

From LoRa to the Cloud: Bridging Physical and Digital Worlds

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<http://grc.webs.upv.es/>

The Grupo de Redes de Computadores (GRC) (Networking Research Group) of the Universitat Politècnica de València (UPV) was founded in 2000. The group research efforts focus on offering Data Communication Solutions for Mobile Systems. The main areas of application are:

- AIoT infrastructures for environmental sustainability
- Drone-based networks
- Efficient IoT infrastructures development
- Intelligent Transport Systems
- LPWAN-based networks
- Mobile edge computing
- Pub/Sub systems
- Social sensing



Infos and News:

- [Overview of GRC research \[Sept. 2021\]](#)
- [GRC YouTube channel](#)
- [COVIDsensing: a tool to analize COVID spreading using AI](#)

Events and CfPs:

Conferences:

- [Un-IoT 2023](#), Workshop on Unconventional IoT Applications", in conjunction with 2023 IEEE GLOBECOM, December 4-8, 2023, Kuala Lumpur, Malaysia.
- [ISGTA 2023](#), International Conference on Green Technologies and Applications, Novemeber 27th to 29th, 2023 in Portalegre, Portugal.
- [NET4us 2023](#), 2nd Workshop on Networked Sensing Systems for a Sustainable Society in conjunction with ACM MOBICOM, 2-6 Oct. 2023, Madrid, SPAIN
- [GoodIT 2023](#), International Conference on Information Technology for Social Good, 6-8 September 2023, Lisbon, Portugal.
- [VENITS 2023](#), 6th International Workshop on Vehicular Networking and Intelligent Transportation Systems, July 18, 2023, Hong Kong, China.
- [MetaNC 2023](#), Workshop on "Metaverse-based Networking and Computing", co-located with IEEE ICC 28 May – 01 June 2023, Rome, Italy.

Journals Special Issues:

- [MDPI Computers](#). Special issue on: [Vehicular Networking and Intelligent Transportation Systems](#), 2023.
- [MDPI Electronics](#). Special issue on: [Wireless Sensor Networks Applications for Smart Cities](#), 2023.
- [MDPI Sensors](#). Special issue on: [New Methods and Applications for UAVs](#), 2023.

- In this talk I'll describe how data can be efficiently transferred from physical devices to cloud-based services.
- I'll first give a brief overview of the key concepts of IoT, showing some example.
- Then, I'll describe LoRaWAN, highlighting the key hardware components: end nodes, gateways, and Network servers.
- Finally, I'll briefly discuss how data can be distributed to cloud services for visualization, processing, and analysis.

For a copy of these slides →



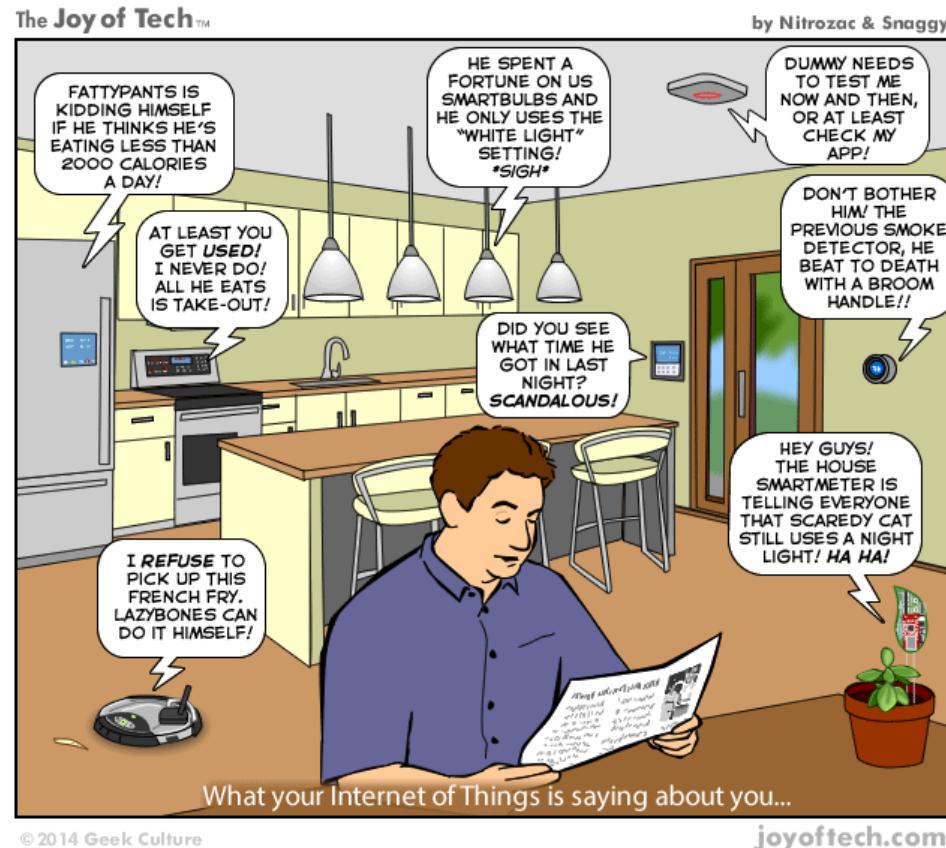
<https://bit.ly/lora2cloud>

A *brief introduction to IoT*

Internet of Things (IoT)

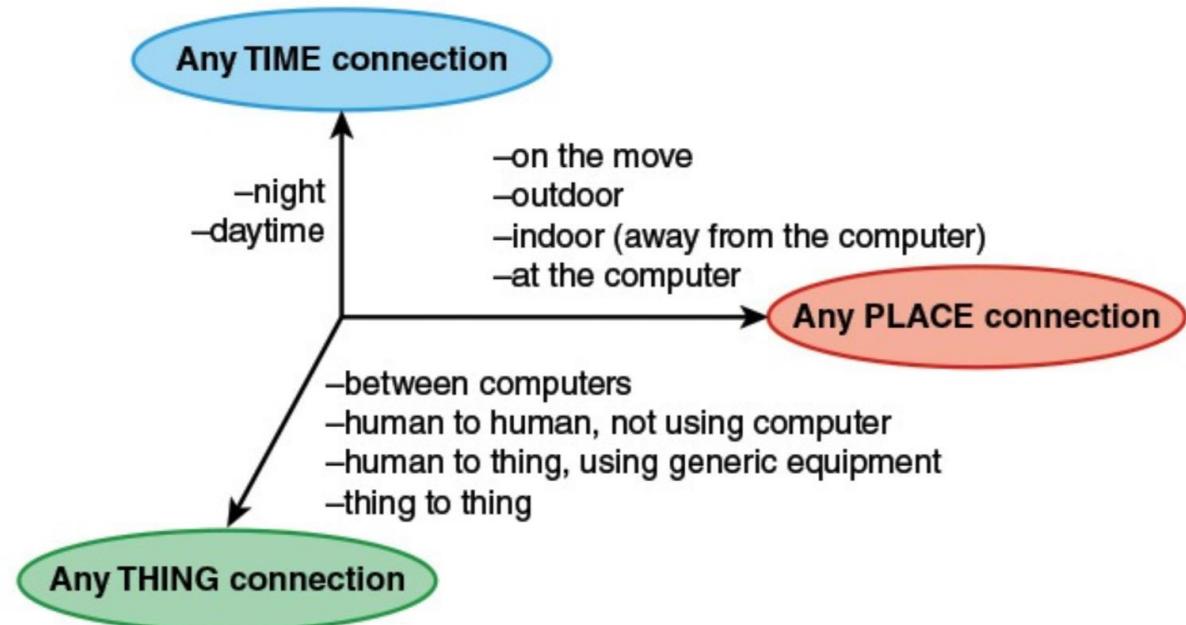
A quick and “physical” definition (<https://iot.IEEE.org/definition.html>):

“A network of **items**—each embedded with **sensors**—which are connected to the **Internet**.”



Internet of Things (IoT): a more general definition

“The IoT can be viewed as a **global infrastructure** for the information society, **enabling advanced services** by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies (ICT).”



