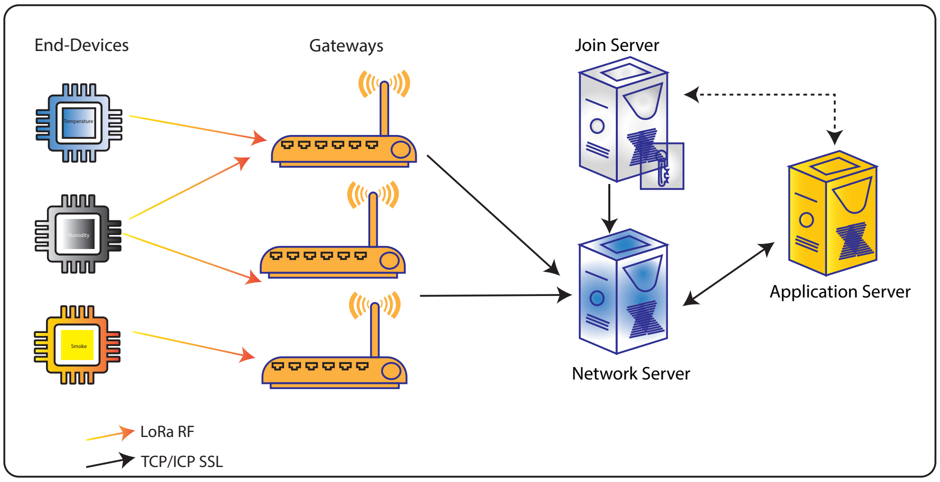


Fig. 1: Network architecture of LoRaWAN.

in a large-scale installation are beyond the budget when it comes to developing countries. Investigating a low-cost solution is essential to monitor the environmental condition. This paper presents a low-cost IoT-based LoRaWAN solution for the well-being of citizens in an urban/rural area. The proposed implementation considers the Adafruit RFM95W LoRa transceiver and the Dragino LPS8 gateway with temperature and humidity sensors. The experiment has considered in a real-time environment in Stockholm, Sweden, and the simulation results reveal the performance evaluation.

The rest of the paper is explained in the following sections. Section II describes the work related to environmental monitoring by employing the LoRaWAN solution. Section III describes LoRaWAN technology. Section IV explains the overview and practical demonstration of the proposed experiment. The result obtained from the proposed work is highlighted in Section V. Finally, the overall work is concluded in Section VI.

II. RELATED WORK

LoRaWAN technology is still in an infancy stage and getting huge interest from the researchers at the academia and industrial level day by day. This section presents recent research from the literature that considers conventional experimental techniques for environmental monitoring.

Thu, Min Ye, et al [9] proposed a scalable implementation for environmental monitoring based on LoRaWAN. The experiment was implemented in Myanmar that considered four different parameters from the environment such as; temperature, humidity, dust, and carbon dioxide in the air. An online dashboard has been created for the users to monitor the data collected by the sensors used in the experiment. Furthermore, a machine learning-based model has been taken into account to make future predictions for the environmental parameters and take proactive action in a pervasive condition.

The rapid growth in industries has made the atmosphere pollutant. A mixture of different types of gases such as carbon monoxide (CO), carbon dioxide (CO2), and formaldehyde (CH2O) with air has significantly made life cumbersome. Therefore, the authors in [10] proposed a multi gas sensing solution to detect harmful gases. The solution makes use of dual technological flavors such as Wi-Fi and Bluetooth. To save the network from early death, the Wi-Fi module uses sleep mode after event detection, while the Bluetooth remains active for real-time detection. A smartphone application is designed to check the real-time event and take instant action if the concentration beyond the threshold is alerted.

Another IoT solution for smart sensing using LoRaWAN is discussed in [11] which consists of sensor nodes, communication links, and cloud storage. Furthermore, the Cayenne myDevice cloud server is considered to store and visualize the data detected by the sensor node. To reduce the maintenance cost, the sensor node is powered by dual input sources, for instance, solar panels, and energy harvesting using radio frequency. Energy harvesting is the alternate source in case the solar panel is not good enough for a sensor node. This solution uses Raspberry Pi 3 as the main computing unit with the addition of LoRa concentrators such as RAK831 from the Rakwireless technology vendor to adopt the LoRaWAN gateway.

