Review of LoRaWAN Applications

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Abstract. This paper presents a systematic review of LoRaWAN applications. We analyzed 71 cases of application, with focus on deploy and challenges faced. The review summarizes the characteristics of the network protocol and shows applications in the context of: smart cities, smart grids, smart farms, location, industry, and military. Finally, this article analyzes some security issues.

1. Introduction

Low Power Wide Area Network (LPWAN) is a low-power, low-cost, wide area coverage and low data transfer wireless communication, designed to Internet of Things (IoT) [Petäijäjarvi et al. 2017]. Examples of LPWAN technologies are LoRa and LoRaWAN [Alliance 2015].

LoRa is a physical layer modulation technique, based on Chirp Spread Spectrum, and patented by the French company Semtech. It can be used in the unlicensed radio frequency spectrum for data transmission, including ISM band. LoRaWAN is a network protocol convergent to the LPWAN and defines the system architecture. This systematic review seeks to highlight the potential of using LoRa and LoRaWAN in real IoT applications. Previous studies [Saari et al. 2018] pointed out some characteristics of the technology, but the practical scenarios and considerations about deploy have not yet been explored. To explore these aspects, this paper, in Section 2 presents the general characteristics of the technology. Section 3 summarizes the methodology used in this systematic review. In Section 4 the selected articles are organized in categories according to their area of application. Section 5 reports some security issues and concerns. Finally, Section 6 concludes the study.

2. LoRa and LoRaWAN protocols

The architecture and specification of LoRa and LoRaWAN can be found in LoRaWAN Alliance portal. The Figure 1 presents the layered organization, at the top level are the applications. It is also worth mentioning that, at bottom level, are the regional specifications. These definitions are based on local regulations in each country that determine the best allocation of the radio transmittable space, since it is essential to have the fewest collisions and especially that such transmissions do not interfere in operations considered critical, such as communications to public security and patrimony of such governments. On account of these definitions, some countries also determine that a maximum duty cycle value (1% in most countries) is respected, which is crucial for good data flow and fair usage of airtime.

Regarding the LoRa transmission settings, the Spreading Factor (SF) is a firmware-configured integer variable that varies from 7 to 12. The variable SF is used
to change the modulation of the information to be transmitted according to the needs of each application. By using the same SF for the same channel may cause packet collisions; but different SFs for the same channel do not present problems due to the immunity to interference, that is an important characteristic of the technology. Thus, to choose the right SF parameter have a direct consequence in two questions: air time and distance of reach [Andrei et al. 2017].

In addition, the SF parameter has influence in the maximum payload. In LoRaWAN, due to the duty cycle restrictions, by using SF7 the maximum payload size is 242 bytes. It is 51 bytes with SF12 [Ferrari et al. 2017].

3. Systematic review methodology

The methodology adopted in this review [Kitchenham 2004] is organized as follows. Initially, in Phase 1, IEEE, ACM, Springer, ScienceDirect digital libraries were used for search (keywords: “LoRaWAN”, “LoRa”, “LPWAN”, “IoT” and “sensor” with the AND connector). In Phase 2, the title and abstract were analyzed for suitability. In Phase 3, primary reading was performed and, in Phase 4, we applied some exclusion criteria. Articles that met all the requirements were carefully analyzed in Phase 5.

Regarding the exclusion criteria, all papers published before 2015 (when LoRa version 1.0 was released) and not written in English were excluded. During the last phase, Phase 5, all articles were into Application, Theoretical and Experimental groups, as shown in Table 1. The group of Application articles contemplated all the cases in which LoRa helped in the solution of some real situation. The Theoretical was formed by studies without implementation in the field. The Experimental cases were composed of articles that underwent tests with LoRa, but also did not envisage practical application.

| Type of work     | IEEE Xplore | ACM | Science Direct | Springer Link | Total |
|------------------|-------------|-----|----------------|---------------|-------|
| Application      | 59          | 4   | 4              | 4             | 71    |
| Theoretical      | 51          | 4   | 9              | 7             | 71    |
| Experimental     | 22          | 3   | 2              | 2             | 29    |
| Total            | 132         | 11  | 15             | 13            | 171   |

This paper is focused on articles from the first group, the real applications. We were interested in investigate deploy, equipment used, and perceived problems in practice.
Table 2. Country of origin