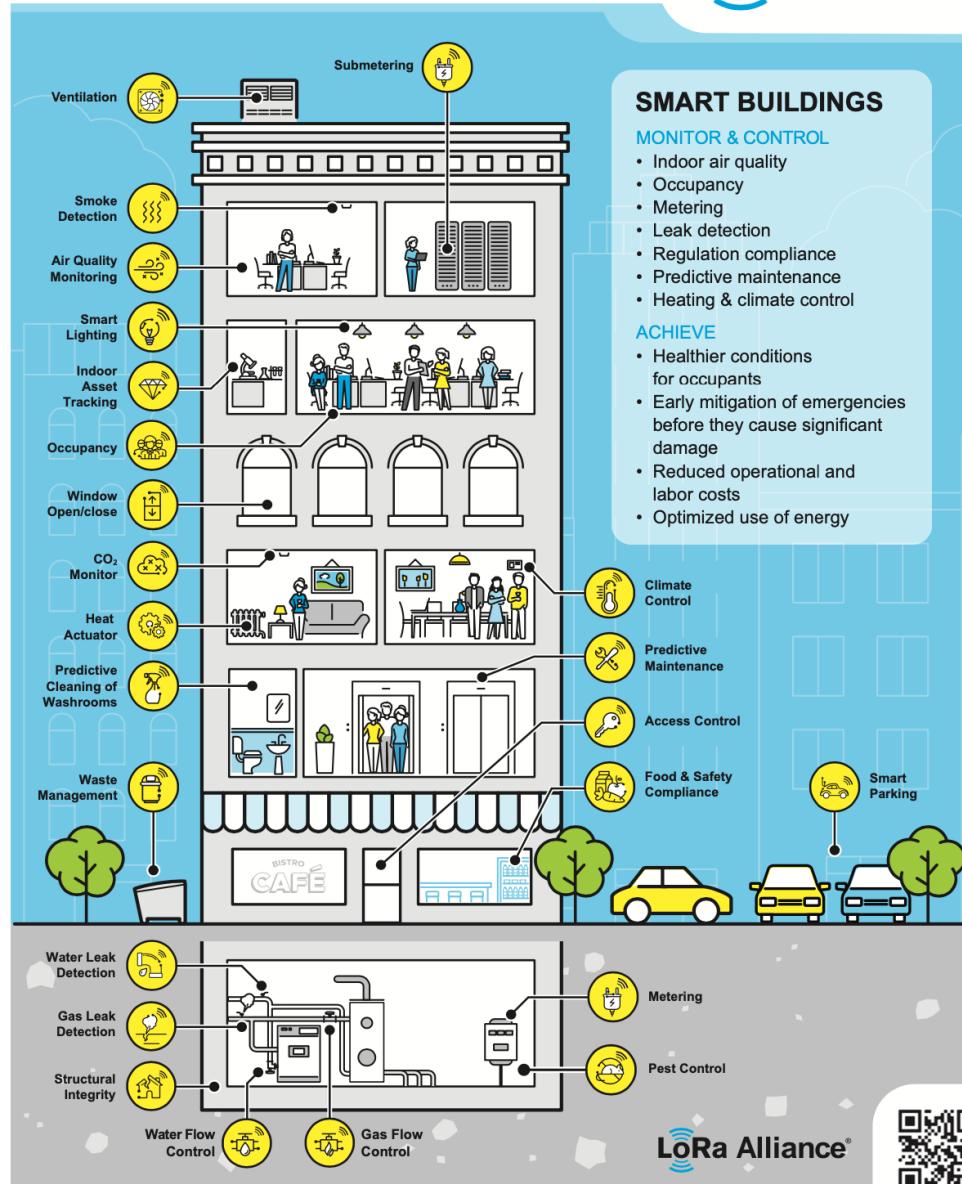
Source: Recommendation ITU-T Y.2060

The IoT landscape



<https://www.nffinc.com/>

BUILDING INTELLIGENCE WITH LoRaWAN®



Edge ML University Program 2023:

Workshop on Widening Access to TinyML Network by Establishing Best Practices in Education

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LoRaWAN® FOR PROFITABLE AND EFFICIENT UTILITIES

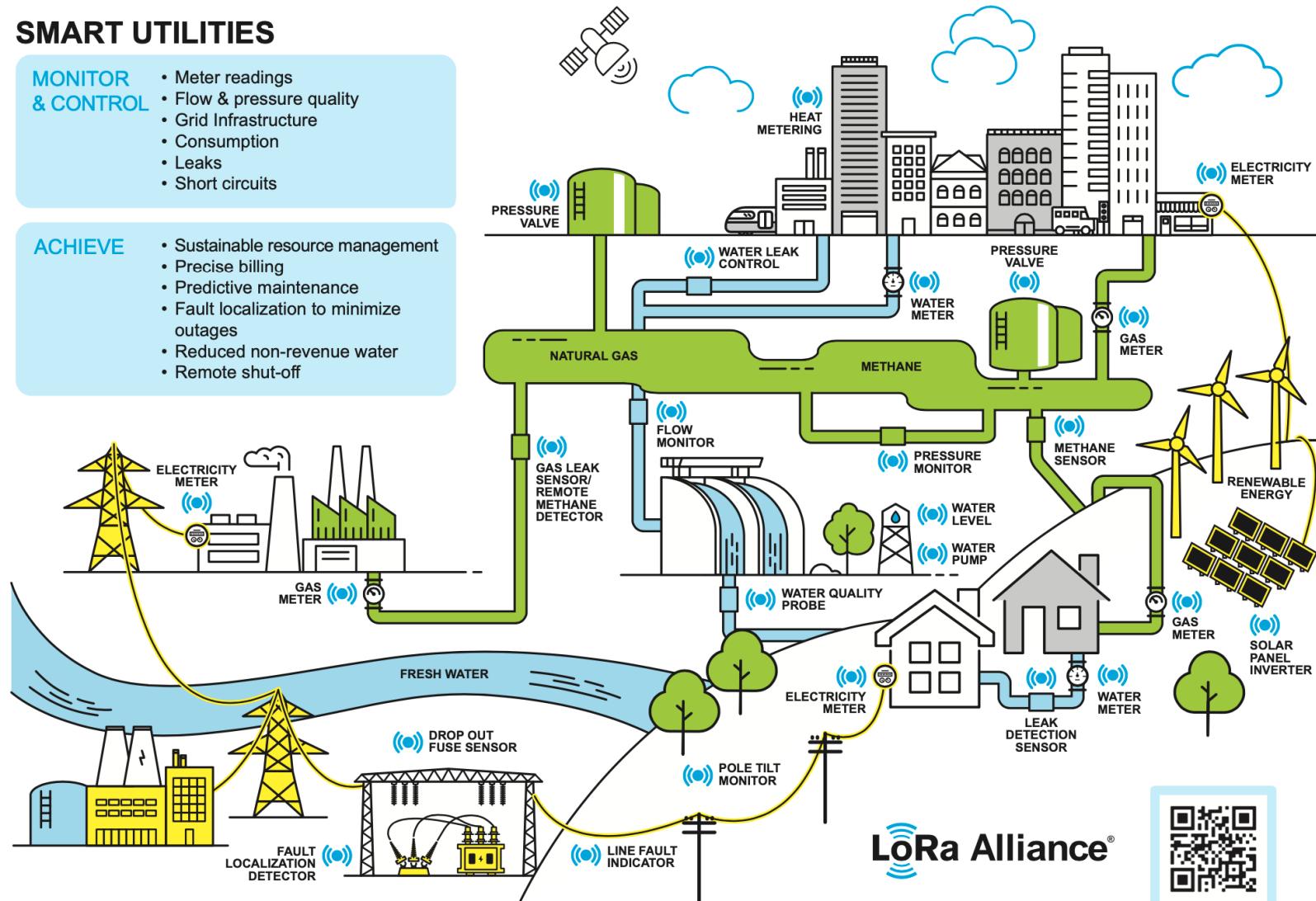
SMART UTILITIES

MONITOR & CONTROL

- Meter readings
- Flow & pressure quality
- Grid Infrastructure
- Consumption
- Leaks
- Short circuits

ACHIEVE

- Sustainable resource management
- Precise billing
- Predictive maintenance
- Fault localization to minimize outages
- Reduced non-revenue water
- Remote shut-off



LoRa Alliance®



IoT simplified model

■ Devices (“things”)