T. Addabbo et al [12] proposed a wireless sensing architecture for the environmental monitoring system. This experiment dynamically collects data from pervasive areas through public transport. The LoRa modulation technique is utilized to transmit and receive collected data from the sensing devices. The device is equipped with the GPS and LoRaWAN modules, respectively, to localize and communicate with the server. This dynamic LoRa enabled architecture detects toxic gases e.g, CO, CO2, NOX these pollute the quality of fresh air.

The authors in [13] presented a practical demonstration for uncertain air pollution using an Unmanned Aerial Vehicle (UAV). The air quality sensor is equipped with the UAV, that can sense the environment and transmit the sensed packet during flight mode by utilizing the LoRa modulation technique. The authors developed a web based user interface (Web-UI) to configure the route for the UAV in flight mode. Furthermore, instant action can be performed by utilizing web-UI if detected any event is transmitted by the UAV from the fly zone.

III. LORA AND LORAWAN TECHNOLOGIES

It is worth mentioning to differentiate the word LoRa, which marks its place to the physical layer, and LoRaWAN is the upper layer (MAC-layer) in the OSI model. This section presents a brief overview of LoRa and LoRaWAN.

A. Physical Layer-LoRa

Long Range (LoRa) is a proprietary chirp spread spectrum (CSS) modulation whose key properties are determined by the spreading factor (SF), bandwidth (BW), and coding rate (CR) [14]. The spreading factor is the ratio of symbolic and chip rate as in Eq. (1) that facilitates the signal with multiple grades starting from SF=7 to Sf=12. The SF method utilizes forward error correction (FEC) to provide long-range communication with the price of low speed.

$$SF = \ln \left[\frac{R_c}{R_s} \right] \tag{1}$$

LoRa modulation with minimal error is cumbersome in some situations because of the diverse effects in the channel. Therefore, it implies FEC implementation by encoding 4-bits data with the variant of redundant bits for instance 5-bits to 8-bits as shown in Table 1. This implementation significantly reduces interference in the channel. Selecting the CR value is adjusted in accordance with the channel effect. A higher value of CR is recommended for a high interference channel. However, the higher CR value results in higher latency in transmission. The BW also represents as chirp rate in LoRa modulation is the frequency range that is used for imposing the baseband data. LoRa transmits the packet by using the BW value of 125 kHz, 250 kHz, 500 kHz. It is impervious to interference because of all of these properties combined.

TABLE I: Coding rate used for LoRa packet.

Coding rate (CR)	CR = 4/(4+CR)
1	4/5
2	4/6
3	4/7
4	4/8

B. MAC Layer- LoRaWAN

LoRaWAN recently commercialized by LoRa Alliance is a network protocol and together with LoRa (physical layer), that enables a long-range communication link. It has a significant influence on determining battery lifetime, security, quality of service, and network scaling. The device purposely installed in the network can last for up to several years powered by a battery source. It provides packet exchanging convenience with a range of 50 km in rural areas by ensuring high security encryption such as 128-bit AES cryptographic technique. The adaptive data rate (ADR) allows the node located near the gateway to send the packet with a high data rate and use a lower data rate several kilometers from the gateway.

C. Data Layer

The deployment of LoRaWAN architecture can be accomplished by using star topology. In this deployment fashion, a node can establish a connection with one gateway which is referred to as a standard start topology. However, it is important to mention that a node can be connected to other gateways if available in the communication range. Therefore, it advances the packet with another topology called star-of-starts network topology. The node can start communication with the gateway without prior synchronization.

D. Adaptive Data Rate

LoRaWAN allows the network server to change the parameters for the end device dynamically. The parameters such as SF, frequency, and transmitting power collaboratively maintain the quality of service in network. A lower SF selection transmits the packet with low latency, while a higher SF extends the packet to the long range with the cost of high latency. Transmission with higher SF is not recommended as the probability of collision is high. The adaptive data rate (ADR) allows the node located near the gateway to send the packet with a high data rate and use lower data rate with a distance of several kilometers from the gateway.