| Local                        | References                                                                 |
|------------------------------|---------------------------------------------------------------------------|
| Argentina                    | [Grión et al. 2017, Candia et al. 2018]                                    |
| Australia                    | [Radcliffe et al. 2017]                                                   |
| Australia/Russia             | [Fedchenkov et al. 2017]                                                  |
| Belgium                      | [Laveyne et al. 2017, Podevijn et al. 2018]                                |
| Brazil                       | [Barriqueló et al. 2017, Filho et al. 2016, Carrillo and Seki 2017]        |
| Bulgaria                     | [Penkov et al. 2017, Hristov et al. 2018, Mateev and Marinova 2018]        |
| China                        | [Li et al. 2018]                                                          |
| China/England                 | [Yu et al. 2017]                                                          |
| Czech Republic                | [Gottthard and Jankech 2018]                                              |
| Denmark                      | [Fargas and Petersen 2017, Bardram et al. 2018]                            |
| England                      | [Battle and Gaster 2017]                                                  |
| Finland                      | [Petäjäjärvi et al. 2017, Petäjäjärvi et al. 2015]                         |
| France                       | [Neumann et al. 2016, Varsier and Schwoerer 2017, Loriot et al. 2017]      |
| France/Ireland               | [Havard et al. 2018]                                                     |
| Germany                      | [Poenicke et al. 2018]                                                    |
| Germany/Tunisia               | [Mdhaaffar 2017]                                                          |
| Greece                       | [Zinas et al. 2017]                                                       |
| India                        | [James and Nair 2017, Salpekar et al. 2017, Sahoo and Patnaik 2017]        |
| Italy                        | [Geetha and Gouthami 2017, Manoharan and Rathinasabapathy 2018]            |
| Italy/Sweden                  | [Rizzi et al. 2017]                                                       |
| Italy/Turkey                  | [Buyukakkaslar et al. 2017]                                               |
| Japan                        | [Boshita et al. 2018]                                                     |
| Kazakhstan/Russia             | [Tikhvinskiy et al. 2017]                                                 |
| Lithuania                     | [Nakutis et al. 2018]                                                     |
| Macedonia                     | [Davcev et al. 2018]                                                      |
| Malaysia                      | [Nor and Mubdi 2017, Assri et al. 2017, Ibrahim et al. 2018a, Ibrahim et al. 2018b, Ibrahim et al. 2018c] |
| Morocco                       | [Karkoush et al. 2018]                                                    |
| Netherlands                   | [Ayele et al. 2017]                                                       |
| Pakistan                      | [Arsalan et al. 2018]                                                     |
| Romania                       | [Andrei et al. 2017]                                                      |
| Scotland                      | [Wixted et al. 2016]                                                      |
| Serbia/Slovenia               | [Kos et al. 2017]                                                         |
| Singapore/Myanmar             | [Thu et al. 2018]                                                         |
| South Korea                   | [Jeon et al. 2018, Park et al. 2017]                                       |
| Taiwan                        | [Chou et al. 2017, Ke et al. 2017, Lee and Ke 2018, Liu et al. 2018]       |
| Thailand                      | [Vatcharatiansakul et al. 2017, San-Urn et al. 2017]                      |
| Tunisia                       | [Rahim et al. 2018]                                                       |
| Turkey                        | [Al-Turjman 2017]                                                         |
| Uruguay                       | [Bellini and Amaud 2017]                                                  |
| USA                           | [Danieletto et al. 2017, Jalaian et al. 2018]                              |
| USA/Finland                   | [Hämäläinen and Li 2017]                                                  |
| USA/Portugal                  | [Dongare et al. 2017]                                                     |
3.1. Research questions

The research questions used during Phase 5 were:

1. What are the main features of LoRa technology?
2. What applications are LoRa and LoRaWAN being used for??
3. What are the main challenges that LoRa faces today?

4. Results

The list of 71 analyzed articles is, ordered by country, in Table 2. Malaysia, India, and the state of Taiwan have 5 articles each. In Brazil, four articles were identified. Some articles were developed in partnership between universities of different countries.

4.1. Question 1: what are the main features of LoRa technology?

Several papers did analogies among LoRa, LoRaWAN and OSI network model, where LoRa integrates the physical layer and LoRaWAN the network layer [Dongare et al. 2017]. Besides these analogies, an article clarified the classes of LoRa [Vatcharatiansakul et al. 2017]. According to the study, Class A is intended for simple sensors and for better battery utilization. Class B is intended for actuators. And Class C is for powered devices that need low latency but with reduced battery efficiency, they are bi-directional and always active. Most of the current LoRa applications is based on Class A.

The throughput can be between 0.3 kbps and 50 kbps, considering the different spreading factor configurations for 915 MHz and the number of 64 channels for uplink and downlink [Adelantado et al. 2017]. The battery for a stand-alone system can remain active for up to 10 years [Lee and Ke 2018].

About the range distance, the expected range is 5 km for urban areas and up to 14 km for rural areas, or areas without significant obstacles [Adelantado et al. 2017], and 30 km on the water surface [Petäjäjärvi et al. 2015]. In Bucharest, Romania [Andrei et al. 2017], a hardware was prototyped to validate the maximum transmission distances reached using LoRa. They reached, using SF7, a range of 4.3 km in urban area and 9.7 km in rural areas, with the gateway antenna positioned in high places. Besides, it was reported that an Arduino would not be able to operate as a real gateway because it only possessed 2 kB of SRAM.

4.2. Question 2: what applications are LoRa and LoRaWAN being used for?

The practical use cases are detailed below, organized by area of application:

- **Applications for Smart Cities.** In South Korea, a network that reaches 99% of the population is being developed using LoRaWAN, while Amsterdam, Netherlands, was covered entirely with 10 gateways [Battle and Gaster 2017] [Ayele et al. 2017]. London and surrounding areas, England, are already adequately covered by LoRa [Yu et al. 2017]. The total project cost of 11,681 nodes and 47 gateways exceeded one million pounds, for a financial return in up to 7 years. Around 90% of the investment was explained by the costs of installing, maintaining and leasing local infrastructure.
There are several applications in public transport and traffic monitoring. In India [James and Nair 2017], some buses are equipped with transceivers and bus stops with receivers (nRF24L01 transceiver integrated to PIC18F and ESP8266). In Nagoya, Japan [Boshita et al. 2018], it was possible to track the location of buses using such transceivers at bus stops with a LoRa AL-050 next to an Arduino Uno and GPS U-blox NEO-7N to capture bus positioning in time real. In Argentina [Grión et al. 2017], Cordoba and Buenos Aires are cities that already have LoRa networks implemented with nodes made of BeagleBone Black, GPS, and LoRa module. In Selangor, Malaysia, with the aim of improving the traffic monitoring in denser urban areas in Malaysia, where there are intense vehicle flows and thus enables the management of vehicle passage at the proposed locations [Nor and Mubdi 2017]. In Marrakesh, Morocco [Karkoush et al. 2018], a prototype capable of implementing a camera is shown in the windbreak of the vehicles, thus detecting if a driver slept while driving. In Tainan, Taiwan [Chou et al. 2017], LoRa used to vehicle condition monitoring. Another application class is urban monitoring. Authors in Yangon, Myanmar, and Tampines, Singapore [Thu et al. 2018], have created sensors (with The Things Uno) that capture temperature, humidity, dust, and carbon dioxide in the air of cities. Air quality monitoring was also studied in La Plata, Argentina [Candia et al. 2018]. In the same scenario, some authors from Manouba, Tunisia [Rahim et al. 2018], focused on the feasibility of non-packet transmission with a LoRaWAN network implementing a sensor network in a city to monitor air quality. Monitoring the environment in cities was also the approach implemente in Hsinchu City, state of Taiwan [Wang et al. 2018]. Urban pollutants control, in New York, USA [Danieletto et al. 2017], used LoRa to monitor the air in different neighborhoods.

In St. Petersburg, Russia [Fedchenkov et al. 2017], waste management applications were developed through LoRaWAN. To assist in DHL cargo management at an airport in the Magdeburg region of Germany [Poenicke et al. 2018], sensors were placed on the load conveyors (more than 1700 nodes) that communicate with a central gateway.

Authors in Brescia, Italy [Carvalho et al. 2018], covered an area of 3.3 km$^2$ to evaluate variables in non-real time, such as the volume of dumps and monitoring of heaters. The maximum delay for both fixed and moving nodes was 250 ms due to the quality of the internet, which is sufficient for non-real time IoT applications. With similar hardware, in Selangor, Malaysia, a parking lot was implemented using LoRaWAN; the project cost was considerably cheap considering its components [Assri et al. 2017, Jeon et al. 2018]. In Kongens Lyngby, Denmark [Bardram et al. 2018], LoRa was used to monitor free boat spots in a harbor; the solution used ultrasonic sensors. In Brno, Czech Republic [Gotthard and Jankech 2018], a solution to assists in the management of large cars. Other studies, at Europe [Neumann et al. 2016, Wixted et al. 2016, Havard et al. 2018] and Australia [Radcliffe et al. 2017], have used general LoRa applications to characterize protocol behavior.

**Smart Grids.** Some solutions for Smart Grids were implemented in Brazil. In Santa Maria [Barriquello et al. 2017], 130 nodes were used to implement Smart Grids. Similar tests were conducted by [Silva et al. 2018]. In Campinas,
Brazil [Filho et al. 2016], LoRaWAN and Mesh RF were compared for supply grid remote sensing.

In Meylan, France [Varsier and Schwoerer 2017], it was showed the use of LoRaWAN with electric energy meters implementing nodes and gateways in Paris and analyzing the maximum reaches. In all 19 gateways separated by 1 km of each other were positioned and, in this scenario, $17 \text{ km}^2$ were covered using 11 B packets. The authors stressed, however, that since LoRa can be adapted for use in urban environments, the duty cycle issue is purely legal and not an impossibility in transmission, so it may or may not be respected. Another similar study [Nakutis et al. 2018], noted that if two packets are received simultaneously by a gateway, each coming from a node with the same SF and same frequency, the highest power packet will be decoded if it has 6 dB higher than the other packet.

In Sofia, Bulgaria [Mateev and Marinova 2018], low-cost hardware was used to obtain sensors information. In Ghent, Belgium [Laveyne et al. 2017], the temperature control in components related to power transmission lines could be done with the LoRa used an SX1276, component of commercial module RFM95. This service can be used to optimize energy deploy in smart cities [Al-Turjman 2017]. Similarly, applications with smart meters for water and gas consumption could be carried out by different authors in Tamilnadu and Uttar Pradesh, India [Manoharan and Rathinasabapathy 2018, Salpekar et al. 2017]. In Hualien, Taiwan [Liu et al. 2018], authors were able to monitor the water quality in a lake using an ArduinoProMini sensor node for the gateway to communicate with a server via MQTT.

**Smart Farms.** Precision agriculture was the main application. In Campinas, Brazil [Carrillo and Seki 2017], precise rural coverage information was studied under different gateway positioning heights, including using drones. Also in Torino, Italy [Usmonov and Gregoretti 2017], and in Tronoh, Malaysia [Ibrahim et al. 2018a, Ibrahim et al. 2018b]. Authors in Kuala Lumpur and Tronoh, still in Malaysia [Ibrahim et al. 2018c], have created an IoT network to monitor mushroom greenhouses. In Orissa, India [Sahoo and Patnaik 2017], a circuit capable of monitoring solar panels via LoRaWAN. In Skopje, Macedonia [Davcev et al. 2018], a vineyard is monitored using sensor for air temperature, humidity, leaf water content and soil moisture.