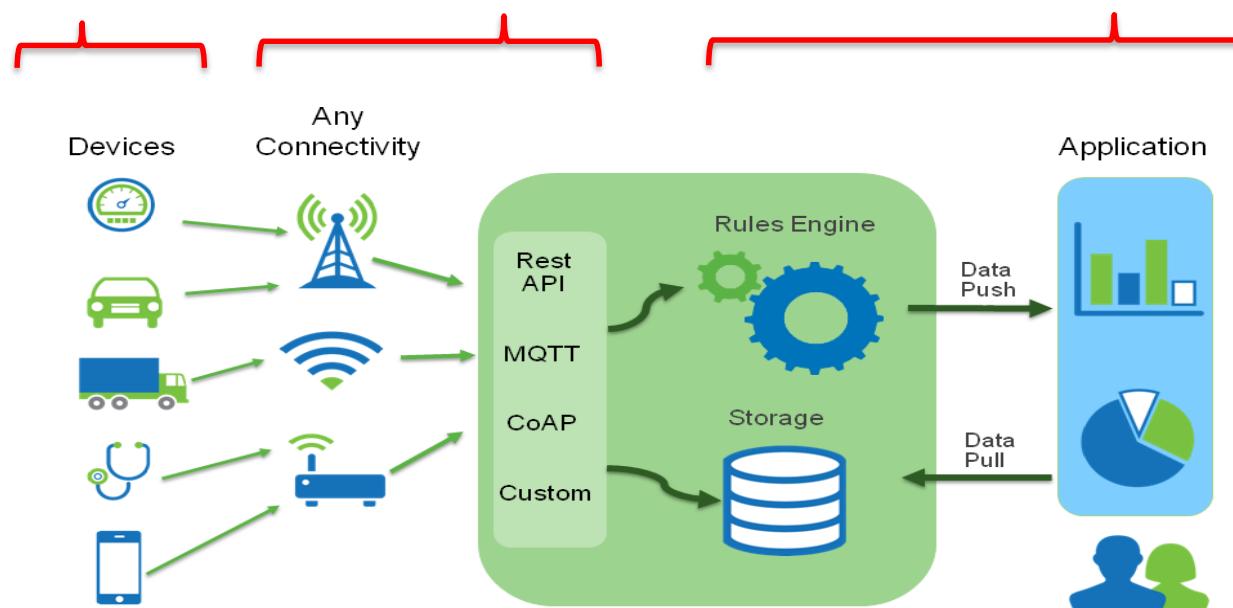
- These could be sensors, actuators, robots, cars, whatever can be connected.
- A lot of inheritance from the world of “sensors networks”

■ Connectivity

- To connect things reliably to Internet.
- Wireless connectivity is central to this task

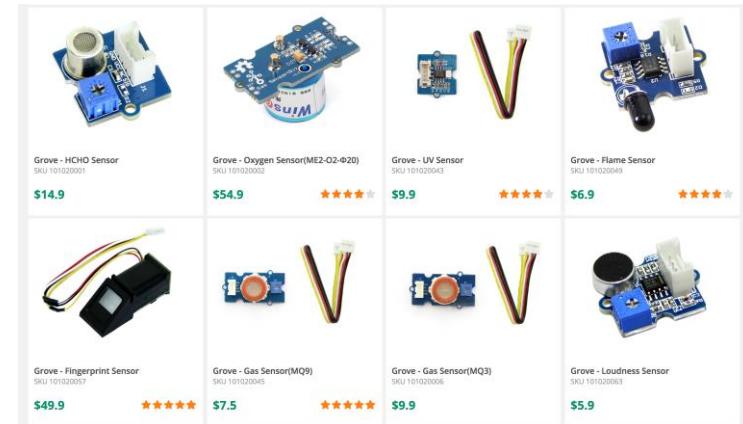
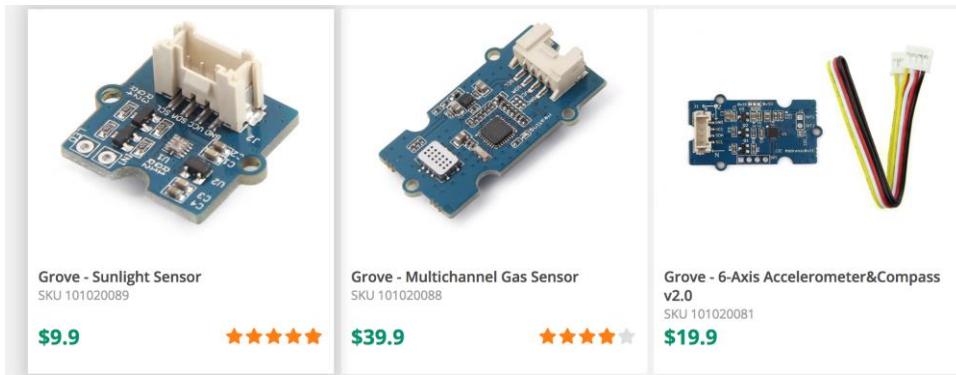
■ Platform

- the collected data needs to be stored and processed somewhere.
- Typically cloud-based infrastructures... but the edge is growing



Classic things

cheap...



expensive...

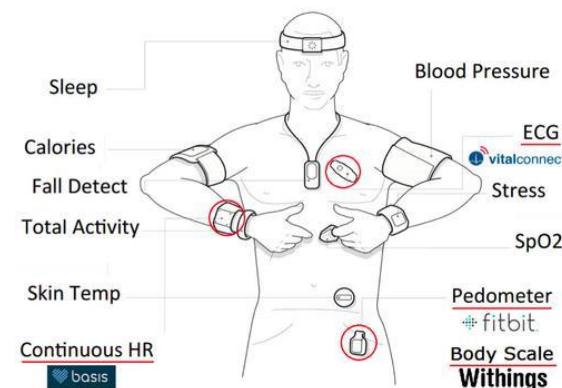


1.2 Oxygen Optode 4531 dimensions



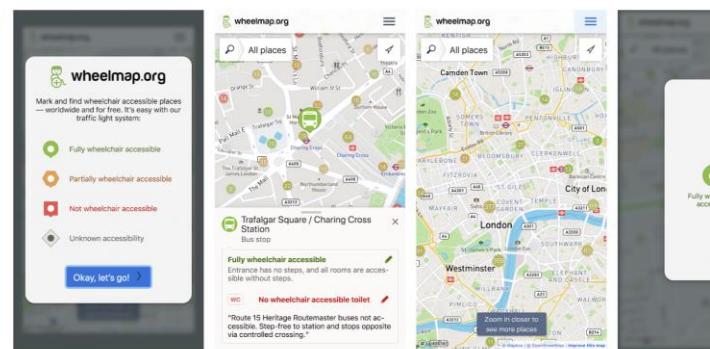
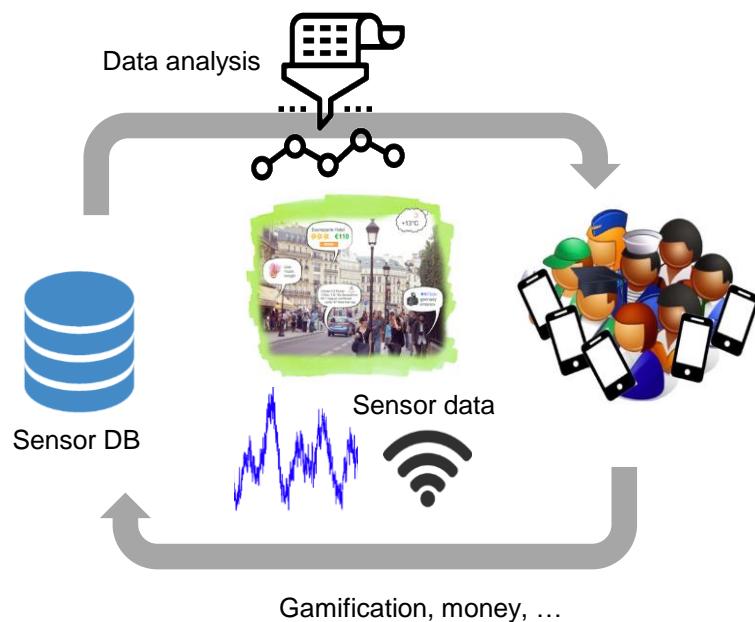
Parameter	Output	Default range ²⁾	Calibrated range	Accuracy	Resolution
Oxygen Concentration	0 - 5V	0 to 800µM	0 to 500µM	<8µM or 5% whichever is greater	<1µM
	4 - 20mA	0 to 800µM	0 to 500µM	<9µM or 5.2% whichever is greater	<1µM
Oxygen Saturation	0 - 5V	0 – 200%	0 - 120%	<5 %	<0.4%
	4 - 20mA	0 – 200%	0 - 120%	<5.2 %	<0.4%
Temperature	0 - 5V	-5 to + 35°C	0 - 36°C	±0.1°C	±0.01°C
	4 - 20mA	-5 to + 35°C	0 - 36°C	±0.15°C	±0.02°C

Also Things++ (... maybe with TinyML)