E. Device Activation

The end device needs to be activated before communicating to the network. Generally, there are two different methods use for the end device activation. The first method is activation by personalization (ABP) while the other is activation by personalization (OTAA) [15] which are briefly described below:

ABP- In ABP activation phase, the and device only needed session keys and device address (DevAddr) that are hardcoded in the device. The session keys consist of network session key (NwkSKey) and application session key (AppSKey). The NwkSKey is used for the integrity to protect the message from tempering. While the AppSKey is used to encrypt or decrypt the payload use for exchanging between the end device and the application server.

OTAA- It is the most secure and preferred activation method for the end device. In OTAA method, the end device first sends a join request message to the network server. The join request message is consist of globally unique device identifier (DevEUI), APPEUI, and DevNonce which is a random number starting from zero. The network server is responsible of analyzing the the join request and if found correct keys, it sends back a response called join accept message. The join accept message is formed with three values such as AppNonce (random number b network server), device address (DevAddr), and network identifier (NetID). Unlike the ABP method, the OTAA is considered the most secure method as the keys are changed after time interval.

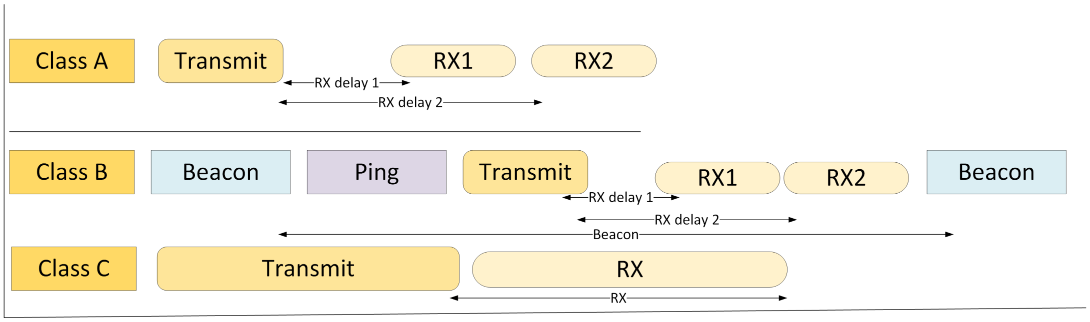


Fig. 2: LoRaWAN end devices transaction of Class A, B, and C.

F. Device Classes

The LoRaWAN end device is classified into three difference classes such as; Class A, Class B, and Class C. All devices consider Class A implementation, while the rest two are extensions of Class A. The characteristic of each class is described below:

Class A(ll): Class A, a short term of the word “All” which means it must be implemented in every LoRaWAN end device. It is the default class in which the end device opens two short windows after completing uplink transmission. It enables a bi-directional communication facility and go back to sleep mode until find its own application. Class A end devices are the most energy efficient; however, it causes high latency because of the sleep mode.

Class B(eacon): Class B is the extended version of Class A and opens receive windows in addition of Class A. Class B devices open downlink ping slots by synchronizing with the network server via periodic beacons. This makes the network to exchange downlink transmission with a trad-off of latency and power consumption of the end device. However, Class B devices’ power consumption is still valid for an application powered with a battery.

Class C(ontinues): Class C devices are known as the most efficient devices in terms of latency as it opens all receiver windows at the same time. In this class, the network server communicates with devices via a downlink transmission and assumes that the receiver windows of the end device is open. Therefore, it provides communication with no latency; however, the energy consumption of the Class C end devices is high as compared to Class A and Class B devices. Class C devices are suitable for an application where continues power is provided. The transaction of Class A, B, and C is shown in Fig. 2.

IV. PROPOSED SYSTEM DESIGN

This section discuses the hardware used for the proposed implementation.