Monitoring herds is another common application. In Montevideo, Uruguay [Bellini and Amaud 2017], each animal has a collar or ear tag with an accelerometer integrated with LoRa. In Ioannina, Grevena and Kavala, Greece [Zinas et al. 2017], a monitoring network for animals under LoRa transmission was developed by developing the nodes with Arduino SODAQ v2. An Android application (CowTrack) has also been developed to monitor animals. Monitor cows in fields was also studied in Baotou, China [Li et al. 2018]. Drones with LoRaWAN were used to identify the incidence of forest fires in Ruse, Bulgaria [Hristov et al. 2018]. In this scenario, 6000 sensor nodes were located at strategic points. Once detected by drones, the occurrence of fire is notified for authorities.

**Health Care.** LoRa was used to monitor heart rate, respiration, blood fluid level, and other indicators, in Istanbul, Turkey [Hämäläinen and Li 2017], and Rome, Italy [Buyukakkaslar et al. 2017]. In the studies in Sfax, Tunisia, and...
Marburg, Germany [Mdhaffar 2017], LoRa was used to monitor patients who are located far from health centers. In Belgrade, Serbia, and Ljubljana, Slovenia [Kos et al. 2017], it was verified the implementation of remote sensing to monitor the health of athletes employing several sensors in the body. In Karachi, Pakistan [Arsalan et al. 2018], authors have developed an embedded system that is capable of evaluating soldiers’ health variables and sending data through LoRaWAN to a central data center.

- **Location.** In Kongens Lyngby, Denmark [Fargas and Petersen 2017], LoRa was used to predict location with accuracy of 100 m for static cases. For moving cases, it is possible to report only approximations. The result was considered positive given that a network consisting of GPS and GSM consumes from 400 to 600 mA. This was also proven in other studies [Debauche et al. 2018, Podevijn et al. 2018].

LoRa and LoRaWAN have also been validated in applications for University Campus management (Lille, France [Loriot et al. 2017], and Chiayi, Taiwan [Ke et al. 2017]), Industry automation (Brescia, Italy, and Sundsvall, Sweden [Rizzi et al. 2017]), and Military context (Moscow, Russia, and Almaty, Kazakhstan [Tikhvinskiy et al. 2017] and in Bangkok, Thailand [San-Urn et al. 2017]). In Maryland, USA [Jalaian et al. 2018], authors used LoRaWAN communication during military tactical operations.

In all segments, system integration has used Message Queuing Telemetry Transport (MQTT) [Bonavolonta et al. 2017]. The work carried out in Plovdiv, Bulgaria [Penkov et al. 2017], validated the operation of LoRa with MQTT.

### 4.3. What are the main challenges that LoRa faces today?

Based on the information obtained from the articles, the interference that the transmission via LoRa may cause in other signals is a point that deserves attention [Tikhvinskiy et al. 2017, Geetha and Gouthami 2017]. It should be noted, however, that this finding was obtained at a specific frequency in the European scenario and does not necessarily represent interference in all other scenarios. In Brazil, for example, since LoRa operates at 915 MHz, the same types of situations shown by the authors are not relevant.

In continuous and real time data sensing (such as on ECG or athlete monitoring), LoRa technology may not be the right choice [Mdhaffar 2017, Kos et al. 2017]. The authors’ results, in this type of application, showed that the data rate for LoRa might not be sufficient. It is also noticed that there are still few studies carried out in Brazil, justifying that the development of LoRa technology in the national territory lacks practical implementations. Therefore, duty cycle and transfer rate are the performance limiters to adhere to LoRa as the best technology for remote sensing and IoT. The integration of LoRa with cellular networks would bring numerous benefits [Park et al. 2017].

### 5. Security

Most of LoRaWAN applications did not analyzed cybersecurity risks. In this particular case, LoRaWAN, from version 1.0 (2015) to version 1.1 (2017), has made significant security improvements. An important point is that LoRaWAN protocol does not support firmware update, so that components of version 1.0 and 1.1 may compose a appli-
This compatibility scenario shall be considered in cybersecurity analysis.

Cyberattacks can cause significant business impact to organizations that do not have the suitable cybersecurity mechanisms in place. Successfully attacks can affect the organization reputation, may result in sentitive data loss or exposure of intellectual properties.

Formal analysis of LoRaWAN specification version 1.1 showed that — if all the requirements are followed — there will be no cybersecurity vulnerabilities [Eldefrawy et al. 2019]; it does not consider the inherent vulnerabilities of wireless communication. In that case the cybersecurity vulnerabilities can occurs mainly in design and deploy process. Most of the vulnerabilities of LoRaWAN are related to OTAA join procedure (device activation process) [van Es et al. 2018, Dönmez and Nigussie 2019].

6. Conclusion

This work observed that the technology was satisfactorily applied for most of the projects studied. The applications were dependent on the experimental environment, being influenced by topology, SF used, urban density, hardware (dedicated or prototype printed circuit), antenna, mode package management, and other factors. Such details were not always adequately informed in the articles.