Beyond conventional things

- Humans as a sensor
 - Crowdsensing
 - social sensors: E.g., tweeting real-world data and/or events



Wheelmap <https://wheelmap.org/>

SOZIALHELDEN e.V. Travel & Local

★ ★ ★ ★ 796

Parental guidance

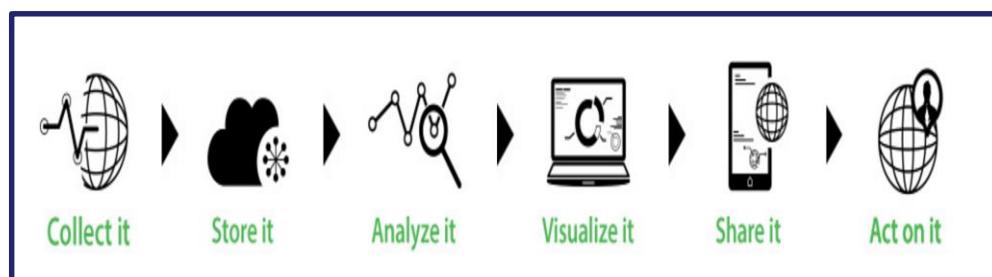
You don't have any devices

Add to Wishlist

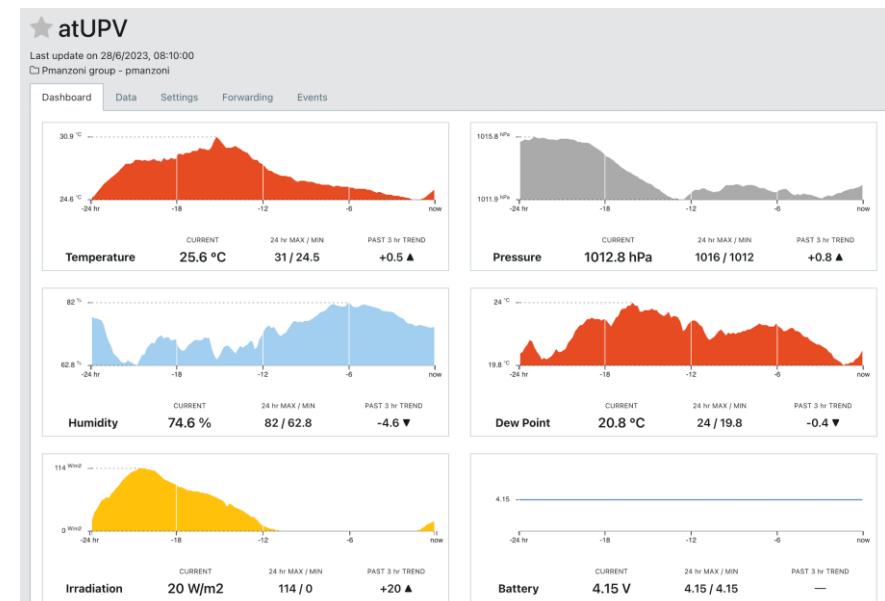
Install

- Microsoft Azure IoT Hub
 - <https://azure.microsoft.com/es-es/products/iot-hub>
- Amazon AWS IoT
 - <https://aws.amazon.com/es/iot/>
- ~~Google Cloud IoT~~
 - Maybe
<https://firebase.google.com/>
- And Oracle, Cisco, IBM...

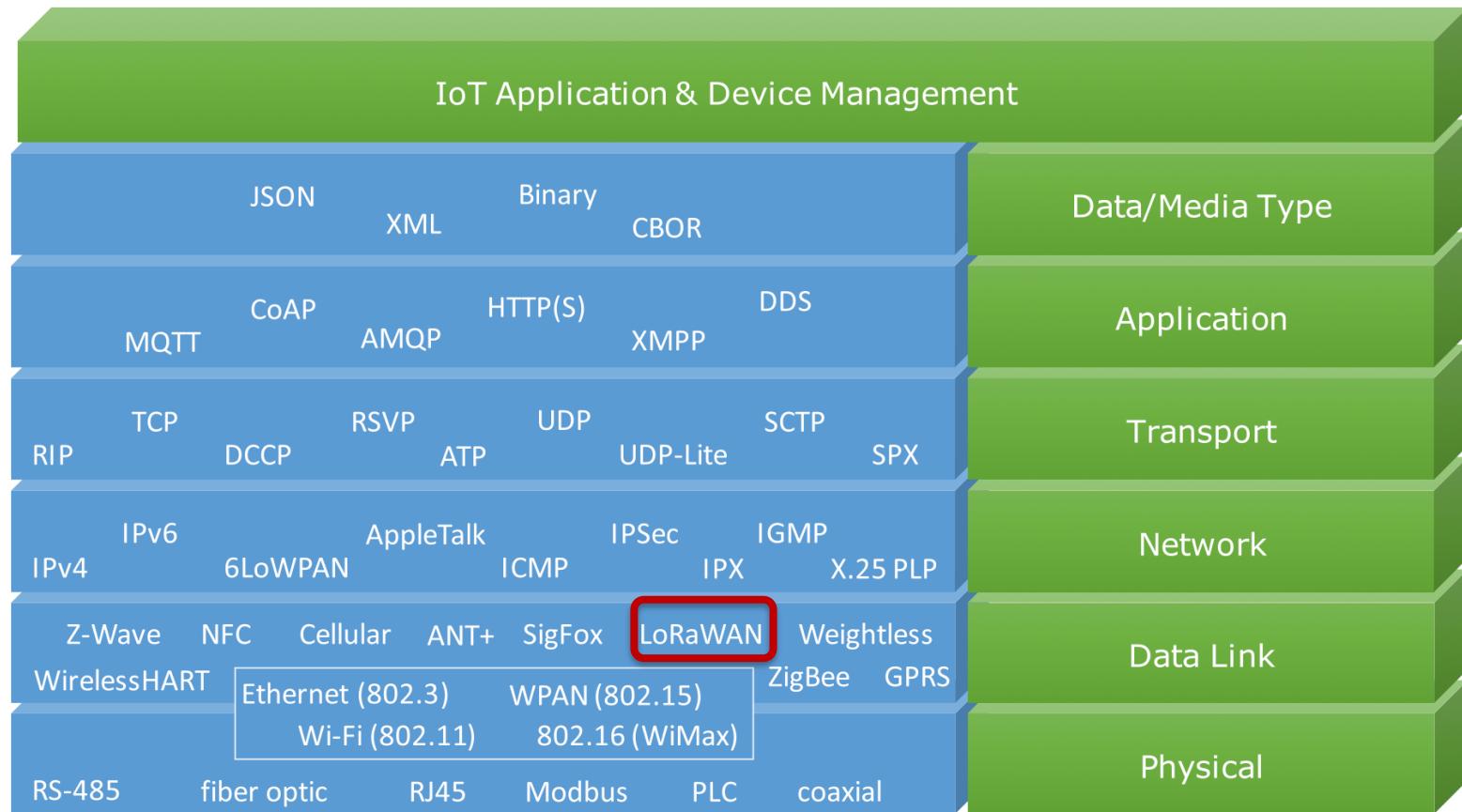
- FIWARE
 - <https://www.fiware.org/>
- ThingSpeak™
 - Based on MATLAB
 - <https://thingspeak.com/>
- ubidots
 - <https://ubidots.com/>
- ThingsBoard
 - Open-source
 - <https://thingsboard.io/>
- TIG stack
 - Telegraf/InfluxDB/Grafana



Platforms: data visualization & analysis



A communication-centric IoT reference model



E. Al-Masri et al., "Investigating Messaging Protocols for the Internet of Things (IoT)," in IEEE Access, vol. 8, pp. 94880-94911, 2020, doi: 10.1109/ACCESS.2020.2993363.