- The LoRaWAN end device and gateway are the essential parts of the network. Both the device and gateway are composed of a microcontroller and LoRa radio module. This paper makes use of the Adafruit RFM95W LoRa module[1], which comes with the package of well-known transceivers e.g, Semtech SX1276 [16]. This transceiver provides ultra-long-range communication with a few variants of spread spectrum such as SF7-SF12. In addition, it can achieve a very good sensitivity with a minimal cost of energy consumption. Due to its diverse nature and reasonable price value, SX1276 finds applications over different areas such as meter reading, monitoring, irrigation, and building automation systems, etc.
- In practical, the LoraWAN implementation consists of nodes, at least a single gateway, and servers for receiving and performing analysis. This work considers the Dragino LPS8[2] gateway which is comprised of SX1308[3] LoRa concentrator, as shown in Fig. 3. LPS8 provides diverse features i,e users can customized frequency range based on the region. It uses an open source semtech packet forwarder that makes LPS8 fully compatible with LoRaWAN. The SX1308 digital basband chip finds application in smart sensing network, smart cities, and smart agriculture system.

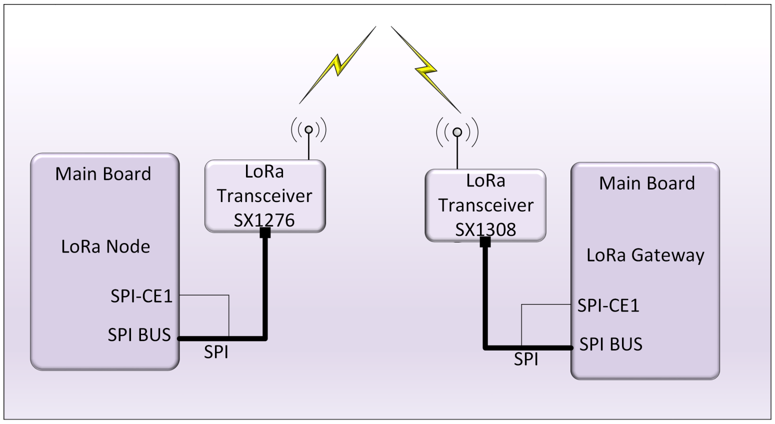


Fig. 3: Dragino LPS8 LoRaWAN gateway.

- Digital humidity temperature (DHT22)[4] is a calibrated low-cost sensor that features wide measuring and good accuracy than the former variant referred to as DHT11.

---

[1] https://github.com/adafruit/Adafruit_CircuitPython_RFM9x.

[2] https://dragino.com/products/lora-lorawan-gateway/item/148-lps8.html

[3] https://www.semtech.com/products/wireless-rf/lora-core/sx1308

[4] https://learn.adafruit.com/dht

It has ±0.5°C accuracy for temperature and ±2%RH accuracy for humidity. The reason for using this sensor in our experiment is because it provides precise reading within an affordable price range.

- To analyze the data acheived from the proposed setup, we used the TheThingsNetwork (TTN)[5] which provide a complete solution for LoRaWAN implementation. TTN provides built-in integrations such as MQTT, Webhooks, AWS IoT etc which can be used to visualize the data received from the end device.

V. MEASURED RESULTS AND ANALYSIS

This section presents the general capabilities of LoRa radio transceiver that we use for our experiment. The experiment was conducted with Intel(R) Core (TM) i7-1165G7 and 16 GB of RAM. This work considers the received signal strength indicator (RSSI), as it has a significant role in wireless network which can be used for localization of the end user in the network.

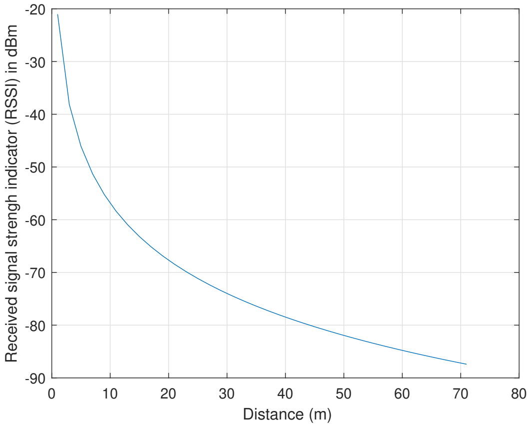
Received Signal Strength Indicator (RSSI): RSSI, also known as the received power level, is an estimated measurement of radio frequency at node received from an access point. It is measured in decibel milliwatt (dBm) and possesses negative value. Typically, the RSSI value of the LoRa is -120 dBm. For instance, the signal having RSSI is -30dBm is considered the strong signal, while -120dBm shows the weak signal.