LoRa demonstrated several positive points (mainly, greater distance range and low energy consumption), making it a very viable option for IoT in many scenarios. As future works, we intend to complement the bibliographic review by examining the categories of theoretical and experimental articles. Besides, it is desired to deepen the comparisons on results of latency and energy consumption. Finally, we are currently working on a low-cost LoRa solution for monitoring weather events; in near future, we hope to provide another practical application of LoRa.

References

[Adelantado et al. 2017] Adelantado, F., Vilajosana, X., TusetPeiro, P., Martinez, B., Melià-Seguí, J., and Watteyne, T. (2017). Understanding the limits of lorawan. IEEE Communications Magazine, 55(9):34–40.

[Al-Turjman 2017] Al-Turjman, F. (2017). Mobile couriers selection for the smart-grid in smart-cities pervasive sensing. Future Generation Computer Systems, 82:327–341.

[Alliance 2015] Alliance, L. (2015). A technical overview of lora and lorawan. White Paper, November.

[Andrei et al. 2017] Andrei, M., Radoi, L., and Tudose, D. (2017). Measurement of node mobility for the lora protocol. 16th RoEduNet Conference Networking in Education and Research (RoEduNet), Targu Mures, Romania.

[Arsalan et al. 2018] Arsalan, M., Musani, A., Ailia, S., Baig, N., and Shaikh, M. (2018). Military uniform for health analytics for field intelligent zone (muhafiz). 2nd International Conference on Smart Sensors and Application (ICSSA), Kuching, Malaysia.

[Assri et al. 2017] Assri, S., Zaman, F., and Mubdi, S. (2017). The efficient parking bay allocation and management system using lorawan. IEEE 8th Control and System
Graduate Research Colloquium (ICSGRC 2017), pages 4-5, Shah Alam, Malaysia, 55(9):34–40.

[Ayele et al. 2017] Ayele, E., Hakkenberg, C., and Meijers, J. (2017). Performance analysis of lora radio for an indoor iot applications. International Conference on Internet of Things for the Global Community (IoTGC). Funchal, Portugal.

[Bardram et al. 2018] Bardram, A., Larsen, M., Malarski, K., Petersen, M., and Ruepp, S. (2018). Lorawan capacity simulation and field test in a harbour environment. Third International Conference on Fog and Mobile Edge Computing (FMEC), Barcelona, Spain.

[Barriquello et al. 2017] Barriquello, C., Bernardon, D., Canha, L., Silva, F., Porto, D., and Ramos, M. (2017). Performance assessment of a low power wide area network in rural smart grids. 52nd International Universities Power Engineering Conference (UPEC), Heraklion, Greece.

[Battle and Gaster 2017] Battle, S. and Gaster, B. (2017). Lorawan bristol. Proceedings of the 21st International Database Engineering and Applications Symposium, pages 287-290.

[Bellini and Amaud 2017] Bellini, B. and Amaud, A. (2017). A 5ua wireless platform for cattle heat detection. 8th Latin American Symposium on Circuits and Systems (LASCAS), Bariloche, Argentina.

[Bonavolonta et al. 2017] Bonavolonta, F., Tedesco, A., and Moriello, R. (2017). Enabling wireless technologies for industry 4.0: State of the art. International Workshop on Measurement and Networking (MN). Naples, Italy.

[Boshita et al. 2018] Boshita, T., Suzuki, H., and Matsumoto, Y. (2018). Iot-based bus location system using lorawan. 21st International Conference on Intelligent Transportation Systems (ITSC), Hawaii, USA.

[Buyukakkaslar et al. 2017] Buyukakkaslar, M., Erturk, M., Aydin, M., and Vollero, L. (2017). Lorawan as an e-health communication technology. IEEE 41st Annual Computer Software and Applications Conference, Turin, Italy.

[Candia et al. 2018] Candia, A., Represa, S., Giuliani, D., Luengo, M., Porta, A., and Marrone, L. (2018). Solutions for smartcities: proposal of a monitoring system of air quality based on a lorawan network with low-cost sensors. Congreso Argentino de Ciencias de la Informatica y Desarrollos de Investigacion (CACIDI), Buenos Aires, Argentina.

[Carrillo and Seki 2017] Carrillo, D. and Seki, J. (2017). Rural area deployment of internet of things connectivity lte and lorawan case study. IEEE XXIV International Conference on Electronics, Electrical Engineering and Computing (INTERCON), Cusco, Peru.

[Carvalho et al. 2018] Carvalho, D., Depari, A., Ferrari, P., Flammini, A., Rinaldi, S., and Sisinni, E. (2018). On the feasibility of mobile sensing and tracking applications based on lpwan. IEEE Sensors Applications Symposium (SAS), Seoul, South Korea.

[Chou et al. 2017] Chou, Y., Mo, Y., and Su, J. (2017). i-car system: A lora-based low power wide area networks vehicle diagnostic system for driving safety. International Conference on Applied System Innovation (ICASI), Sapporo, Japan.
[Danieletto et al. 2017] Danieletto, M., Li, L., and Dudley, J. (2017). Application of icomo device towards geographic disease enrichment pattern revealed from electronic medical record at a large urban academic medical center. Proceedings of the 11th EAI International Conference on Pervasive Computing Technologies for Healthcare, pages 282-287, Barcelona, Spain.

