UNIVERSIDAD
DE GRANADA

LoRa-based WSN and its applications

Dr. Sandra Sendra Compte

Outline

University of Granada

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UNIVERSIDAD DE GRANADA

UNIVERSITY OF GRANADA

- University of Granada (UGR) is a public educational institution that offers modern and flexible degrees and courses designed to meet and cover the demands of current society.

- UGR also teach official postgraduate programmes controlled by demanding educational quality control systems.

- UGR teach 75 degrees in the 28 teaching centres

- The teaching is organized through 116 departments. The postgraduate School offers 68 Masters, 116 doctorates and 113 complementary courses.

- The UGR takes more than 60,000 undergraduate and postgraduate students and another 20,000 attend complementary courses, language courses, summer courses, etc. They also have around 3,650 teachers and more than 2,000 administrative, technical and service personnel.

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UNIVERSITY OF GRANADA

ICT Research Center (CITIC)

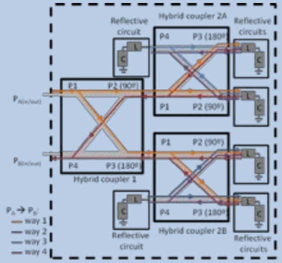
Higher School of Informatics and Telecommunication Engineering

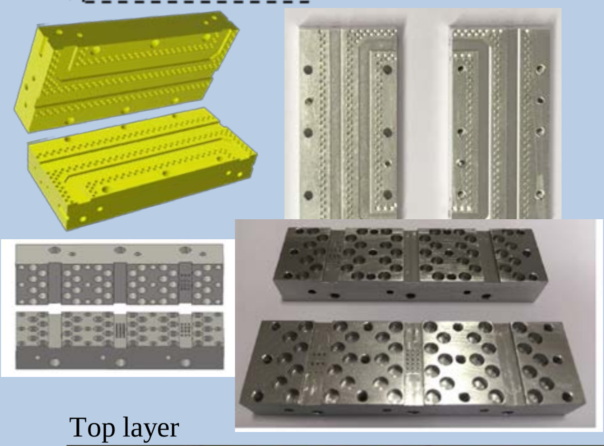
Dept. of Signal Theory, Telematics and Communications

Smart Wireless Applications and Technologies Group

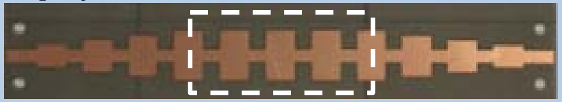
→ Permanent staff: 4 associate professors + several PhD/ MSc Students.

Design of devices

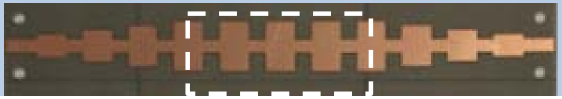


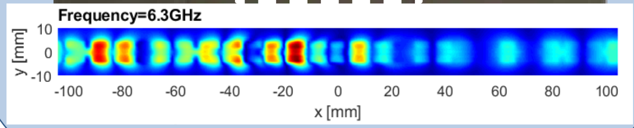


Top layer

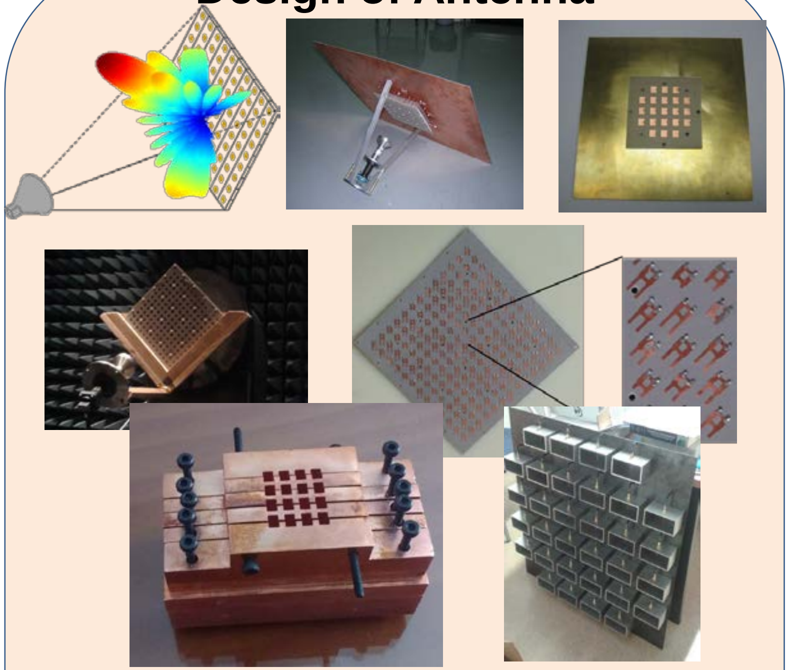


Bottom layer

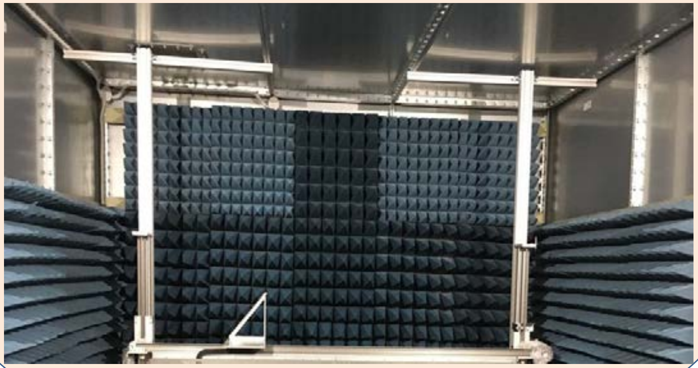




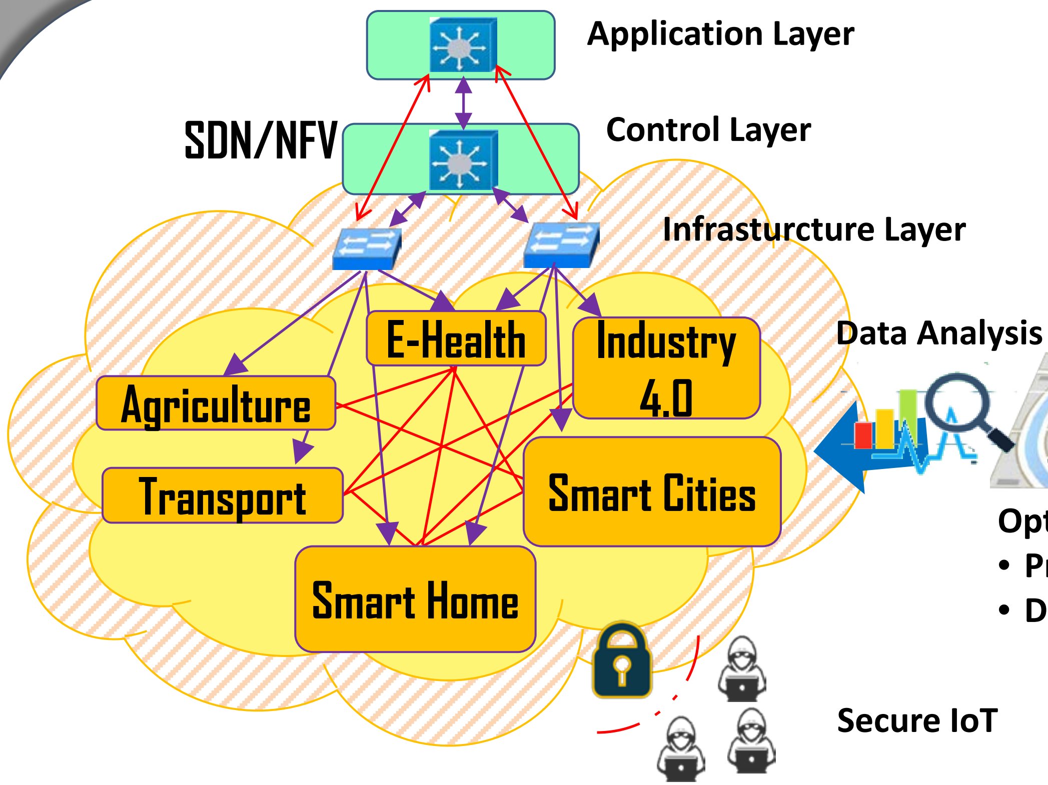
Design of Antenna

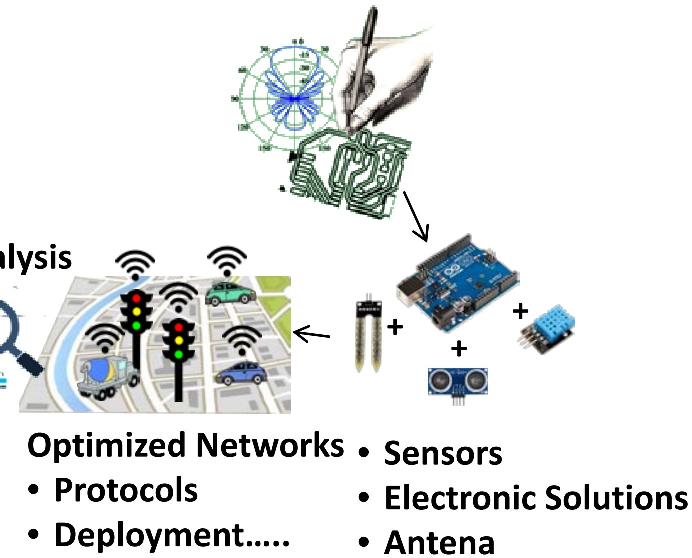


Measurement system for Antenna up to 300 GHz.



IoT and Communications Laboratory

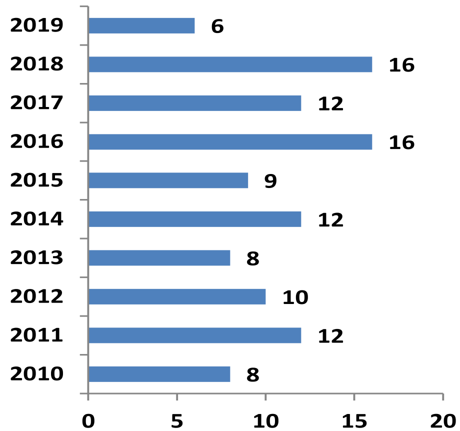


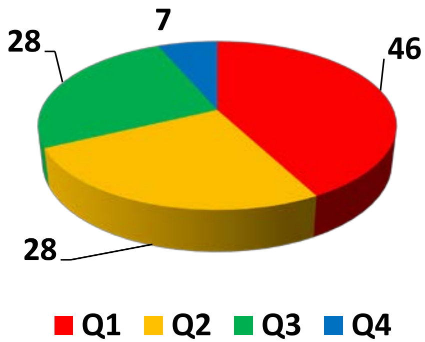


Smart applications of neurometry

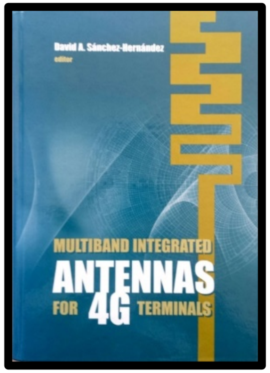
Group Numbers

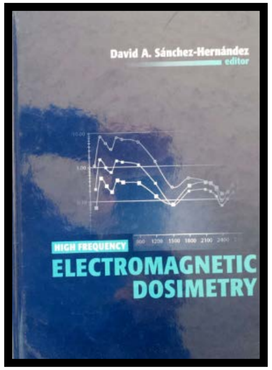
Indexed Journal (+105)





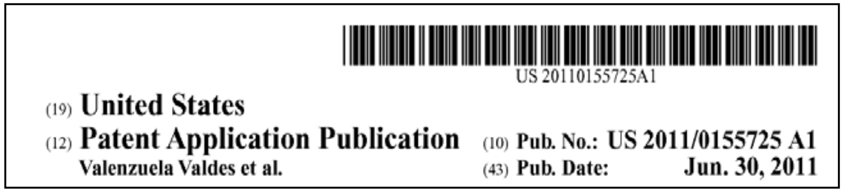
Book and Chapters (10)





National and International Conferences (+120)

Patents (9)


US 20110155725A1
(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2011/0155725 A1
Valenzuela Valdes et al. (43) Pub. Date: Jun. 30, 2011