Various problems compete with the signal such as noise, interference, fading, etc., as it travels from the transmitter to the receiver. Mitigation of these factors is cumbersome and almost impossible. Therefore, we calculated the RSSI by using the Hata model in [17] which is a propagation model for predicting loss that occurs in the original signal. As can be seen in Fig.4(a), the RSSI value starts from -20dBm, and then monotonically decreases by increasing the distance between the transmitter and receiver. Then, we performed an experiment by keeping the gateway indoors at a constant position and moving the end-device away from the gateway as shown in Fig.4(c). Finally, we validate the RSSI using MATLAB as shown in Fig.4(b) for the indoor and outdoor activity by keeping in view the distance between the end device and the gateway. As can be seen in Fig.4(b), initially the RSSI value is high; however, as the end-device goes away from the gateway the RSSI value gets reduced. Because multiple environmental effects such as noise, fading, etc., weaken the signal quality.

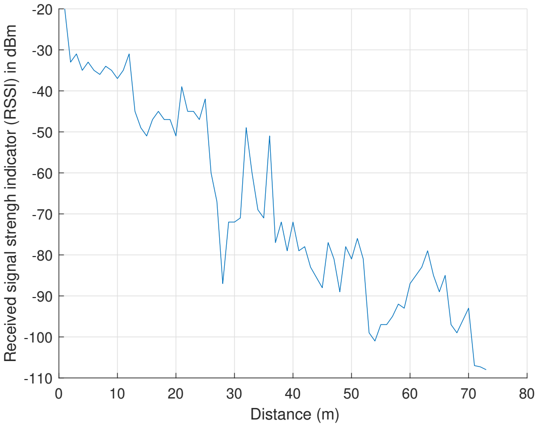
A. Lessons Learned

This section presents lessons learned from our experiment, and the following two questions may arise in the readers' minds.

Q1: How this experiment adheres to the smart sensing systems?



(a) RSSI using Hata Model



(b) RSSI value from the real experiment

(c) Real world scenario for experiment

Fig. 4: a) Simulations result of RSSI using Hata Model [17], b) RSSI value, when the gateway is indoor and the end device started towards outdoor, c) Experiment conducted in real environment.

Objective: This experiment provides a precise solution to a task where physical access is not possible. One can monitor the environment for a specific task, for instance, Mushroom cultivation needs a temperature of 12°C. Therefore, the smart sensing system gives you an opportunity to check the temperature on an online dashboard remotely i.e., TTN or other android applications such as Ubidots, thingspeak, TTN-Mapper, etc.

---

[5] https://eu1.cloud.thethings.network/console/

Q2: What benefits you observed with LoRa when compared to the existing Environment Monitoring Systems?
Objective: As we discussed previously, a conventional monitoring system requires huge costs for installation and maintenance, and such a large-scale cost is out of the budget for those who cannot afford it. Therefore, we observed that LoRa based smart monitoring system provides a solution at an extremely low price, as many vendors produce LoRa modules at a cost of a few dollars.

VI. CONCLUSION

Sensing and monitoring environmental effects are an essential part of well-being in both urban/rural areas. This work presents an experimental demonstration for environmental monitoring using LoRaWAN which is a newly adopted rival of existing technologies such as SigFox and NB-IoT etc. LoRaWAN enables long-distance communication at the cost of ultra-low energy consumption. The proposed experiment utilizes the Adafruit RFM95W LoRa transceiver and Dragino LPS8 LoRaWAN gateway. An open-source network server is used to visualize the information detected from the surrounding environment. Furthermore, the MATLAB simulation validated the signal behavior between the end device and the gateway in the LoRaWAN network.

ACKNOWLEDGEMENT

This paper has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 832907 (EnergyShield).

REFERENCES

[1] R. Taylor, D. Baron, and D. Schmidt, "The world in 2025-predictions for the next ten years," in *2015 10th International Microsystems, Packaging, Assembly and Circuits Technology Conference (IMPACT)*. IEEE, 2015, pp. 192–195.