[Davcev et al. 2018] Davcev, D., Mitreski, K., Trajkovic, S., Nikolovski, V., and Koteli, N. (2018). Iot agriculture system based on lorawan. 14th IEEE International Workshop on Factory Communication Systems (WFCS), Imperia, Italy.

[Debauche et al. 2018] Debauche, O., Moulat, M., Mahmoudi, S., Boukraa, S., Manneback, P., and Lebeau, F. (2018). Web monitoring of bee health for researchers and beekeepers based on the internet of things. 9th International Conference on Ambient Systems, Networks and Technologies.

[Dongare et al. 2017] Dongare, A., Hesling, C., Bhatia, K., Balanuta, A., Pereira, R. L., Iannucci, B., and Rowe, A. (2017). Oopenchirp a low-power wide-area networking architecture. IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops), Kona, USA.

[Dönmez and Nigussie 2018] Dönmez, T. C. and Nigussie, E. (2018). Security of lorawan v1. 1 in backward compatibility scenarios. Procedia computer science, 134:51–58.

[Dönmez and Nigussie 2019] Dönmez, T. C. and Nigussie, E. (2019). Key management through delegation for lorawan based healthcare monitoring systems. In 2019 13th International Symposium on Medical Information and Communication Technology (IS-MICT), pages 1–6.

[Eldefrawy et al. 2019] Eldefrawy, M., Butun, I., Pereira, N., and Gidlund, M. (2019). Formal security analysis of lorawan. Computer Networks, 148:328–339.

[Fargas and Petersen 2017] Fargas, B. and Petersen, M. (2017). Gps-free geolocation using lora in low-power wans. Global Internet of Things Summit (GloTS), Geneva, Switzerland.

[Fedchenkov et al. 2017] Fedchenkov, P., Zaslavsky, A., and Sosunova, I. (2017). Enabling smart waste management with sensorized garbage bins and low power data communications network. Proceedings of the Seventh International Conference on the Internet of Things, Article No. 28.

[Ferrari et al. 2017] Ferrari, P., Flammini, A., Rinaldi, S., Rizzi, M., and Sisinni, E. (2017). On the use of lpwan for evehicle to grid communication. AEIT International Annual Conference, pages 1–6, Cagliari, Italy.

[Filho et al. 2016] Filho, H., Filho, J., and Moreli, V. L. (2016). The adequacy of lorawan on smart grids a comparison with rf mesh technology. IEEE International Smart Cities Conference (ISC2), Trento, Italy.

[Geetha and Gouthami 2017] Geetha, S. and Gouthami, S. (2017). Internet of things enabled real time water quality monitoring system. Smart Water Journal, Volume 1-3.

[Gottthard and Jankech 2018] Gottthard, P. and Jankech, T. (2018). Low-cost car park localization using rssi in supervised lora mesh networks. 15th Workshop on Positioning, Navigation and Communications (WPNC), Bremen, Germany.
[Grión et al. 2017] Grión, F., Petracca, G., Lipuma, D., and Amigó, E. (2017). Lora network coverage evaluation in urban and densely urban environment simulation and validation tests in autonomous city of buenos aires. *XVII Workshop on Information Processing and Control (RPIC), Mar del Plata, Argentina.*

[Havard et al. 2018] Havard, N., McGrath, S., Flanagan, C., and MacNamee, C. (2018). Smart building based on internet of things technology. *12th International Conference on Sensing Technology (ICST), Limerick, Ireland.*

[Hristov et al. 2018] Hristov, G., Raychev, J., Kinaneva, D., and P., Z. (2018). Emerging methods for early detection of forest fires using unmanned aerial vehicles and lorawan sensor networks. *28th EAAEIE Annual Conference (EAAEIE), Hafnarfjordur, Iceland.*

[Hämäläinen and Li 2017] Hämäläinen, M. and Li, X. (2017). Recent advances in body area network technology and applications. *International Journal of Wireless Information Networks. Volume 24, Issue 2, pp 63–64.*

[Ibrahim et al. 2018a] Ibrahim, A., Ibrahim, N., Harun, A., Kassim, M., and Kamaruddin, S. (2018a). Bird counting and climate monitoring using lorawan in swiftlet farming for ir4.0 applications. *2nd International Conference on Smart Sensors and Application (ICSSA), Kuching, Malaysia.*

[Ibrahim et al. 2018b] Ibrahim, A., Ibrahim, N., Harun, A., Kassim, M., Kamaruddin, S., Meng, L., and Hui, C. (2018b). Automated monitoring and lorawan control mechanism for swiftlet bird house. *International Conference on Intelligent and Advanced System (ICIAS), Kuala Lumpur, Malaysia.*

[Ibrahim et al. 2018c] Ibrahim, N., Ibrahim, A., Mat, I., and Harun, A. (2018c). Lorawan in climate monitoring in advance precision agriculture system. *21st International Conference on Intelligent Transportation Systems (ITSC), Hawaii, USA.*

[Jalaian et al. 2018] Jalaian, B., Gregory, T., Suri, N., Russell, S., Sadler, L., Lee, M., and Hui, C. (2018). Evaluating lorawan-based iot devices for the tactical military environment. *IEEE 4th World Forum on Internet of Things (WF-IoT), Singapore, Singapore.*

[James and Nair 2017] James, J. and Nair, S. (2017). Efficient, real-time tracking of public transport, using lorawan and rf transceivers. *TENCON IEEE Region 10 Conference, Penang, Malaysia.*