PROJECTS

≈ 4 M€

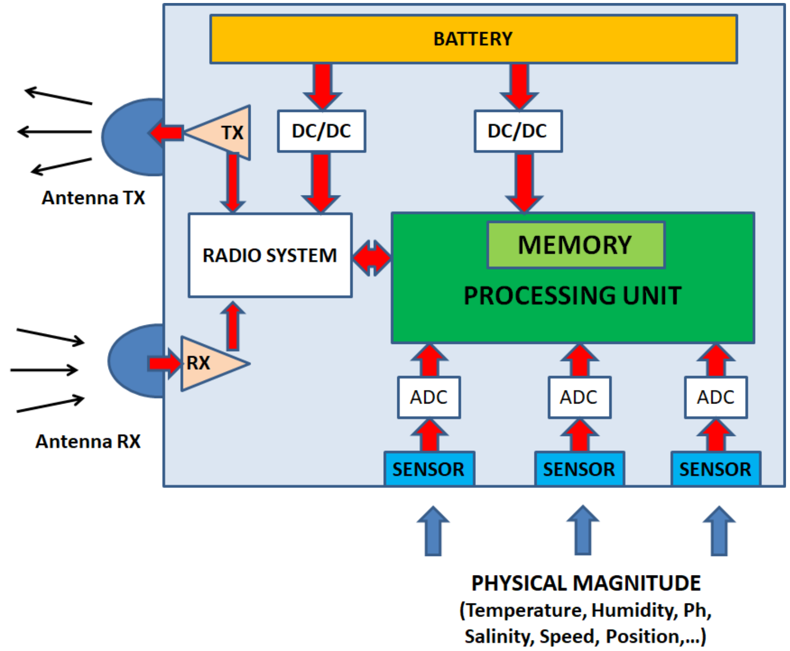
Wireless Sensor Networks (WSNs)

Introduction

- A wireless network sensors can be defined as a set of small, autonomous, easy-to-deploy devices called nodes.

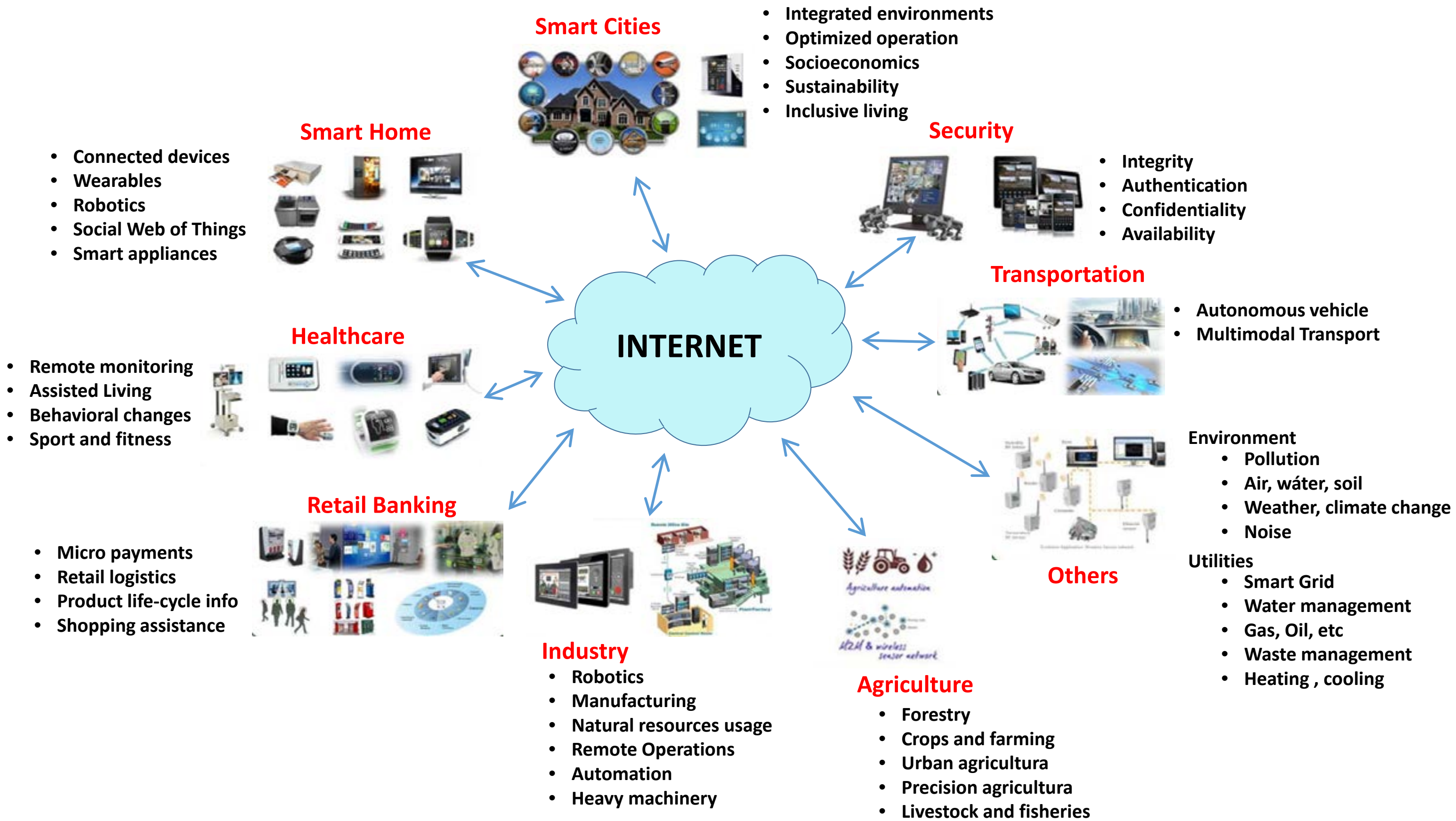
- The nodes are formed by a sensor unit, a microcontroller, a transceiver (transmission / reception of messages) and internal batteries powered by solar panel.

- Each node has the capacity to wirelessly intercommunicate with the rest of the nodes, sending the captured information to a central point (gateway), from which and through the web the information is stored in a server so that it can be analyzed and consulted in the real time in the control center.



Introduction

- The field of application of technology is very diverse, from agriculture, livestock, industrial processes, home automation, environment, logistics, security, accessibility, Smart Metering, Smart Home or Smart City, among some of the most prominent sectors.



Introduction

- The advantages of this technology are:
  - Ease and speed of installation and deployment
  - Low consumption
  - Scalability
  - Devices with own autonomy and without cables
  - Reduced maintenance
  - Remote monitoring in real time, which reports to the client optimization of resources and processes
  - Versatility to adapt the system to the client's needs
  - Ability to couple several sensors in a single communication node
  - High capacity of self-organization and self-configuration with the rest of the nodal devices of the network, which allows the mobility of the devices.

Introduction

- The evolution of technologies and the ability to interconnect different devices have led to the existence of networks capable of communicating and acting together, creating what is known as Internet of Things (IoT).
- Thanks to sensors and actuators, it is possible to measure our environment and share data which, collected by platforms, allows the developers to create useful applications for the society.

LoRa for IoT

LoRaWAN Introduction

LoRa ≠ LoRaWAN

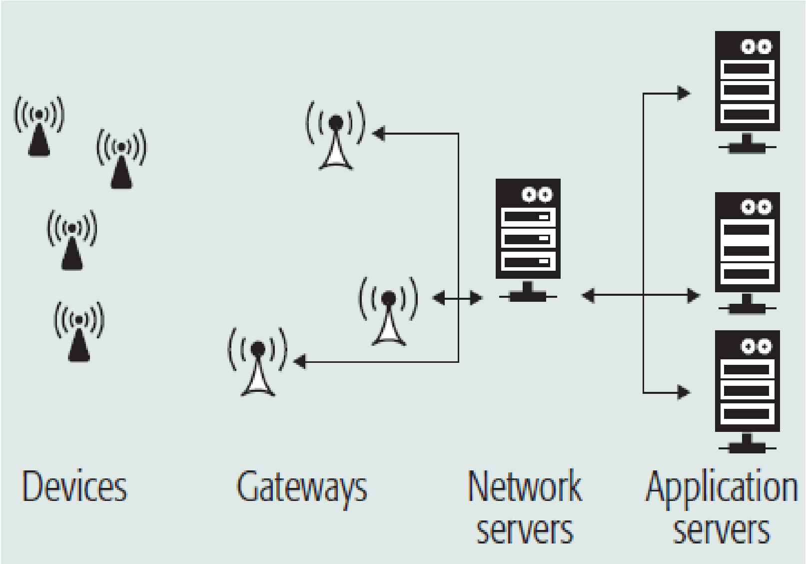
- The first thing that needs to be clarified is that LoRa and LoRaWAN are not the same, LoRa is the type of radiofrequency modulation patented by Semtech. Its main advantages are:
  - High tolerance to interference
  - High sensitivity to receive data (-168dB)
  - Based on chirp modulation
  - Low power Consumption (up to 10 years with a battery *)
  - Long range: 10 to 20km
  - Low data transfer (up to 255 bytes)
  - Point to point connection
  - Working frequencies: 915Mhz America, 868 Europe, 433 Asia
- It is the ideal technology for connections over long distances and for IoT networks that can be used in smart cities, places with little cellular coverage or private networks of sensors or actuators, that's why LoRaWAN was born.

LoRaWAN Introduction

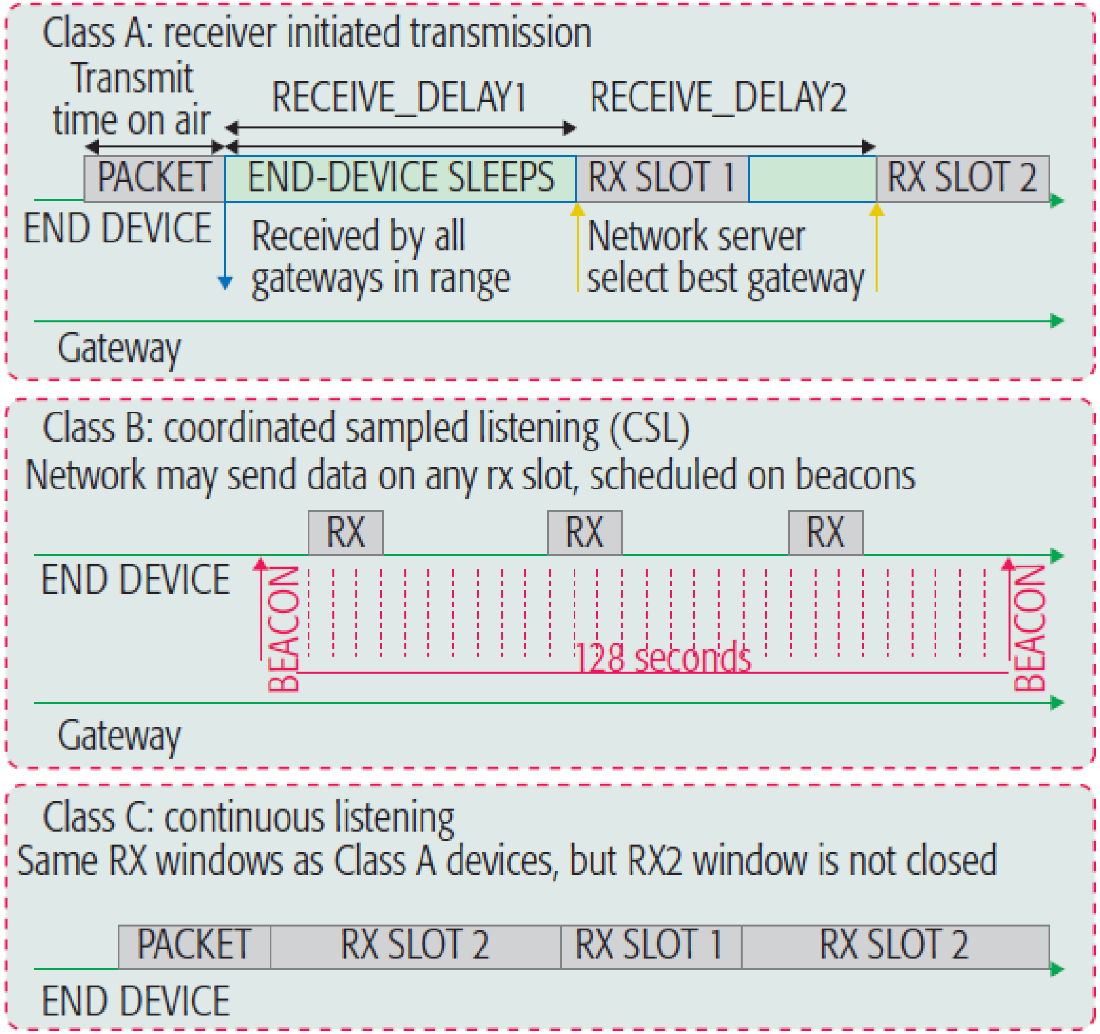
- Unlike other IoT technologies, LoRaWAN does not use a mesh network architecture.