Connectivity: a simplified view

HTTP (REST, CoAP), MQTT

TCP, UDP

IPv4, IPv6, 6LoWPAN

Ethernet

WiFi

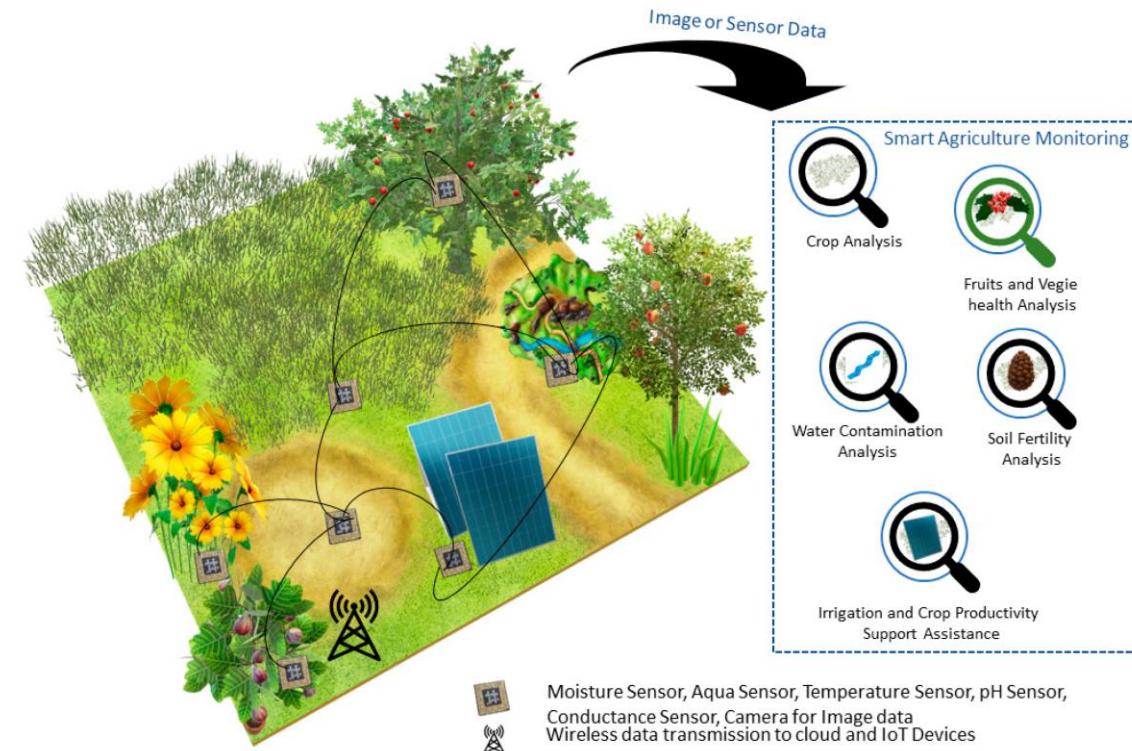
ZigBee, Bluetooth
LE, UWB, RFID, ...

2G: GPRS;
4G:LTE Cat M1
(eMTC)
LTE Cat NB1 (NB-IoT)

LoRaWAN,
SIGFOX

A brief overview of what I'm doing related to IoT

IoT for Environmental sensing



Environmental sensing refers to the tools and techniques designed to accurately observe an environment, characterize its quality, and establish characterizing parameters to quantify an activity's impact on that environment.

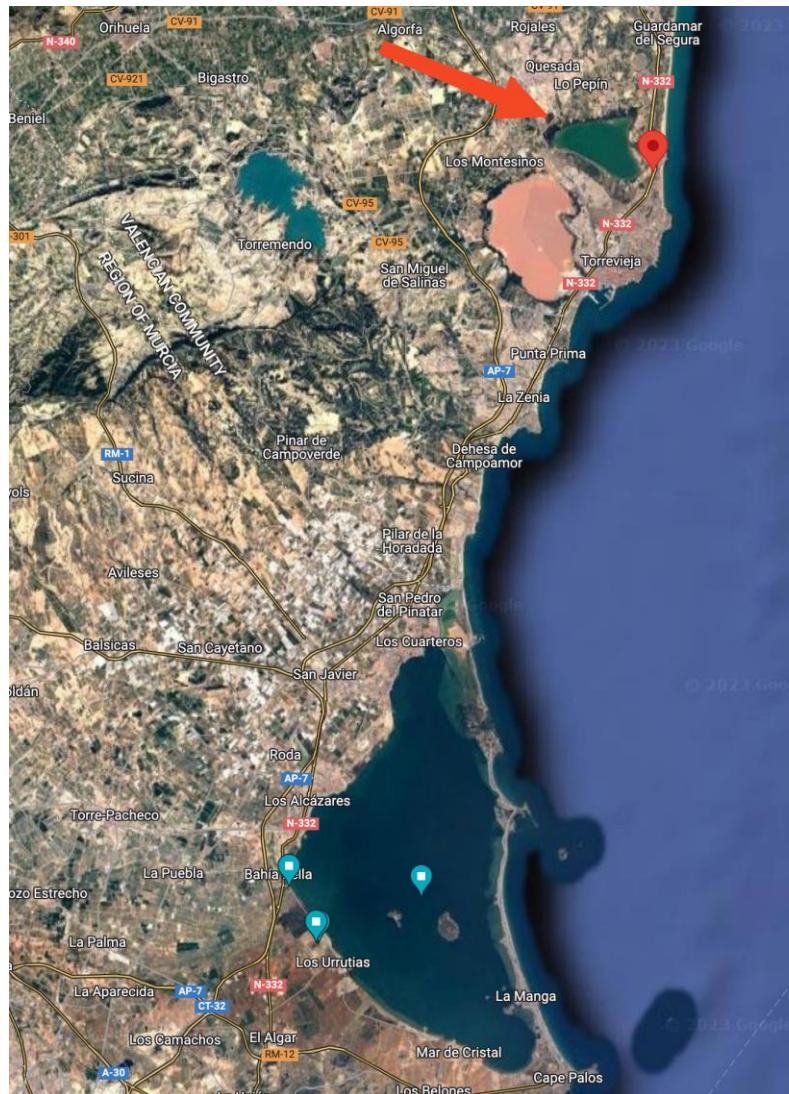
Ullo, S.L.; Sinha, G.R. Advances in Smart Environment Monitoring Systems Using IoT and Sensors. *Sensors* **2020**, *20*, 3113. <https://doi.org/10.3390/s20113113>

IoT for Environmental sensing

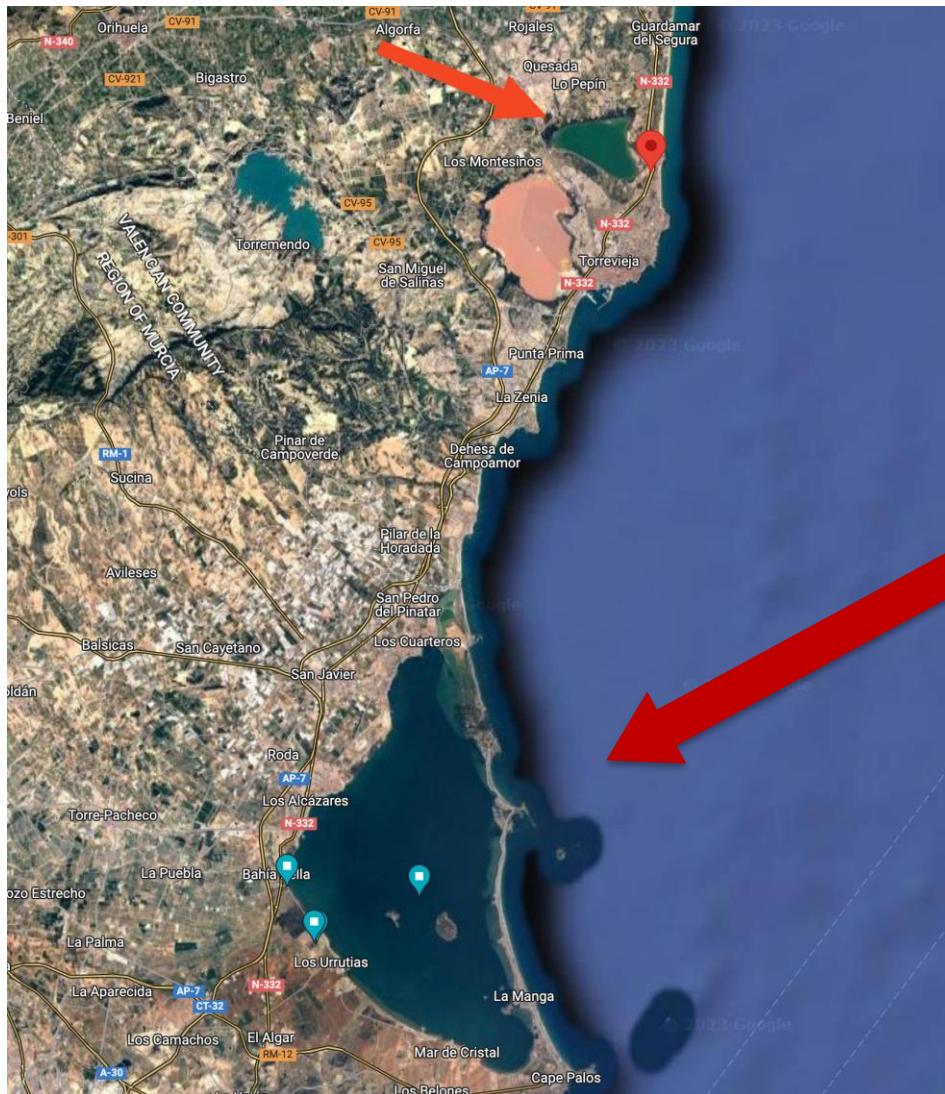
- Environmental sensing typically deals with **rural and extreme environments** such as remote areas, deserts, forests, or mountains.
- These areas generally present several technical challenges
 - lack of reliable communication infrastructure.
 - power supply constraints
 - atmospheric agents
 - device maintenance and servicing
 - ...