[2] I. Butun, N. Pereira, and M. Gidlund, "Security risk analysis of lorawan and future directions," *Future Internet*, vol. 11, no. 1, p. 3, 2018.

[3] C. Bisdikian, "An overview of the bluetooth wireless technology," *IEEE Communications magazine*, vol. 39, no. 12, pp. 86–94, 2001.

[4] Alliance, "Wi-fi certrified wi-fi direct." [Online]. Accessed March 12 2022. [Online]. Available: https://www.wi-fi.org/system/files/wp_Wi-Fi_Direct_20101025_Industry.pdf

[5] A. F. Molisch, K. Balakrishnan, C.-C. Chong, S. Emami, A. Fort, J. Karedal, J. Kunisch, H. Schantz, U. Schuster, and K. Siwiak, "Ieee 802.15. 4a channel model-final report," *IEEE P802*, vol. 15, no. 04, p. 0662, 2004.

[6] B. P. Crow, I. Widjaja, J. G. Kim, and P. T. Sakai, "Ieee 802.11 wireless local area networks," *IEEE Communications magazine*, vol. 35, no. 9, pp. 116–126, 1997.

[7] L. Alliance, "what is lorawan." [Online]. Accessed March 12 2022. [Online]. Available: https://lora-alliance.org/resource_hub/what-is-lorawan/

[8] "Lorawan 1.1 specification," [Online]. Accessed March 12 2022. [Online]. Available: https://lora-alliance.org/resource-hub/lorawanr-specification-v11

[9] M. Y. Thu, W. Htun, Y. L. Aung, P. E. E. Shwe, and N. M. Tun, "Smart air quality monitoring system with lorawan," in *2018 IEEE International Conference on Internet of Things and Intelligence System (IOTAIS)*. IEEE, 2018, pp. 10–15.

[10] C.-M. Huang, Y.-J. Liu, Y.-J. Hsieh, W.-L. Lai, C.-Y. Juan, S.-Y. Chen, C.-C. Yang, and C.-M. Wu, "A multi-gas sensing system for air quality monitoring," in *2018 IEEE International Conference on Applied System Invention (ICASI)*. IEEE, 2018, pp. 834–837.

[11] Y. Wang, Y. Huang, and C. Song, "A new smart sensing system using lorawan for environmental monitoring," in *2019 Computing, Communications and IoT Applications (ComComAp)*. IEEE, 2019, pp. 347–351.

[12] T. Addabbo, A. Fort, M. Mugnaini, L. Parri, A. Pozzebon, and V. Vignoli, "Smart sensing in mobility: a lorawan architecture for pervasive environmental monitoring," in *2019 IEEE 5th International forum on Research and Technology for Society and Industry (RTSI)*. IEEE, 2019, pp. 421–426.

[13] L.-Y. Chen, H.-S. Huang, C.-J. Wu, Y.-T. Tsai, and Y.-S. Chang, "A lora-based air quality monitor on unmanned aerial vehicle for smart city," in *2018 International Conference on System Science and Engineering (ICSSE)*. IEEE, 2018, pp. 1–5.

[14] I. Butun, N. Pereira, and M. Gidlund, "Analysis of lorawan v1. 1 security," in *Proceedings of the 4th ACM MobiHoc Workshop on Experiences with the Design and Implementation of Smart Objects*, 2018, pp. 1–6.

[15] F. Mårlind and I. Butun, "Activation of lorawan end devices by using public key cryptography," in *2020 4th Cyber Security in Networking Conference (CSNet)*. IEEE, 2020, pp. 1–8.

[16] SX1276, "Semtech sx1276." [Online]. Accessed March 12 2022. [Online]. Available: https://www.semtech.com/products/wireless-rf/lora-core/sx1276

[17] A. Medeisis and A. Kajackas, "On the use of the universal okumura-hata propagation prediction model in rural areas," in *VTC2000-Spring. 2000 IEEE 51st Vehicular Technology Conference Proceedings (Cat. No. 00CH37026)*, vol. 3. IEEE, 2000, pp. 1815–1818.