- Although mesh networking may be useful to increase the communication range, it also affects the device battery life due to the forwarding of messages. → LoRaWAN uses a star topology

- LoRaWAN allows end devices to have bidirectional communications, although they are asymmetric, since uplink transmissions (from end devices to gateways) are strongly favored.



LoRaWAN Introduction



LoRaWAN Introduction

- The underlying PHY layer for the three classes is the same.

- LoRa is a proprietary spread spectrum modulation scheme which is based on chirp spread spectrum (CSS).

- Some of the key properties of this modulation are scalable bandwidth, constant envelope, low power, high robustness, multipath and fading resistant, Doppler resistant, long-range capability, enhanced network capacity, and geolocation capabilities.

- Using different spreading factors (SFs), the developer may trade data rate for coverage or energy consumption. The spreading factor is defined as

$$SF = \log_2\left(\frac{R_C}{R_S}\right)$$

RS and *RC* are the symbol and chip rates

LoRaWAN Introduction

- The usage of a high SF decreases the data rate but increases the maximum distance between the transmitter and the receiver, and vice versa.

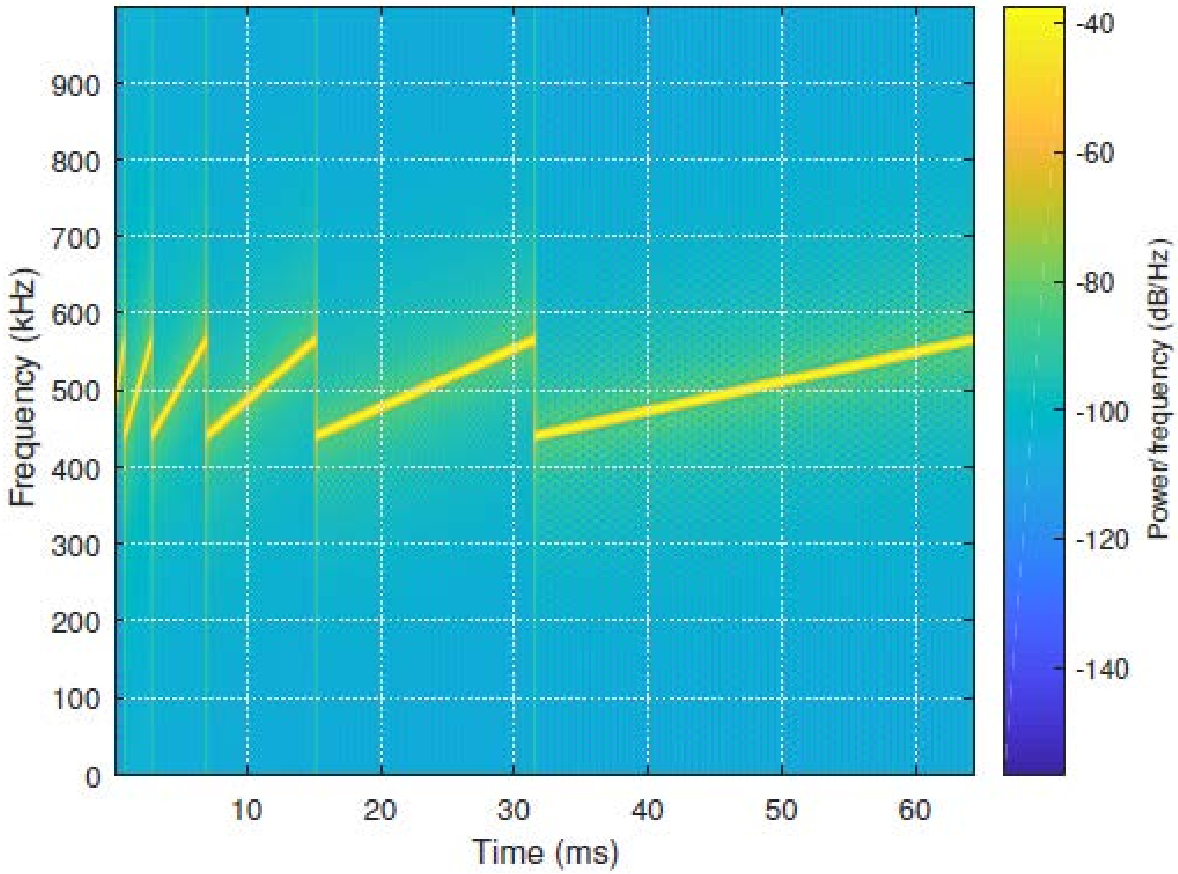
- Since transmissions using different SFs are orthogonal, it is possible to receive multiple frames simultaneously.

- LoRa error correction reduces the bit rate by a factor rate code = 4/ (4+CR), where code rate (CR) is an integer value between 1 and 4.

$$Rb = SF \times \frac{\frac{4}{4+CR}}{\frac{2^{SF}}{BW}}$$

- Since SFs vary from 7 to 12, and frames sent with different SFs can be decoded simultaneously, the maximum aggregated bit rate (assuming *BW* = 500 kHz and *CR* = 1) is 43 kb/s.

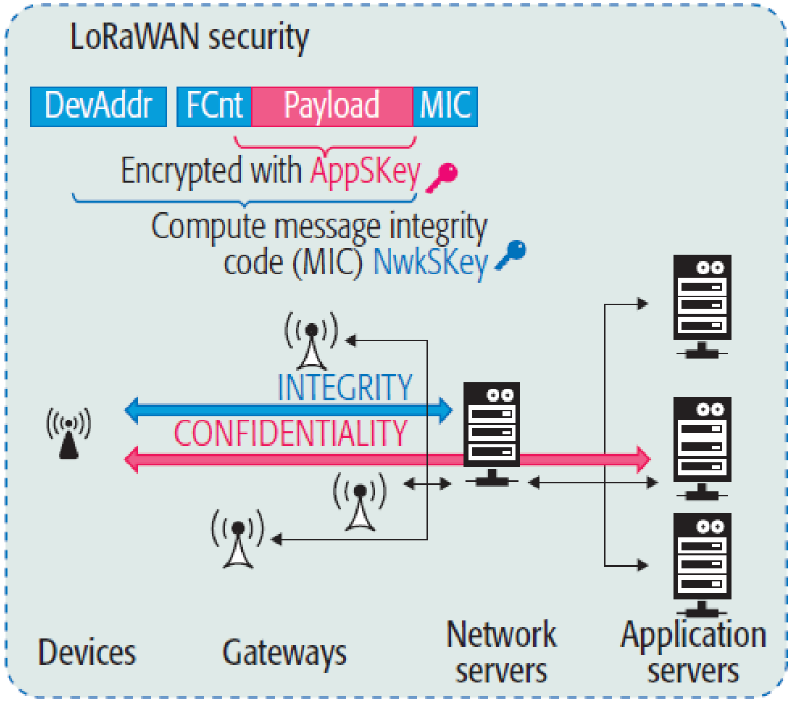
LoRaWAN Introduction



It shows how frequency, time and power vary according to the SF used.

LoRaWAN Security

- As security is crucial, it has been included from the initial versions of the standard.
- Security for LoRaWAN is also designed for low power consumption, low implementation complexity, low cost, and high scalability.
- The main properties of LoRaWAN security are mutual authentication, integrity protection, and confidentiality.



- An end device can be activated using either *over-the-air activation* (OTAA) or *activation by personalization* (ABP). The device stores the following information:
  - *DevAddr* (device address), *AppEUI* (application identifier),
  - *NwkSKey* (network session key), and *AppSKey* (application session key).

LoRaWAN Security

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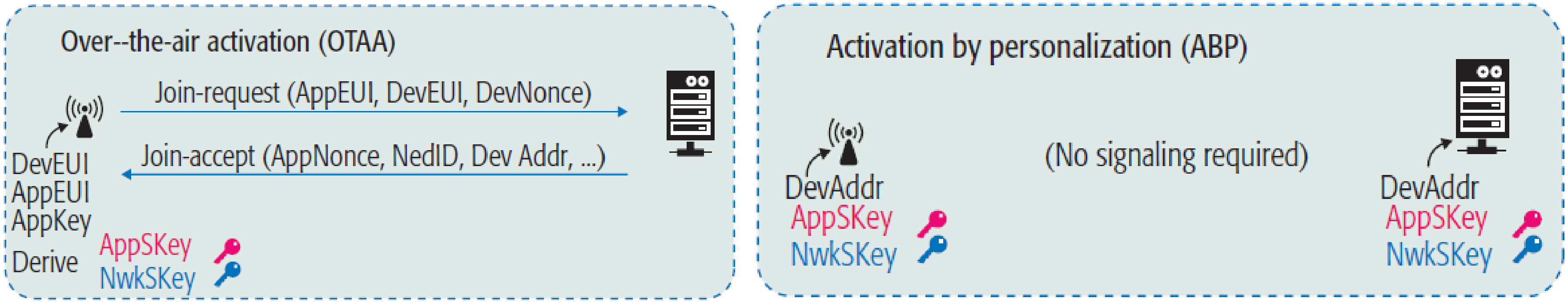

Comparison
WiFi vs. LoRa

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Comparison WiFi vs. LoRa

Parameter	Comparison	
	WiFi	**LoRa**
Frequency Band	2.4 GHz	868 (EU) – 433 (US) [MHz]
Spectrum	Unlicensed	Unlicensed
Data Rate	100 – 300 [Mbps]	125 – 500 [kHz]
Range	30 – 100 [m]	Up to hundreds of kms

- **LoRa** is a proprietary spread spectrum modulation which belongs to Semtech.
- It keeps the same low power characteristics of FSK modulation while increases the communication range.
- According to the frequency band (868 MHz in Europe), it modulates its symbols with a bandwidth of 125 kHz, 250 kHz or 500 kHz (European case) with different Spreading Factors (SF). A lower SF lets increases the maximum distance between transmitter and receiver by decreasing the data rate.
- The use of LoRa modulation with a low spreading factor could facilitate the transfer of small data packets at indoor environments like hospitals.

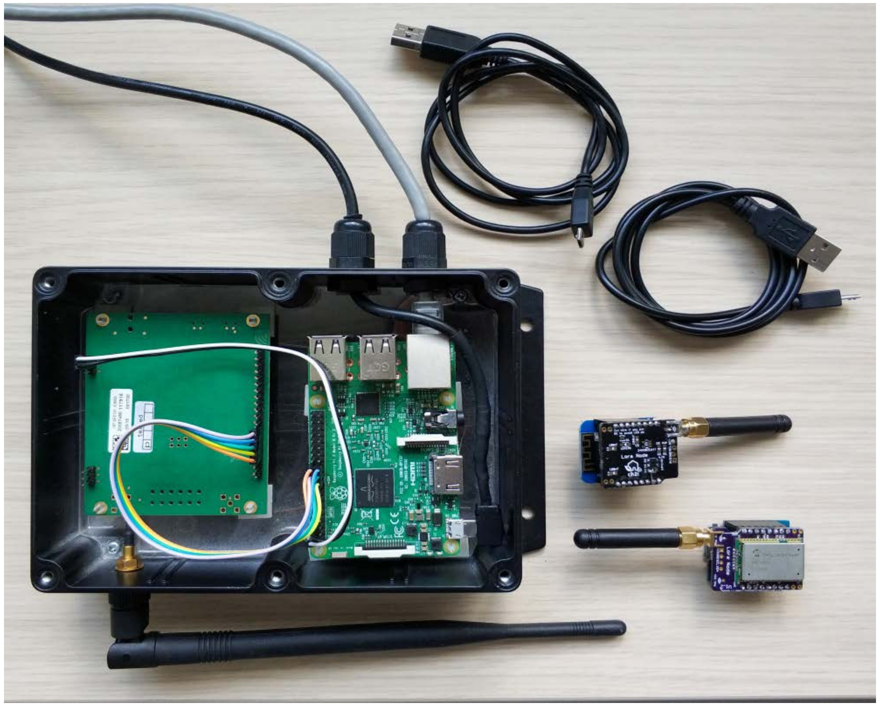
Comparison LoRa vs. LPWAN Tech.