[Jeon et al. 2018] Jeon, Y., Ju, H., and Yoon, S. (2018). Design of an lpwan communication module based on secure element for smart parking application. *IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, EUA.*

[Karkoush et al. 2018] Karkoush, A., Mousannif, H., and Moatassime, H. (2018). Cads: A connected assistant for driving safe. *The First International Conference On Intelligent Computing in Data Sciences, pages 353-360.*

[Ke et al. 2017] Ke, K., Liang, Q., and Zeng, G. (2017). Demo abstract a lora wireless mesh networking module for campus-scale monitoring. *16th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN), Pittsburgh, Pennsylvania, EUA.*

[Kitchenham 2004] Kitchenham, B. (2004). Procedures for performing systematic reviews. *Keele, UK, Keele University, 33:1–26.*
[Kos et al. 2017] Kos, A., Milutinovic, V., and Umek, A. (2017). Challenges in wireless communication for connected sensors and wearable devices used in sport biofeedback applications. *Future Generation Computer Systems*.

[Laveyne et al. 2017] Laveyne, J., Zwaenepoel, B., and Eetvelde, G. (2017). Potential of domestically provided ancillary services to the electrical grid. *52nd International Universities Power Engineering Conference (UPEC), Heraklion, Greece*.

[Lee and Ke 2018] Lee, H. and Ke, K. (2018). Monitoring of large-area IoT sensors using a LoRa wireless mesh network system: Design and evaluation. *IEEE Transactions on Instrumentation and Measurement (Volume: PP, Issue: 99)*.

[Li et al. 2018] Li, Q., Xiao, J., and Liu, Z. (2018). A data collection collar for vital signs of cows on the grassland based on LoRa. *IEEE 15th International Conference on e-Business Engineering (ICEBE), Xian, China*.

[Liu et al. 2018] Liu, Y., Lin, B., Yue, X., Cai, Z., Yang, Z., Liu, W., Huang, S., Lu, J., Peng, J., and Chen, J. (2018). A solar powered long range real-time water quality monitoring system by Lorawan. *The 27th Wireless and Optical Communications Conference (WOCC2018), Hualien, Taiwan*.

[Loriot et al. 2017] Loriot, M., Aljer, A., and Shahroug, I. (2017). Analysis of the use of lorawan technology in a large-scale smart city demonstrator.

[Manoharan and Rathinasabapathy 2018] Manoharan, A. and Rathinasabapathy, V. (2018). Smart water quality monitoring and metering using LoRa for smart villages. *2nd International Conference on Smart Grid and Smart Cities, Kuala Lumpur, Malaysia*.

[Mateev and Marinova 2018] Mateev, V. and Marinova, I. (2018). Distributed internet of things system for wireless monitoring of electrical grids. *20th International Symposium on Electrical Apparatus and Technologies (SIELA), Bourgas, Bulgaria*.

[Mdhaffar 2017] Mdhaffar, A., C. T. L. K. (2017). IoT-based health monitoring via Lorawan. *IEEE EUROCON 2017 -17th International Conference on Smart Technologies*.

[Nakutis et al. 2018] Nakutis, Z., Kuzas, P., Rybelis, T., Grimaila, V., and Daunoras, V. (2018). A technique of synchronization of distributed energy measurement in low voltage electrical grid. *IEEE 9th International Workshop on Applied Measurements for Power Systems (AMPS), Bologna, Italy*.

[Neumann et al. 2016] Neumann, P., Montavont, J., and Noël, T. (2016). Indoor deployment of low-power wide area networks (LPWAN): a Lorawan case study. *Networking and Communications (WiMob), IEEE 12th International Conference on Wireless and Mobile Computing, Rome, Italy*.

[Nor and Mubdi 2017] Nor, R. and Mubdi, S. (2017). Smart traffic light for congestion monitoring using Lorawan. *IEEE 8th Control and System Graduate Research Colloquium (ICSGRC 2017), pages 4-5*.

[Park et al. 2017] Park, S., Hwang, K., and Kim, H. (2017). Advanced multimedia and ubiquitous engineering. *Lecture Notes in Electrical Engineering 448. FutureTech pp 269-276*.
[Penkov et al. 2017] Penkov, S., Taneva, A., and Kalkov, V. (2017). Industrial network design using low-power wide-area. *4th International Conference on Systems and Informatics (ICSIAI), Hangzhou, China.*

[Petäjäjärvi et al. 2015] Petäjäjärvi, J., Mikhaylov, K., Roivainen, A., Hänninen, T., and Pettissalo, M. (2015). On the coverage of lpwans: Range evaluation and channel attenuation model for lora technology. *ITS Telecommunications (ITST), pages 1–5, Copenhagen, Denmark.*

[Petäjäjärvi et al. 2017] Petäjäjärvi, J., Mikhaylov, K., Yasmin, R., Hämäläinen, M., and Inatti, J. (2017). Evaluation of lora lpwan technology for indoor remote health and wellbeing monitoring. *International Journal of Wireless Information Networks, 24(2):153–165.*

[Podevijn et al. 2018] Podevijn, N., Trogh, J., Karaagac, A., Haxhibeqiri, J., Hoebeke, J., Martens, L., Suanet, P., Hendrikse, K., Plets, D., and Joseph, W. (2018). Tdoa-based outdoor positioning in a public lora network. *12th European Conference on Antennas and Propagation (EuCAP 2018), London, UK.*