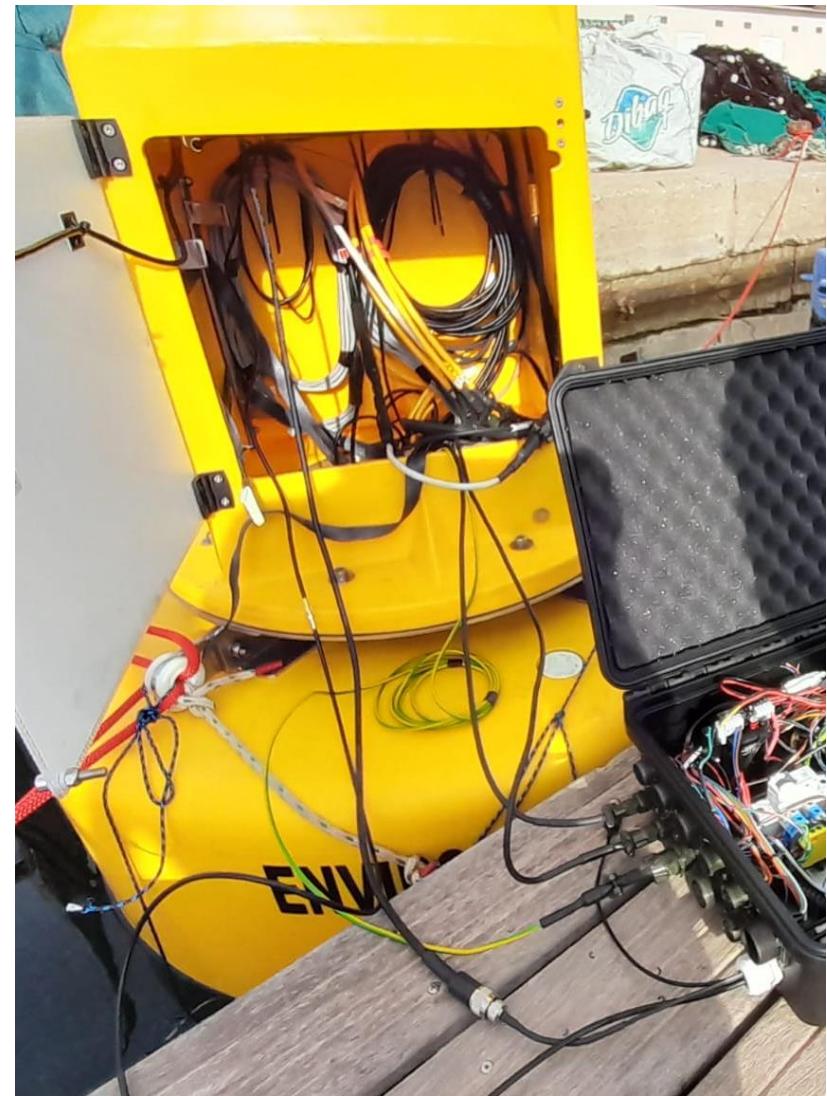
Natural Park of Las Lagunas de La Mata y Torrevieja

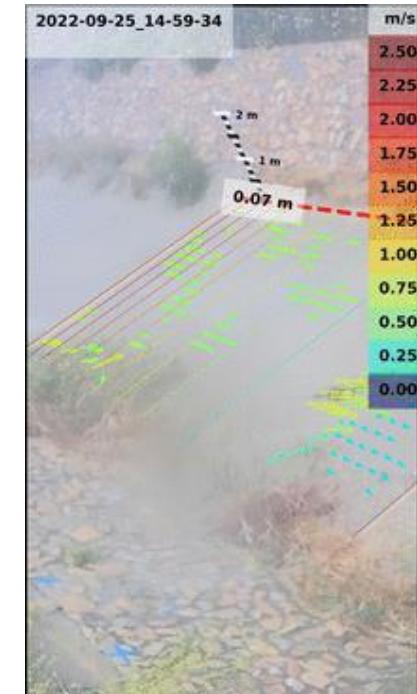
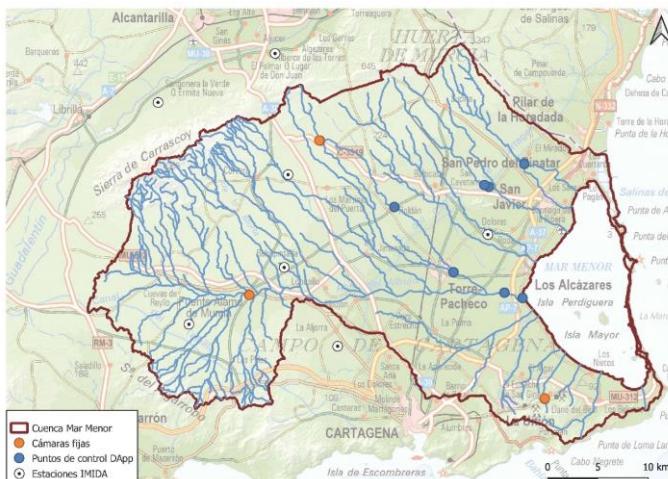