CHARACTERISTICS OF LPWAN TECHNOLOGIES

Parameter	Standard			
	LoRa	**Sigfox**	**RPMA**	**nWave**
Frequency Band	868/915 MHz ISM	868/902 MHz ISM	2.4 GHz ISM	Sub-GHz ISM
Bandwidth	Ultra NB	8x125kHz Mod: CSS	1 MHz 40 channels	Ultra NB
Range	2-5k urban 15k rural	30-50k r. 1000k LoS	500k LoS	10k u. 20-30k r.

LoRa-based Hardware for IoT

LoRa-Based hardware



DIY multi-channel Raspberry Pi Gateway:

- Raspberry Pi 3 Model B,
- IMST ic880A concentrator with a maximum transmission power of 20 dBm
- an 868 MHz antenna with 2 dBi gain.

LoRa-Based hardware

LoRa Lite by IMST

The LoRa Lite Gateway from German company IMST is a reasonably-priced eight-channel gateway based on their iC880A 868 MHz LoRaWAN concentrator and a Raspberry Pi, all fitted on a motherboard in a die-cast box.

LoRa-Based hardware

Base on SX1301 LoRaWan Gateway Module

- Frequency band 433MHz/868MHz/915MHZ
- Sensitivity: down to -138dBm, Output Power up to 20dbm
- open 8 channels uplink and 1 channel downlink for Makers
- SX1301 based processor
- USB or SPI interface

The Things Indoor Gateway

The following are the specs:

- Supports TTN and SLA
- Designed for indoor usage (prototyping)
- Features a setup and reset button
- USB-C port (for power only)
- Supports 868 or 915 frequency bands
- 8 channel, design v1.5 (with LBT)
- Integrated antenna
- ESP8266 SoC, allowing WiFi connectivity
- Able to be plugged directly into a wall outlet

LoRa-Based hardware

TTGO LORA32 V2.0/433/868/915 MHz ESP32

- Chip Wifi ESP32 @ 80 MHz - 802.11 b/g/n
- 900 Mhz LoRa Module
- Compatible with Arduino
- OLED Screen 128x64 px
- MicroUSB (powering and programming)
- Antenna de 2dBi with SMA connector

LoRa-Based hardware

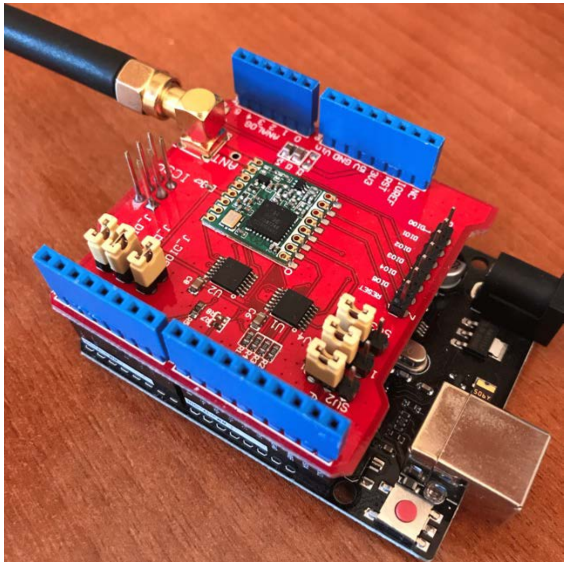
- TTGO T-Beam node. It is built around the ESP32 chip.
- It has 4MB of SPI flash.
- It operates at 433 MHz, 868 MHz and 915 MHz.
- TTGO T-Beam node includes two antennas. A GPS ceramic antenna connected to a u-bloc NEO-6M GPS module and another LoRa antenna with SMA connector.
- It uses a LoRa chip from the HopeRF RFM9X family. The node has a total of 26 pins with GPIO, ADC, VP/VN, DAC, Touch, SPI, I2C, UART and Lora.
- It can be feed by batteries.

LoRa-Based hardware

RAK811 LoRa Tracker
Wireless Remote Positioning Solution

LoRa-Based hardware

Dragino LoRa Shield board



Main features of Dragino LoRa Shield.

Parameter	Value
I/O pins compatible with Arduino	3.3V o 5V
Working Frequency	915 MHz / 868 MHz / 433 MHz
Current in Sleep Mode	1 µA
Antenna connection	SMA/I-PEX

Main features of RFM95W transceiver.

Parameter	Value
Modulations	FSK, GFSK, MSK, GMSK, LoRa y OOK
Sensitivity	-148 dBm
Preamble detection	-
RSSI range	127 dBm
Packaging System	256 bytes with CRC
Programmable Bitrate	Up to 300 kbps

LoRa-Based hardware

Aplicaciones

- Smart Home
- Home Video
- Control Lights
- Snooze Button
- Take Pictures
- Wireless Trigger
- Remote Switch

LoRa-based Applications

Performance of LoRaWAN Networks in Outdoor Scenarios

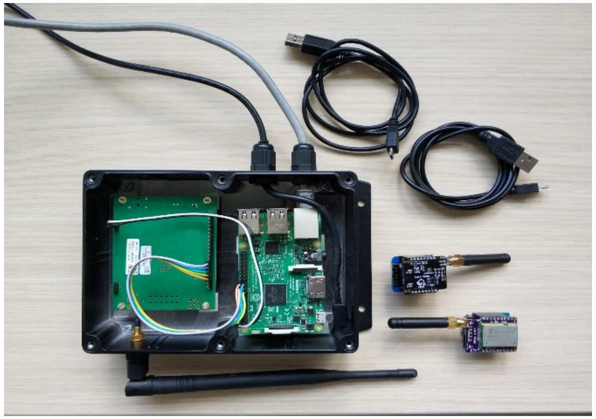
LoRa-Based Appl. - Network

- The critical point in many scenarios resides in the energy consumption due to the batteries which feed these things.
- This is why so-called LPWAN technologies, which permit low power transmission, have been developed. In return, the transmission data rate is reduced (e.g., hundreds of kbps) but it is still enough for many IoT applications.
- Because of their standardization and the usage of non-licensed spectrum, these technologies have become serious competitors of solutions based on cellular networks, such as Long Term Evolution-Category M (LTE-M) or NarrowBand-IoT (NB-IoT).
- The most popular LPWAN technologies are Sigfox, LoRaWAN, Ingenu TPMA, and nWave.

Components of a LoRaWAN network:

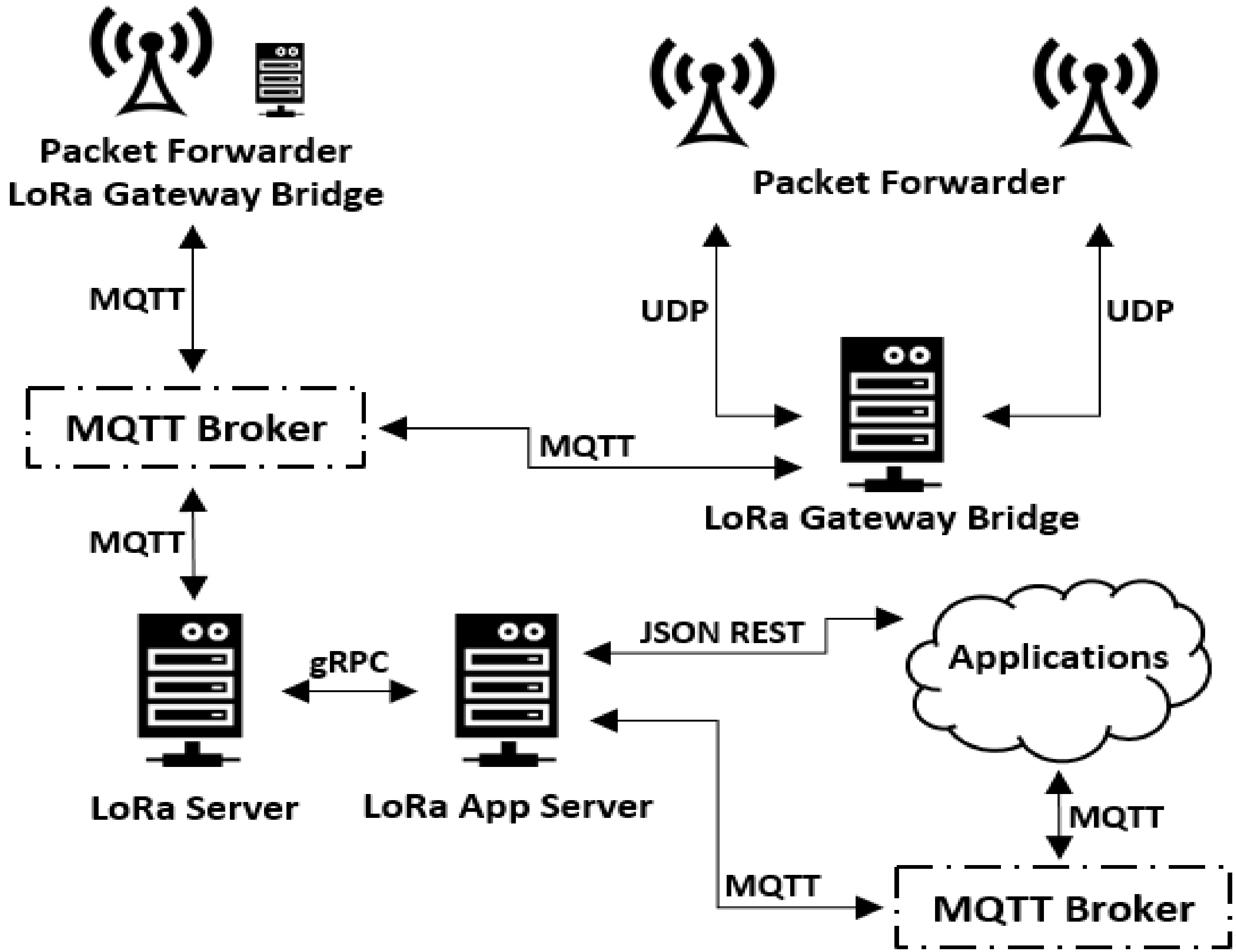
- DIY multi-channel Raspberry Pi Gateway: the chosen gateway is composed of a Raspberry Pi 3 Model B, an IMST ic880A concentrator with a maximum transmission power of 20 dBm and an 868 MHz antenna with 2 dBi gain.

- End-Device: the used end-device is based on the development board ’WeMos D1 Mini’, which uses the ESP8266 chip. A shield with the RN2483A chip (up to 14 dBm of TX power), which implements both the physical and the MAC layers of the LoRaWAN standard, is connected to the WeMos board. These are supplied by a external power bank.



LoRa-Based Appl. - Network

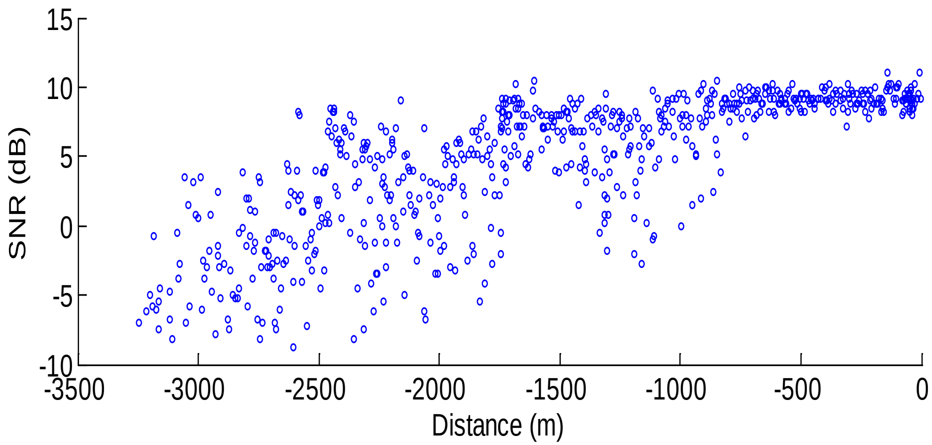
LoRa Server Architecture.