[Poenicke et al. 2018] Poenicke, O., Kirch, M., Richter, K., and Schwarz, S. (2018). Lorawan for iot applications in air cargo - development of a gse tracking system for dhl air cargo hub leipzig. *Smart SysTech 2018; European Conference on Smart Objects, Systems and Technologies, Munich, Germany.*

[Radcliffe et al. 2017] Radcliffe, P., Chavez, K., and Beckett, P. (2017). Usability of lorawan technology in a central business district. *IEEE 85th Vehicular Technology Conference (VTC Spring), Sydney, Australia.*

[Rahim et al. 2018] Rahim, H., Ghazel, C., and Saidane, L. (2018). An alternative data gathering of the air pollutants in the urban environment using lora and lorawan. *14th International Wireless Communications and Mobile Computing Conference (IWCNC), Limassol, Cyprus.*

[Rizzi et al. 2017] Rizzi, M., Ferrari, P., and Flammini, A. (2017). Using lora for industrial wireless networks. *IEEE 13th International Workshop on Factory Communication Systems (WFCS), Trondheim, Norway.*

[Saari et al. 2018] Saari, M., Baharudin, A., Sillberg, P., Hyrynsalmi, S., and Yan, W. (2018). Lora — a survey of recent research trends. *41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia.*

[Sahoo and Patnaik 2017] Sahoo, U. and Patnaik, B. (2017). Design and implementation of remote monitoring system of solar lanterns based on lorawan and cloud technology. *International Conference on Computing Methodologies and Communication (ICCMC), Erode, India.*

[Salpekar et al. 2017] Salpekar, M., Gupta, P., and Tejan, P. (2017). Smart water/gas distribution system with focus on user safety. *IEEE Green Energy and Smart Systems Conference (IGESSC), Long Beach, USA.*

[San-Urn et al. 2017] San-Urn, W., Lekbunyasin, P., Kodyoo, M., and Wongsuwan, W. (2017). A long-range low-power wireless sensor network based on u-lora technology
for tactical troops tracking systems. *Third Asian Conference on Defence Technology (3rd ACDT), Phuket, Thailand.*

[Silva et al. 2018] Silva, F., Barriquello, C., Canha, L., Bernardon, D., and Hokama, W. (2018). Deployment of lorawan network for rural smart grid in brazil. *IEEE PES Transmission and Distribution Conference and Exhibition - Latin America (TD-LA), Lima, Peru.*

[Thu et al. 2018] Thu, M., Htun, W., Aung, Y., Shwe, P., and Tun, N. (2018). Smart air quality monitoring system with lorawan. *IEEE International Conference on Internet of Things and Intelligence System (IoTals), Bali, Indonesia.*

[Tikhvinskiy et al. 2017] Tikhvinskiy, V., Korchagin, P., and Bochechka, G. (2017). Spectrum sharing in 800 mhz band experimental estimation of lora networks and air traffic control radars coexistence. *International Symposium on Electromagnetic Compatibility - EMC EUROPE, Angers, France.*

[Usmonov and Gregoretti 2017] Usmonov, M. and Gregoretti, F. (2017). Design and implementation of a lora based wireless control for drip irrigation systems. *2nd International Conference on Robotics and Automation Engineering (ICRAE).*

[van Es et al. 2018] van Es, E., Vranken, H., and Hommersom, A. (2018). Denial-of-service attacks on lorawan. In *Proceedings of the 13th International Conference on Availability, Reliability and Security*, page 17.

[Varsier and Schwoerer 2017] Varsier, N. and Schwoerer, J. (2017). Capacity limits of lorawan technology for smart metering applications. *IEEE International Conference on Communications (ICC), Paris, France.*

[Vatcharatiansakul et al. 2017] Vatcharatiansakul, N., Tuwanut, P., and Pornavalai, C. (2017). Experimental performance evaluation of lorawan: A case study in bangkok. *14th International Joint Conference on Computer Science and Software Engineering (JCSSE), Nakhon Si Thammarat, Thailand.*

[Wang et al. 2018] Wang, S., Zou, J., Chen, Y., Hsu, C., Cheng, Y., and Chang, C. (2018). Long-term performance studies of a lorawan-based pm2.5 application on campus. *IEEE 87th Vehicular Technology Conference (VTC Spring), Porto, Portugal.*

[Wixted et al. 2016] Wixted, A., Kinnaird, P., and Larijani, H. (2016). Evaluation of lora and lorawan for wireless sensor networks. *IEEE SENSORS, Orlando, EUA.*

[Yu et al. 2017] Yu, F., Zhu, Z., and Fan, Z. (2017). Study on the feasibility of lorawan for smart city applications. *Tenth IEEE International Workshop on Selected Topics in Mobile and Wireless Computing*, pages: 334-340.

[Zinas et al. 2017] Zinas, N., Kontogiannis, S., Kokkonis, G., Valsamidis, S., and Kazanidis, I. (2017). Proposed open source architecture for long range monitoring: the case study of cattle tracking at pogoniani. *PCI 2017 Proceedings of the 21st Pan-Hellenic Conference on Informatics. Article No. 57.*