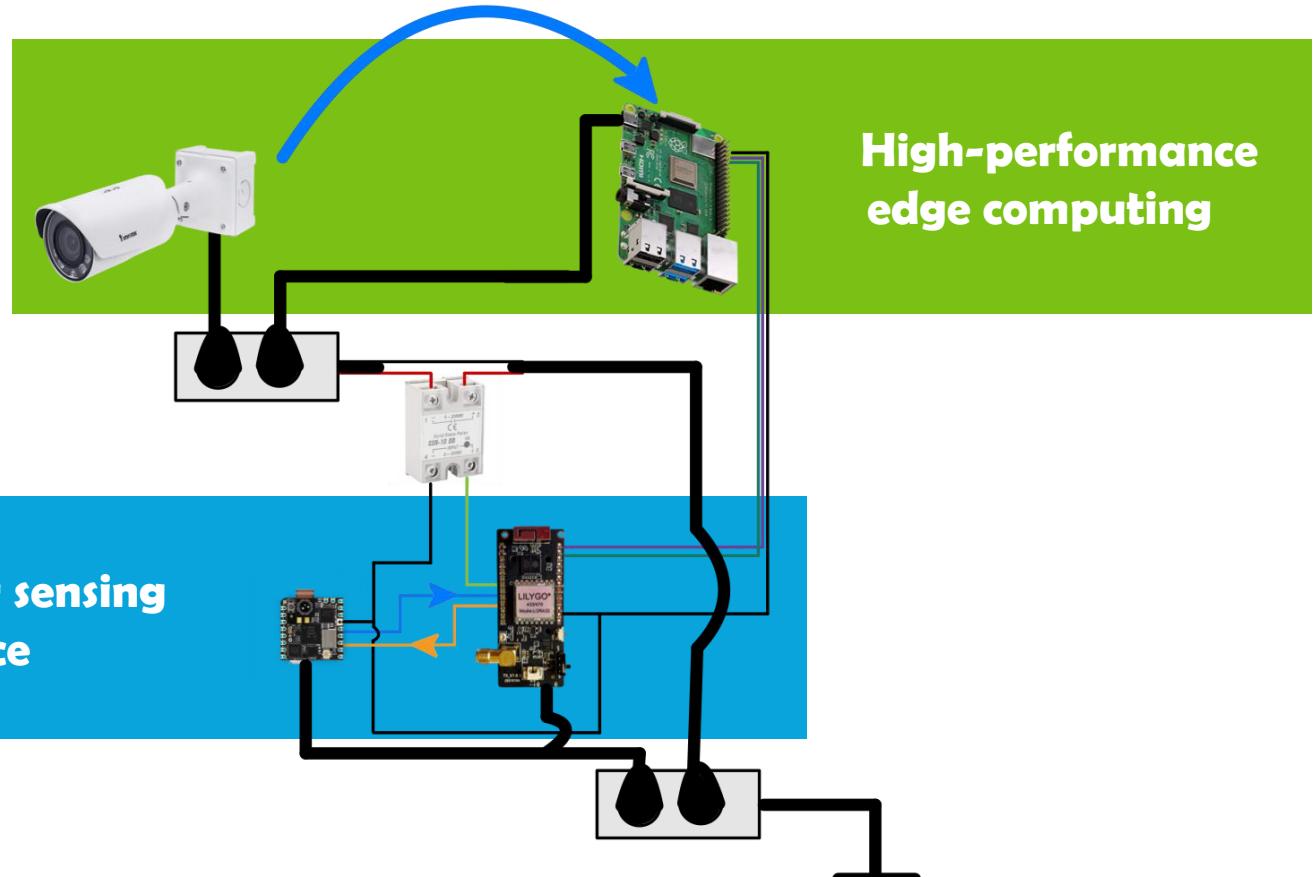
Mar Menor lagoon



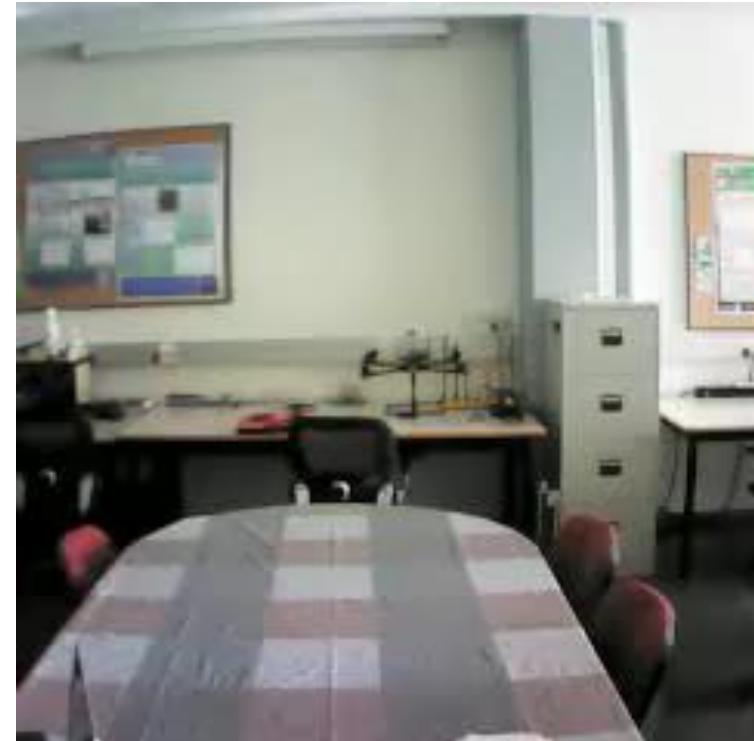
The Mar Menor is the largest saltwater lagoon in Europe, with a surface area of 135 km², a coastline of 73 km and a maximum depth of 7 meters.



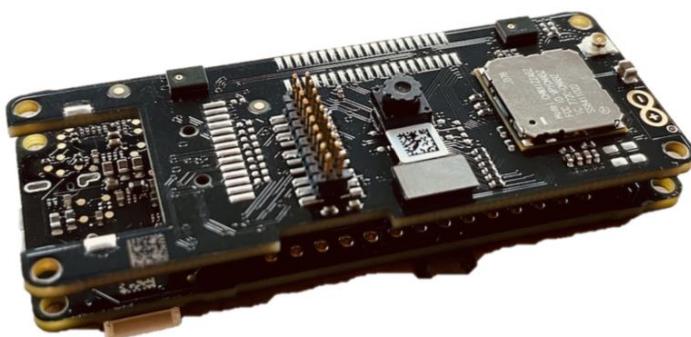
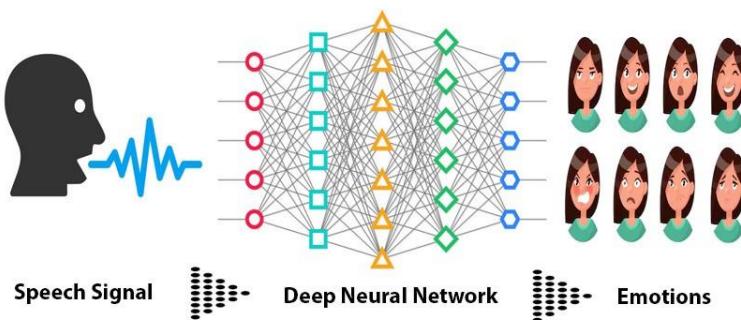




Person counting and classification



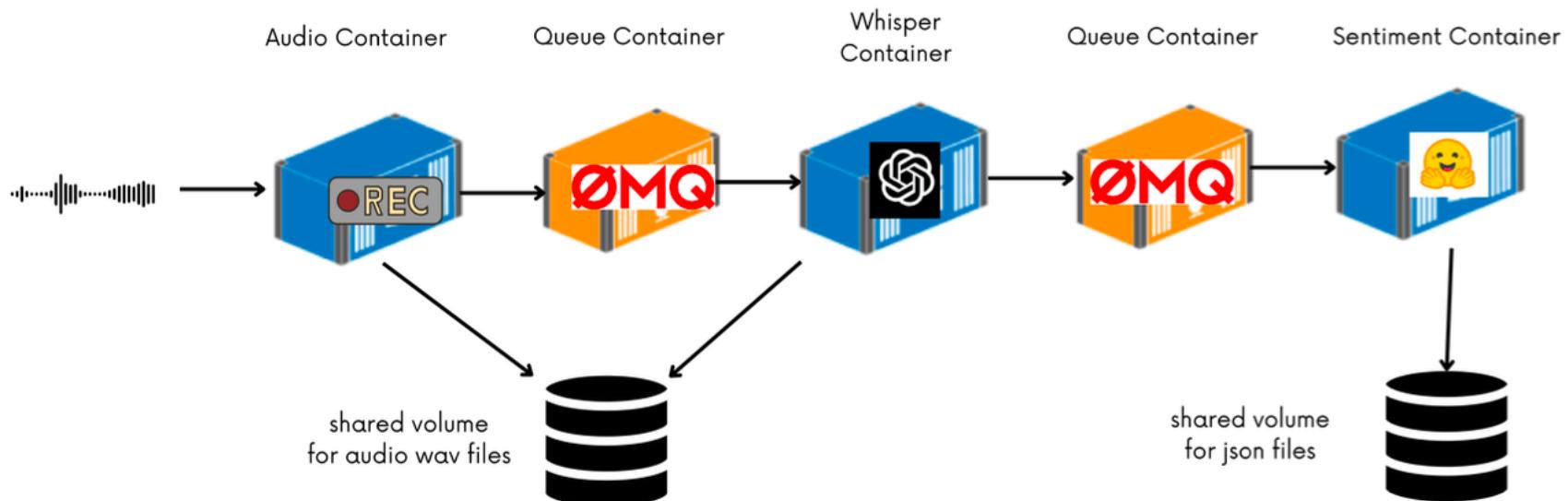
More TinyML: sentiment analysis



Portenta H7

	1c	1d	2c	3c	5c	8c
Bello	90.2% 0.93	93.4% 0.94	95.1% 0.94	91.8% 0.94	94.3% 0.93	90.2% 0.93
Bonito	100% 0.95	95.4% 0.89	96.9% 0.98	98.5% 0.98	92.3% 0.94	98.5% 0.98
Brutto	92.9% 0.95	86.7% 0.91	93.9% 0.96	96.9% 0.97	95.9% 0.97	92.9% 0.94
Carino	93.4% 0.94	86.9% 0.92	93.4% 0.94	96.7% 0.97	95.% 0.92	91.8% 0.93
Feísimo	89.8% 0.91	91.5% 0.84	88.1% 0.92	89.8% 0.93	91.5% 0.93	89.8% 0.91
Feo	96.7% 0.98	96.7% 0.94	93.4% 0.97	96.7% 0.96	95.1% 0.97	91.8% 0.95
Hermoso	98.4% 0.99	95.2% 0.95	100% 0.99	96.8% 0.97	98.4% 0.98	98.4% 0.98
Orrendo	96.7% 0.98	88.3% 0.92	98.3% 0.99	98.3% 0.98	93.3% 0.96	95% 0.97
Orribile	90.3% 0.93	83.9% 0.89	98.4% 0.98	95.2% 0.97	96.8% 0.98	91.9% 0.96
Other	80.4% 0.82	57.6% 0.68	77.2% 0.81	76.1% 0.82	76.1% 0.80	69.9% 0.78
Pesimo	93.3% 0.93	83.3% 0.86%	90% 0.92	90% 0.92	91.7% 0.93	90% 0.92
Precioso	100% 0.99	83.1% 0.90	94.9% 0.97	96.6% 0.97	98.3% 0.98	96.6% 0.97
Stupendo	95.6% 0.95	80.9% 0.87	91.2% 0.95	92.6% 0.95	89.7% 0.94	88.2% 0.94