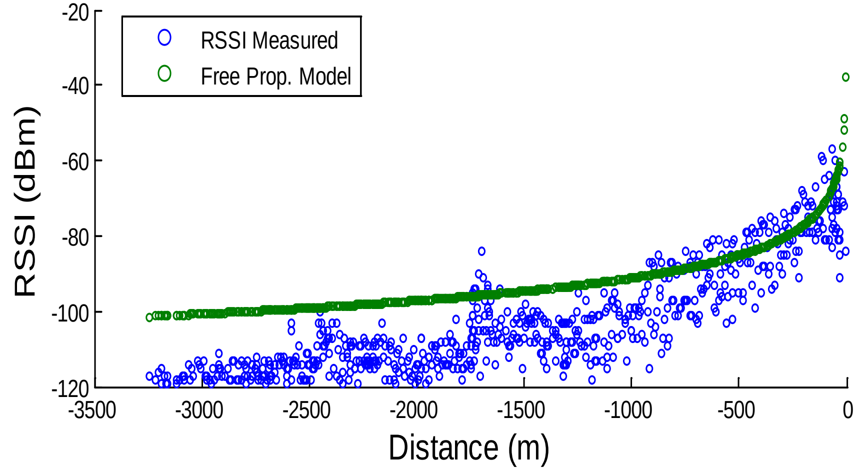


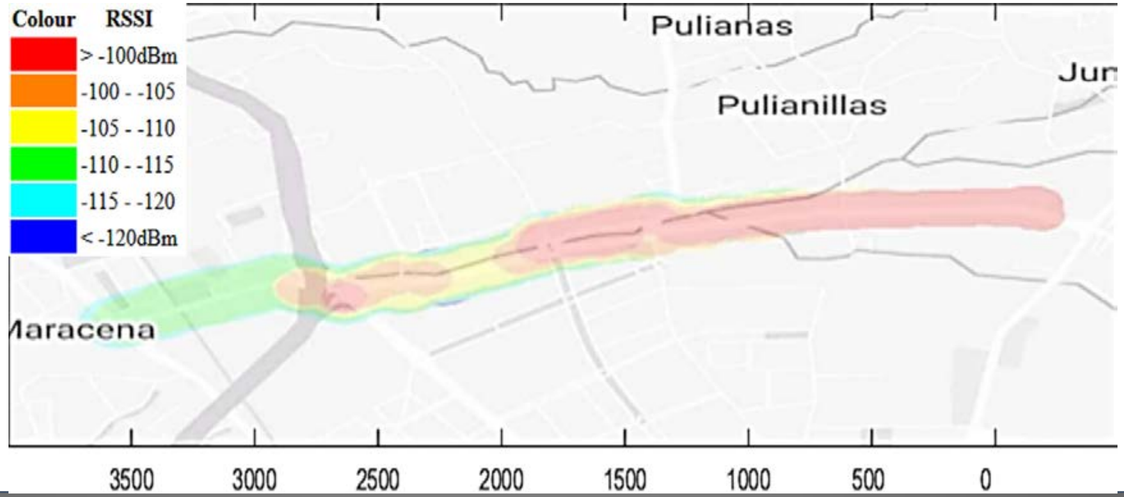
Highway Scenario

- The selected scenario is a road environment very similar to a highway.
- It has three lanes in each side and also, pedestrian and bike lanes which lets us walk to take the measurements.
- Measurements have been taken while walking. The evaluated parameters have been the SNR, the RSSI, the packets loss ratio and the coverage of the end-device.
- The road is place at the north area of Granada. The route has approx. 3.3 km with 74 m of gradient.
- The gateway, whose location is in (37.2136373, -3.5951833) geographical point, is placed on a bridge which crosses the road.

Highway Scenario Results







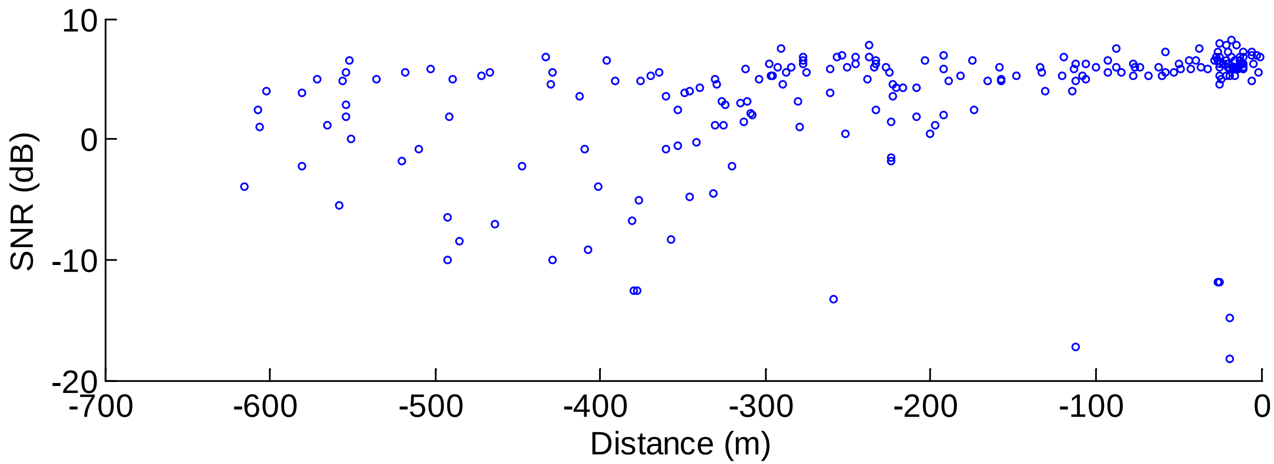
Coast Rural Scenario

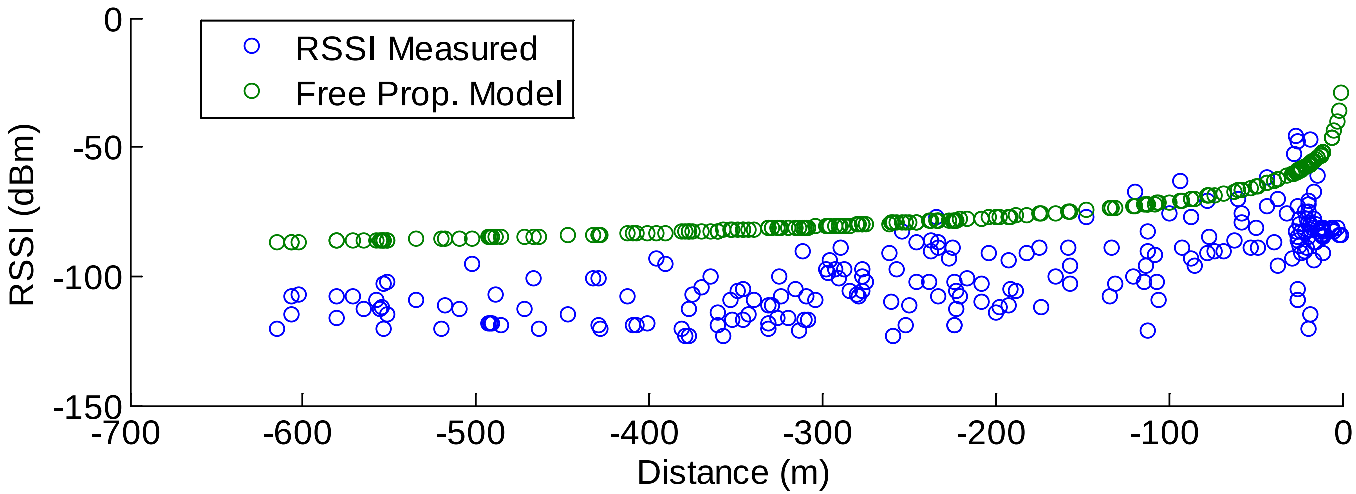
- The gateway with coordinates (38.932457, -0.099974) is placed on the terrace of a second floor house (~9m of height).

- The building is found at Oliva, a coast village of Valencia (Spain).

- The scenario is composed by several small houses and the climate conditions are also different (higher humidity).

Coast Rural Scenario Results





Collaborative LoRa-Based Sensor Network for Pollution Monitoring in Smart Cities

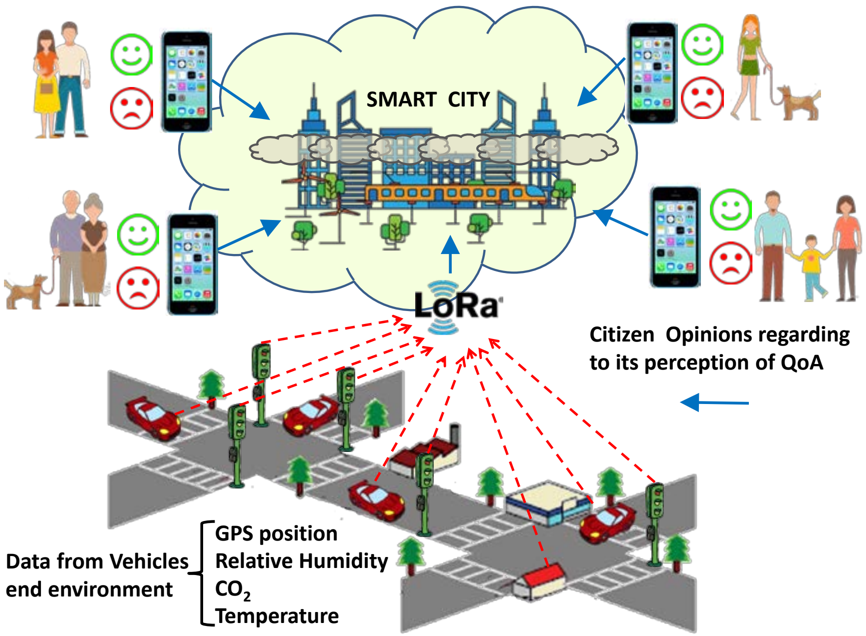
LoRa-Based Appl. - Pollution Monitoring

Motivation

- Urban air pollution is a serious problem in many large cities on the planet.
- The intense traffic, together with factories that do not control their emissions, turns the air of cities of the world into clouds of smog.
- Air pollution will become the main environmental cause of premature mortality in the world.
- It is estimated that by 2050, the number of premature deaths resulting from air pollution will reach 3.6 million each year on the planet.
- Pollution deaths are usually linked to heart disease, stroke, or obstructive and chronic lung disease. It is also related to lung cancer and acute respiratory infections.

LoRa-Based Appl. - Pollution Monitoring

Our Proposal

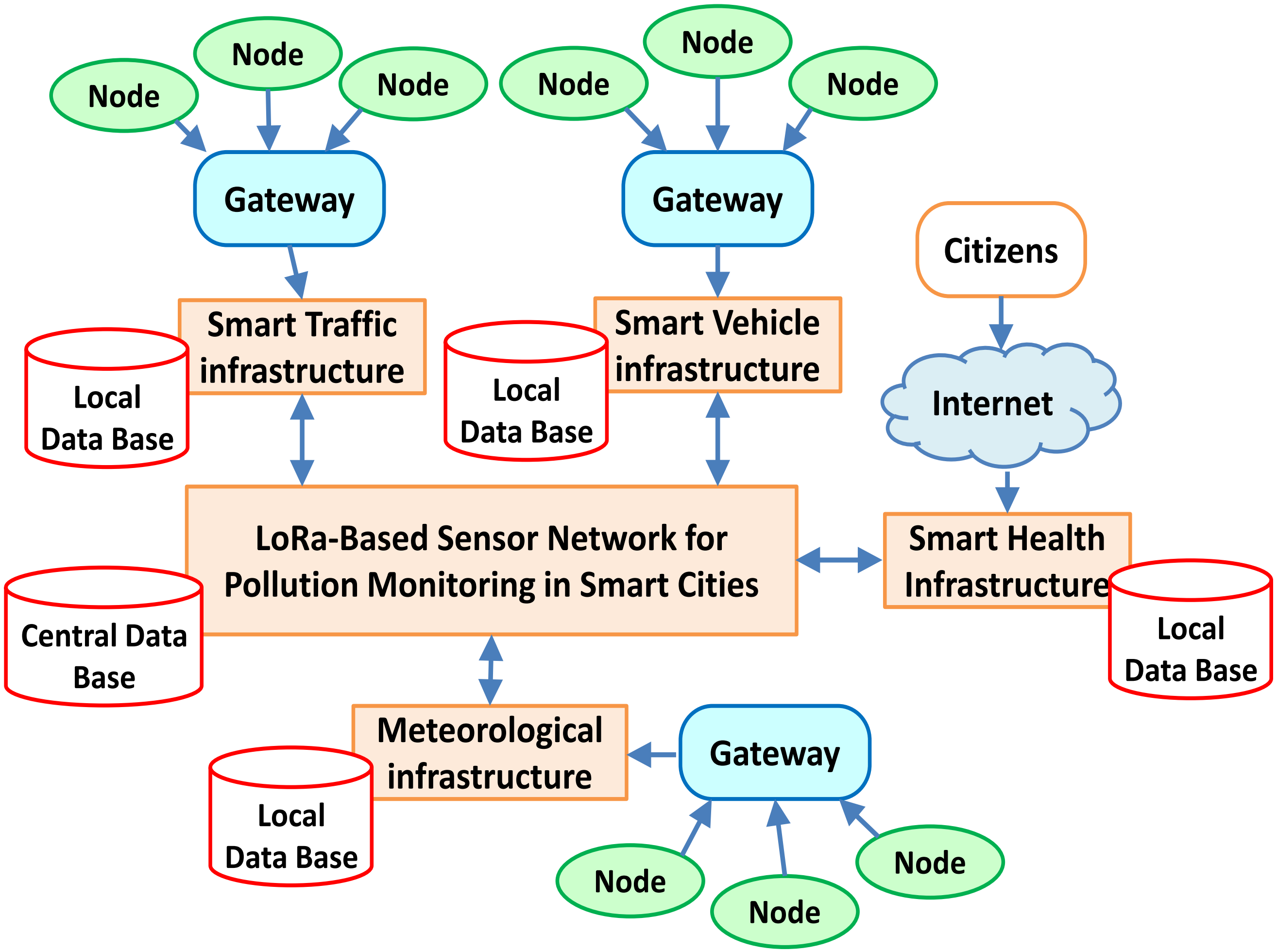


Collaborative LoRa-Based Sensor Network for Pollution Monitoring in Smart Cities

- Smart city →collaborative entity capable of combining data from different sources to make decisions and take measures to improve a situation.
- We focus our proposal on the control of pollution in cities. We consider: Wireless nodes based on LoRa
  - in vehicles
  - Fixed nodes installed in traffic lights and lampposts.
- Monitor the evolution of temperature, relative humidity and CO2 concentrations at the established points and combine all these data to build real-time maps of the evolution of these parameters.
- The proposed network becomes collaborative, as the opinion of citizens is introduced into the network and considered to make decisions on the actions to be taken.

LoRa-Based Appl. - Pollution Monitoring

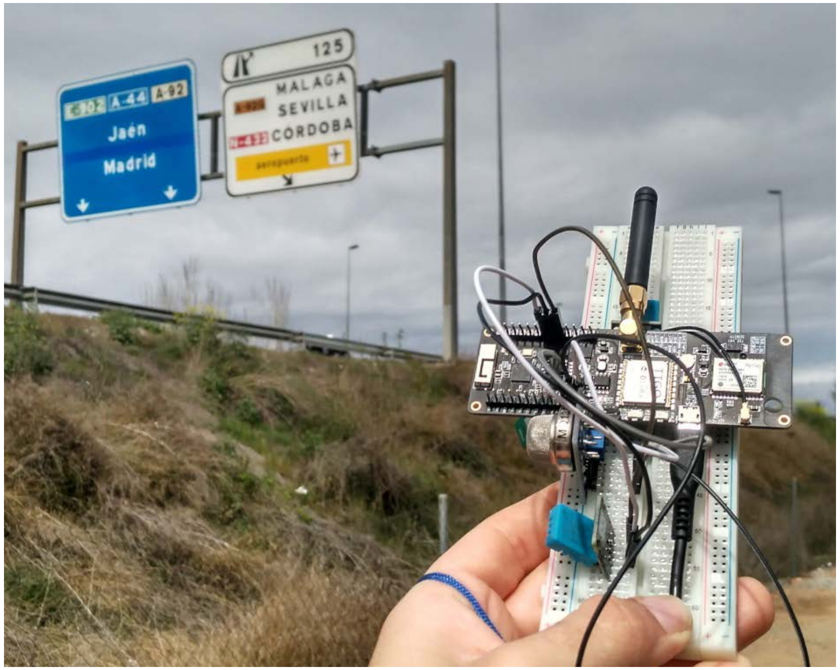
Smart City framework



LoRa-Based Appl. - Pollution Monitoring

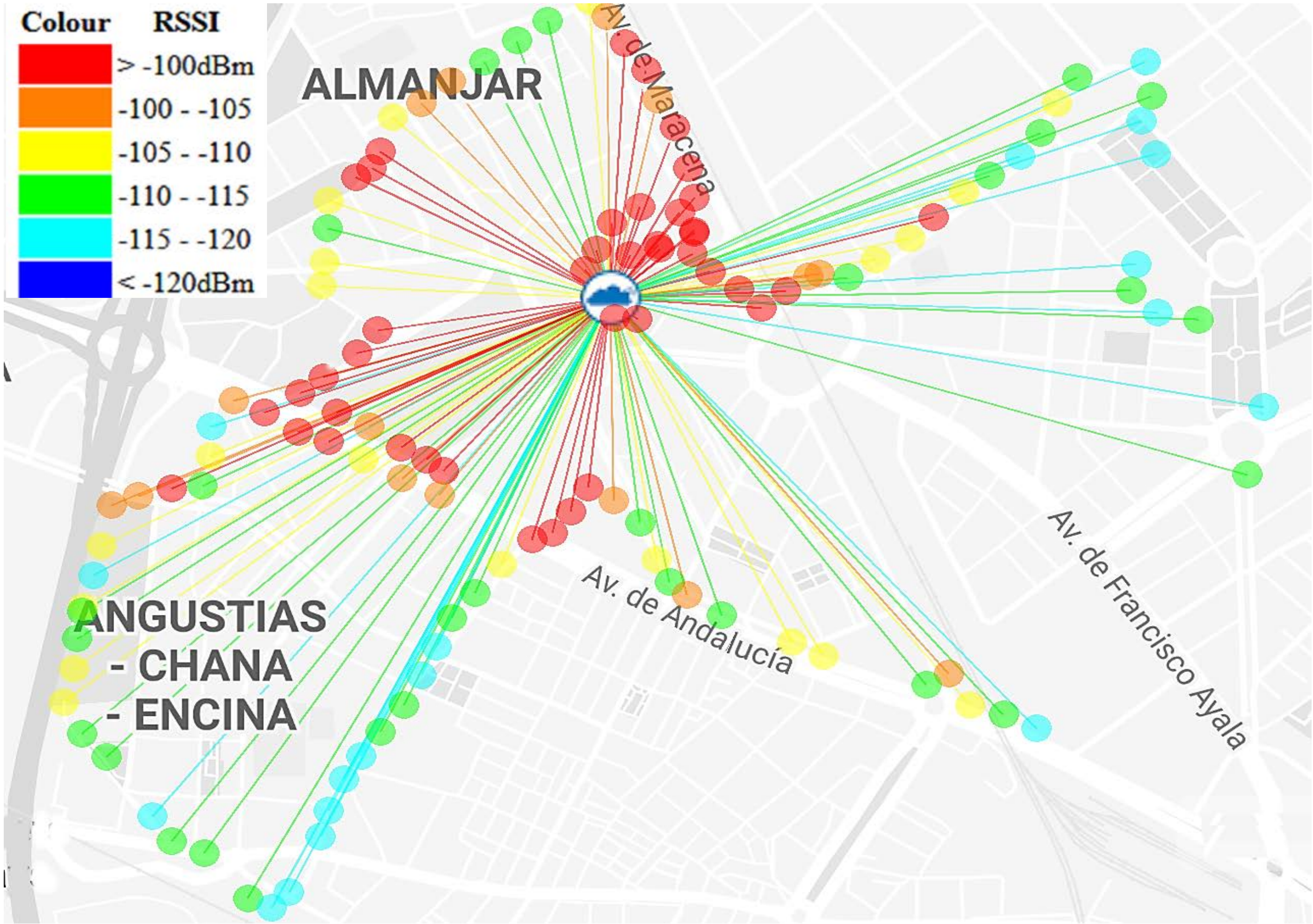
LoRa Node

- To implement each node, we use a TTGO T-Beam node. It is built around the ESP32 chip. It has 4MB of SPI flash.
- It operates at 433 MHz, 868 MHz and 915 MHz, in our case we use the European ISM band at 868 MHz.
- Our TTGO T-Beam node includes two antennas. A GPS ceramic antenna connected to a u-bloc NEO-6M GPS module and another LoRa antenna with SMA connector.
- It uses a LoRa chip from the HopeRF RFM9X family. The node has a total of 26 pins with GPIO, ADC, VP/VN, DAC, Touch, SPI, I2C, UART and Lora.
- Finally, the node can be feed by batteries.



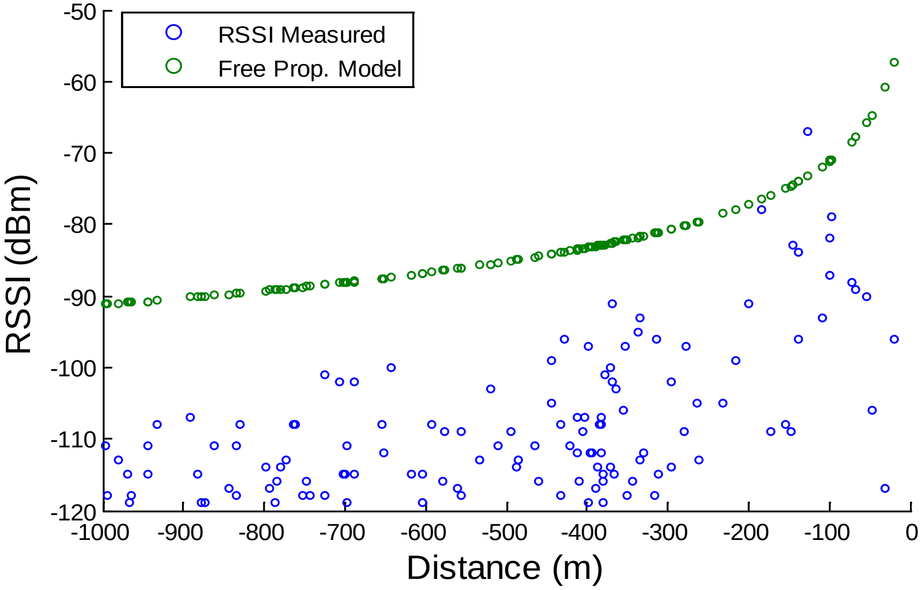
LoRa-Based Appl. - Pollution Monitoring

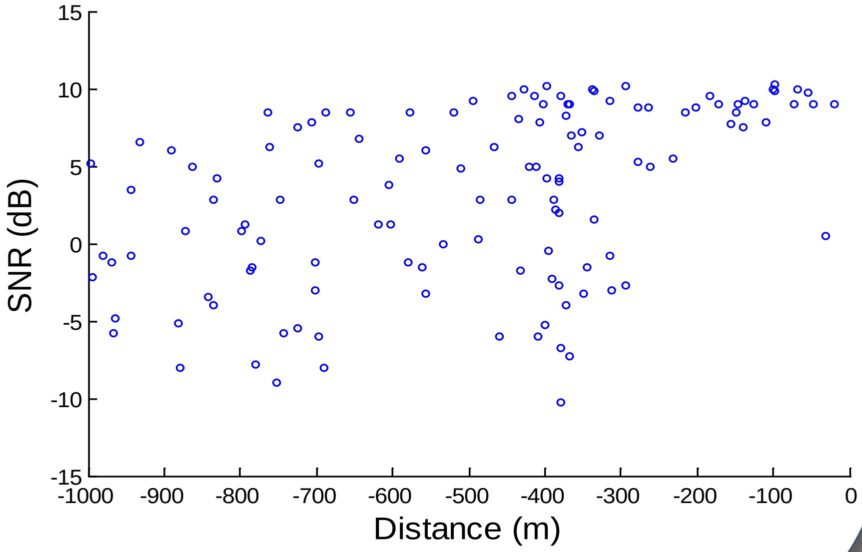
RSSI coverage over the measurement scenario



LoRa-Based Appl. - Pollution Monitoring

Network Measurements



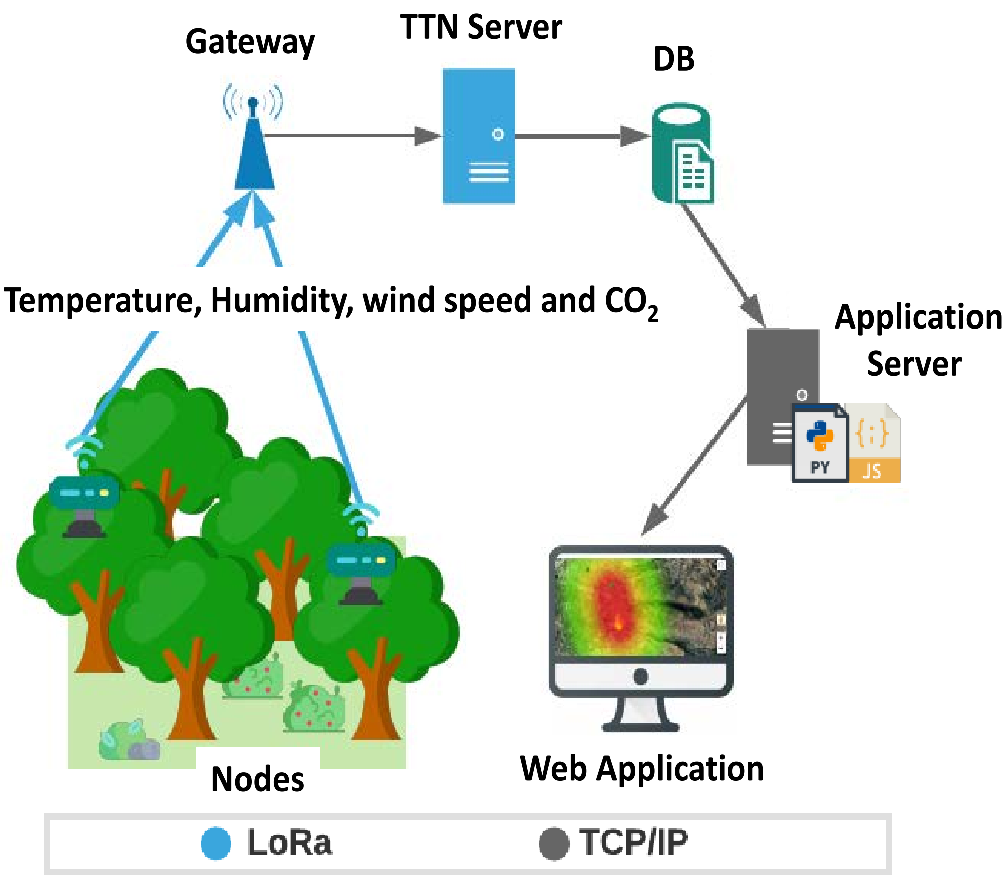


LoRa-Based Appl. - Pollution Monitoring

Environmental parameters

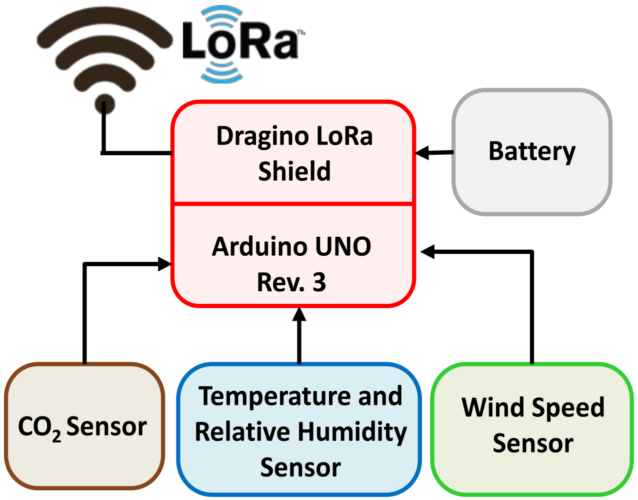
Low Cost LoRa based Network for Forest Fire Detection

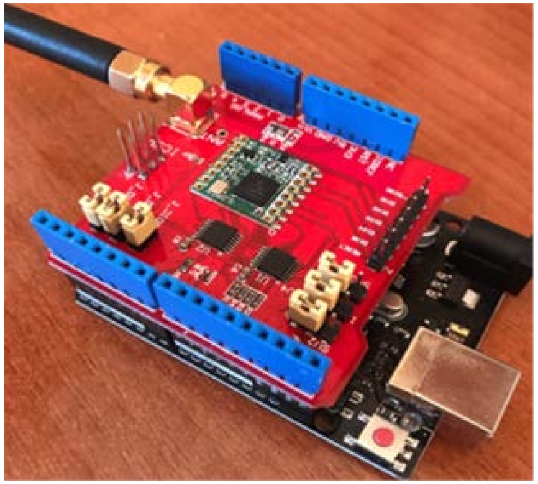
Network architecture



- The system is composed by a set of LoRa nodes that collect information on relative humidity, temperature, wind speed and concentration of CO_2.
- These values will be sent to the TTN server through the LoRa gateway to finally be stored in the DB.
- The application server will perform requests to the DB and after processing the values, they will graphically representation on a website.

LoRa node

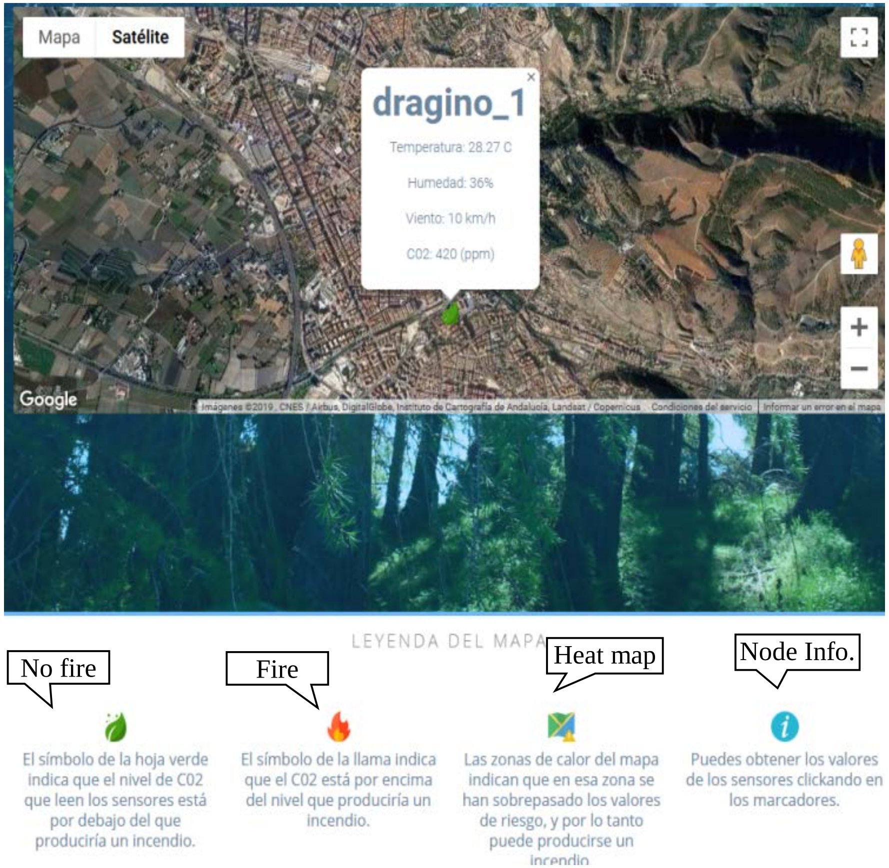


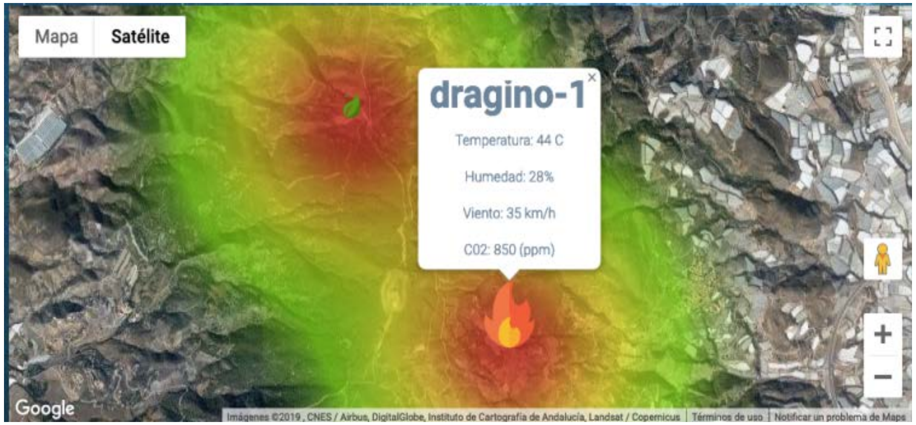


- Arduino Uno Rev3 module, which has a Microchip ATmega328P microcontroller and it is used to process the data. It has 14 digital inputs/outputs and 6 of them can be used for PWM outputs. It also has 6 analog inputs, a 16MHz oscillator and 32 KB of Flash Memory, 2 KB of SRAM and 1KB of EEPROM.

- Dragino LoRa Shield board compatible with our Arduino development board that incorporates the RFM95W transceiver with the SX1276 chip from Semtech. It will allow us the use of LoRaWAN modulation to establish the communication between devices. Our model is factory configured to work in the 868 MHz frequency band.

Web interface



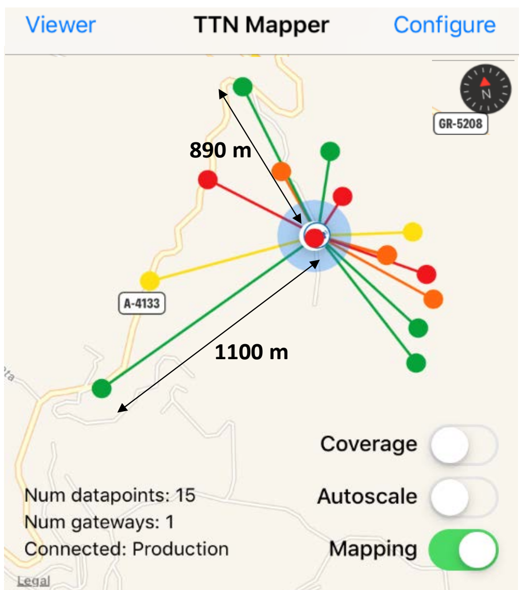


Results

- The tests have been performed in a real environment.
  - LoRa coverage in rural environment.
  - Data from sensors

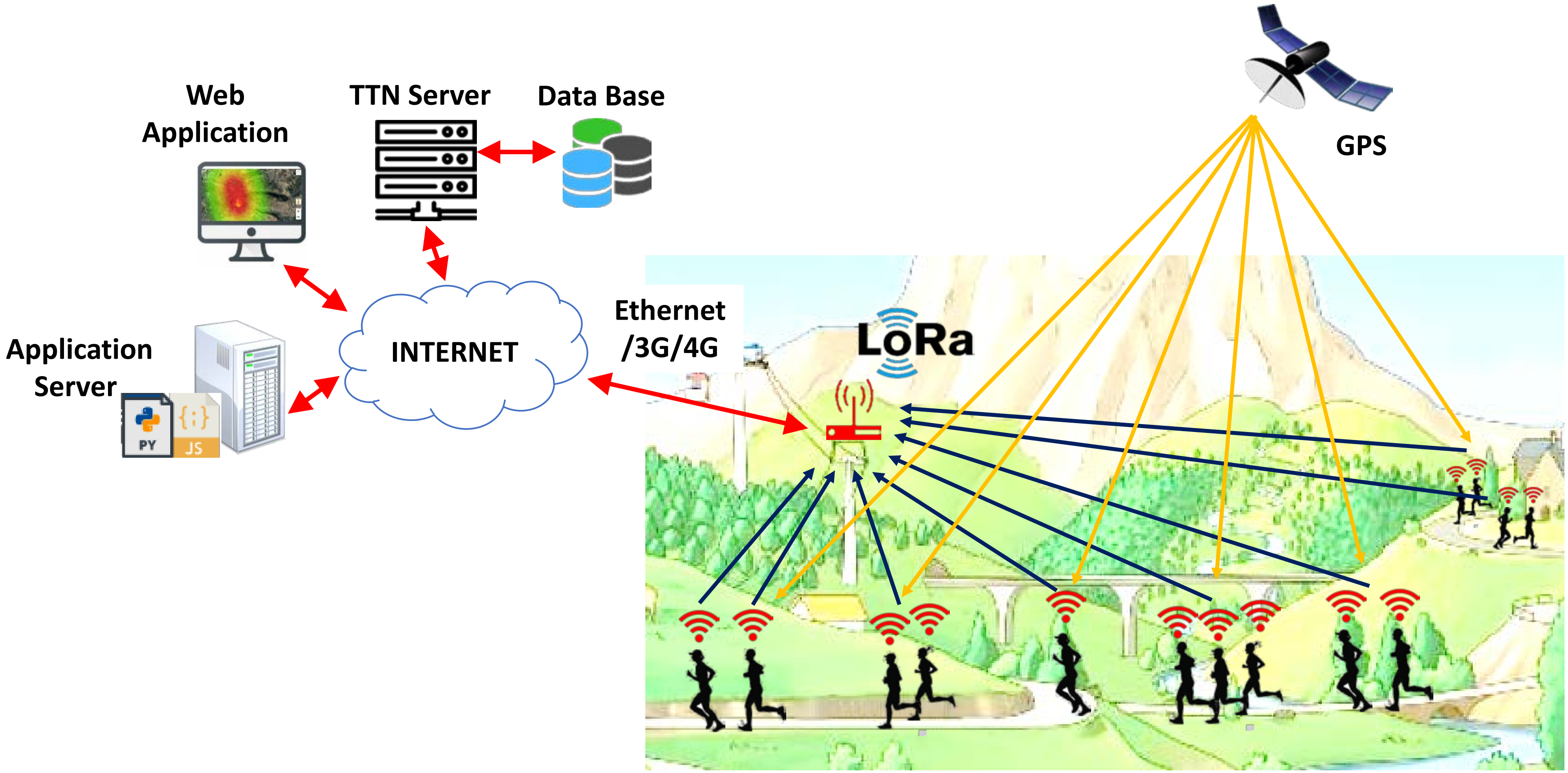
LoRa coverage in rural environment.

- A LoRa network like the one implemented in this proposal is capable of covering an area of approximately 314 ha (3,141,592.65 m2) which is equivalent to having a circular area of 1km radius.
- The LoRa technology would allow us to cover areas of up to 4km in scenarios where we have no obstacles.
- The scenario analyzed has large plant masses that cause a large dispersion in the signal.



LoRa-Based System for Tracking Runners in Cross Country Races

Network architecture for our LoRa-based system for tracking

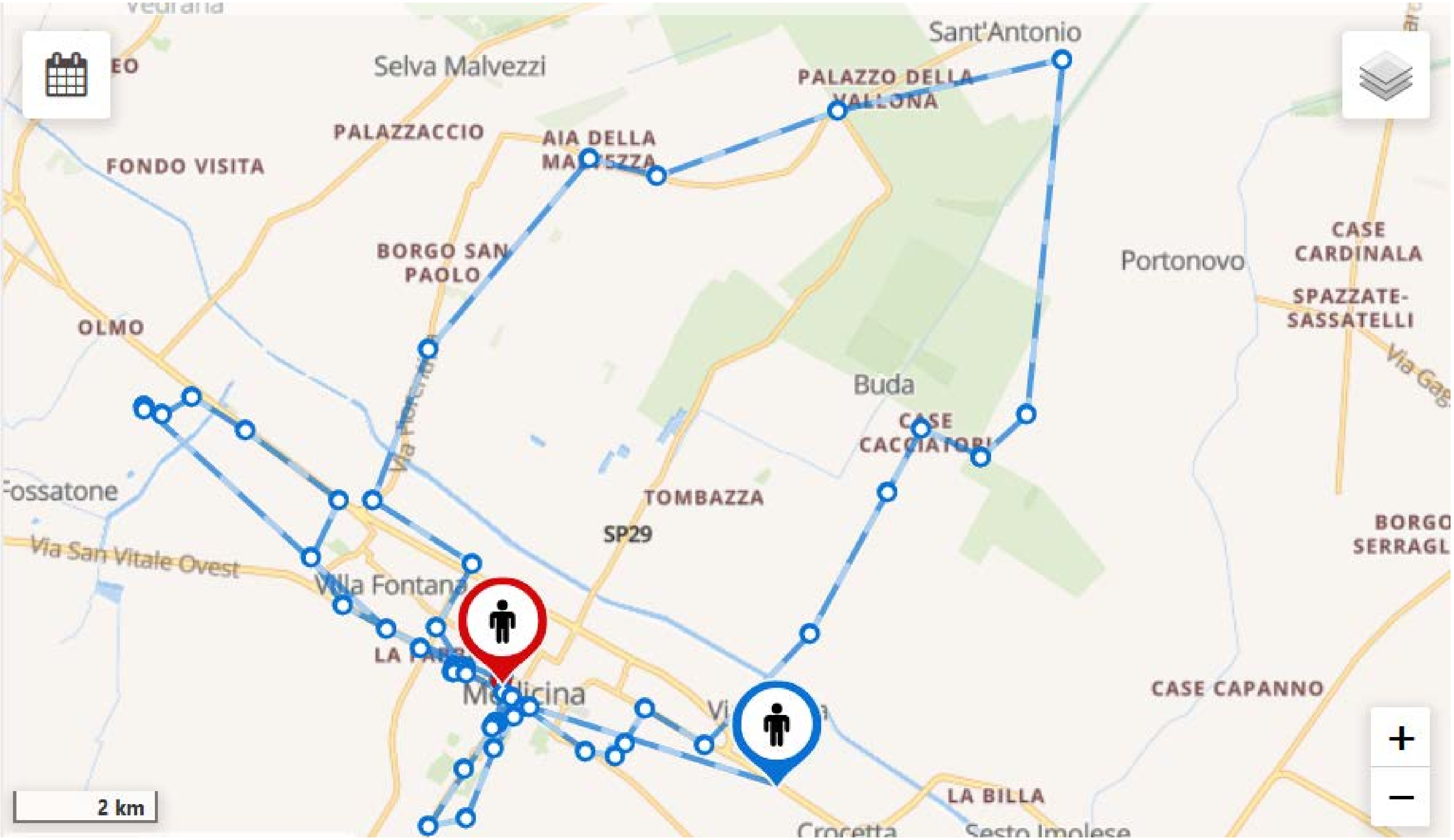


Hardware used

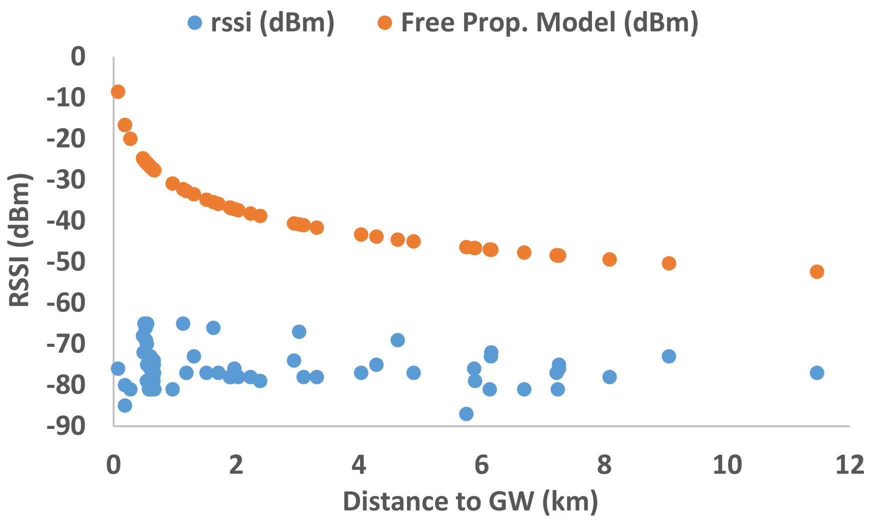
RAK2245 module with a RaspBerry Pi board

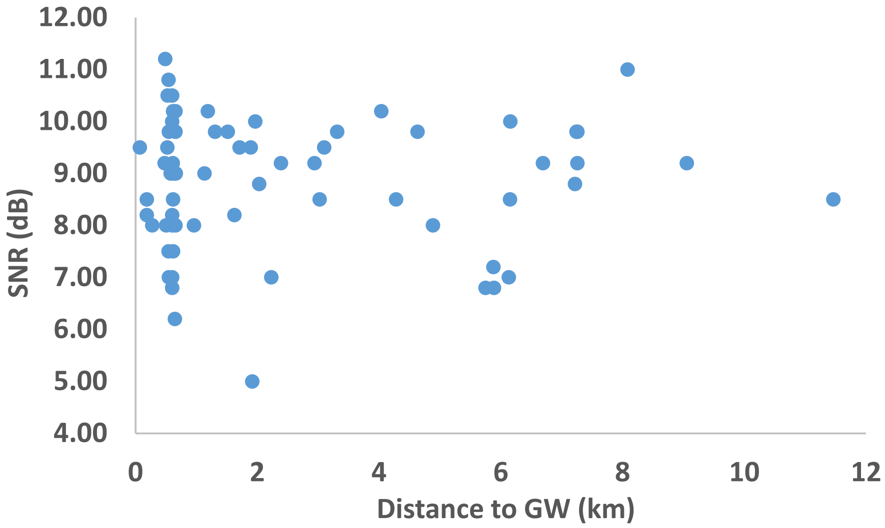
Dragino LoRaWAN GPS Tracker LGT-92

Results


Selva Malvezzi
Sant'Antonio
PALAZZO DELLA VALLONA
PALAZZACCIO
AIA DELLA
FONDO VISITA
BORGO SAN PAOLO
Portonovo
CASE CARDINALA
SPAZZATE-SASSATELLI
OLMO
Buda
TOMBAZZA
SP29
Via San Vitale Ovest
Villa Fontana
CASE CAPANNO
LA BILLA
2 km

Results


rssi (dBm)
Free Prop. Model (dBm)
RSSI (dBm)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
2
4
6
8
10
12
Distance to GW (km)


SNR (dB)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
0
2
4
6
8
10
12
Distance to GW (km)

References

1. J. Lloret, M. Garcia, D. Bri, S. Sendra. A wireless sensor network deployment for rural and forest fire detection and verification. Sensors, 2009, 9(11), 8722-8747.

2. S. Sendra Compte, J. Lloret, M. García Pineda, J. F. Toledo Alarcón. Power saving and energy optimization techniques for Wireless Sensor Networks. Journal of communications, 2011, 6(6), 439-459.

3. J. Lloret, I. Bosch, S. Sendra, A. Serrano, A wireless sensor network for vineyard monitoring that uses image processing. Sensors, 2011, 11(6), 6165-6196.

4. J. Navarro-Ortiz, S. Sendra, P. Ameigeiras, J. M. Lopez-Soler, Integration of LoRaWAN and 4G/5G for the Industrial Internet of Things. IEEE Communications Magazine, 2018, 56(2), 60-67.

5. P. Romero-Diaz, L. Garcia, S. Sendra, and J. Navarro-Ortiz, Performance of LoRaWAN Networks in Outdoor Scenarios, The Eighteenth International Conference on Networks (ICN 2019), March 24-28, 2019, Valencia, Spain

6. S. Sendra, J.L. Garcia-Navas, P. Romero-Diaz, J. Lloret, Collaborative LoRa-Based Sensor Network for Pollution Monitoring in Smart Cities. In Fourth International Conference on Fog and Mobile Edge Computing (FMEC 2019), June 10-13, 2019. Rome, Italy.

7. R. Vega-Rodriguez, S. Sendra, J. Lloret, P. Romero-Diaz, J. L. Garcia-Navas, Low Cost LoRa based Network for Forest Fire Detection, The 6th International Conference on Internet of Things: Systems, Management and Security (IOTSMS 2019), Granada, Spain. October 22-25, 2019

8. S. Sendra, P. Romero-Díaz, J. Navarro-Ortiz and J. Lloret, "Smart Infant Incubator Based on LoRa Networks," 2018 IEEE/ACS 15th International Conference on Computer Systems and Applications (AICCSA), Aqaba, 2018, pp. 1-6. Aqaba, Jordan. Oct. 28- Nov. 1, 2018

Acknowledgment

ACKNOWLEDGMENT

- “Ministerio de Ciencia, Innovación y Universidades” through the “Ayudas para la adquisición de equipamiento científico-técnico, Subprograma estatal de infraestructuras de investigación y equipamiento científico-técnico (plan Estatal I+D+i 2017-2020)” (project EQC2018-004988-P).

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