More «TinyML»: sentiment analysis

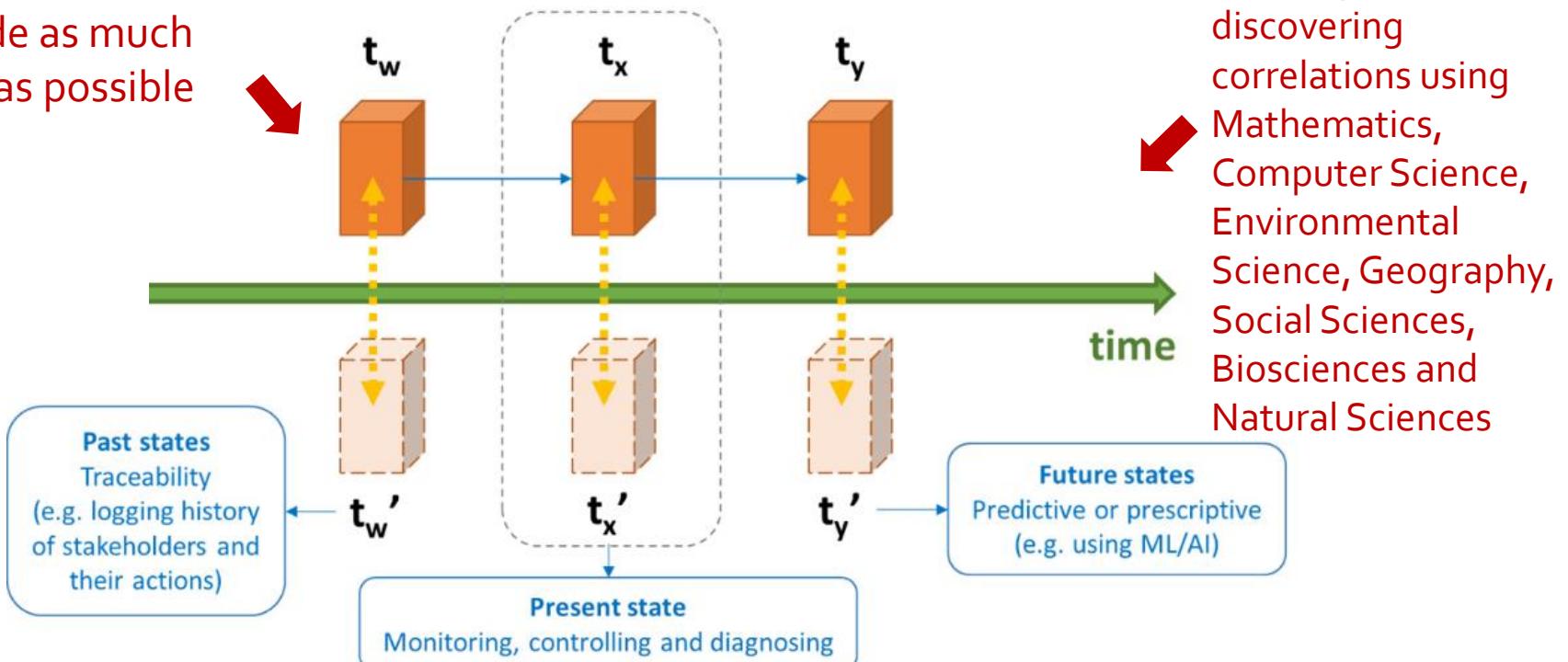


How about platforms? → Digital Twins

A digital twin is a virtual representation or model of a physical object or system. Digital twins are used in various contexts for simulation, analysis, and control. They can help predict issues before they happen, develop new opportunities, and even plan for the future.

Digital twin Dynamic / Lifecycle / Process view

Provide as much input as possible

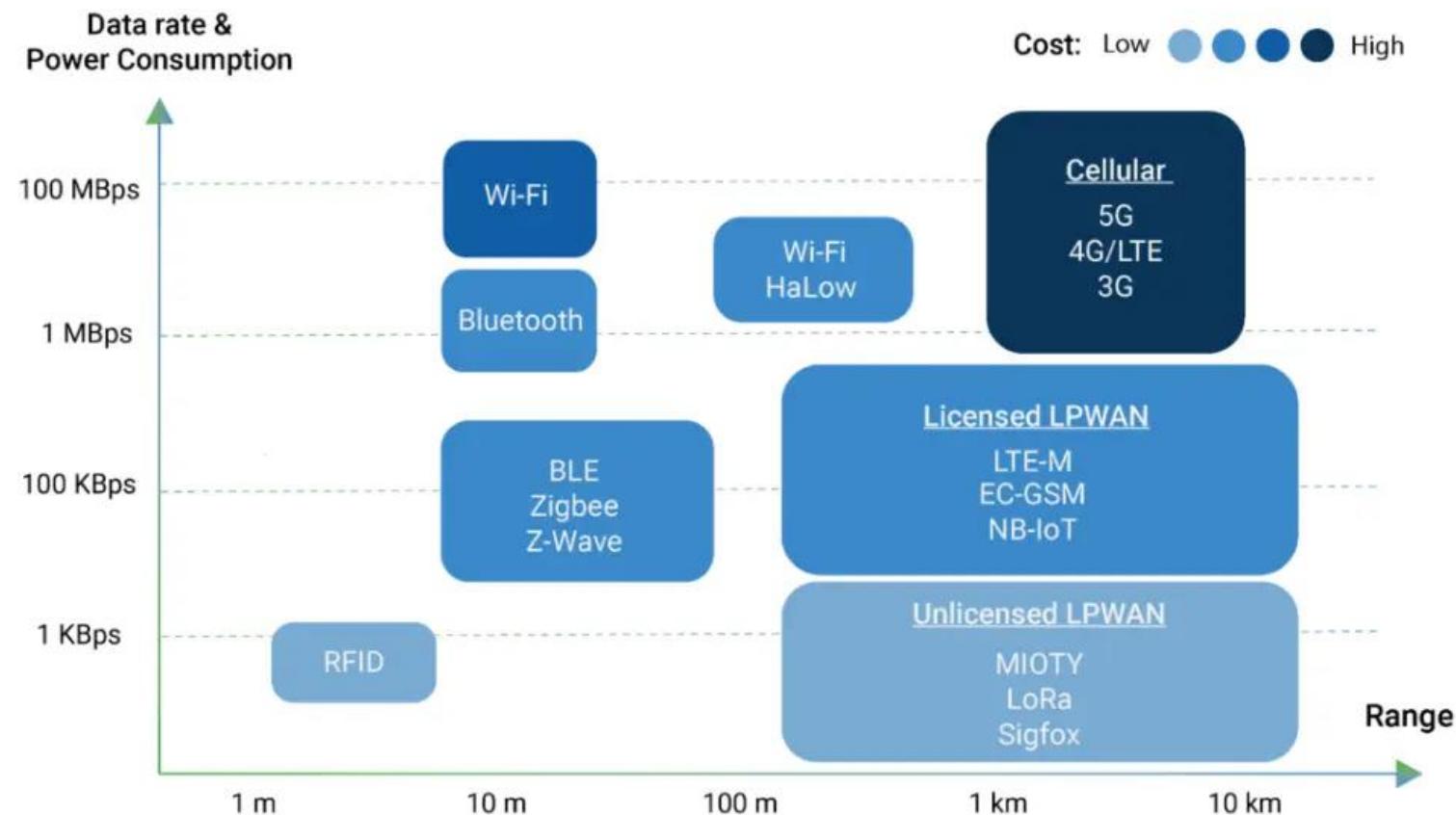


Creating models and
discovering
correlations using
Mathematics,
Computer Science,
Environmental
Science, Geography,
Social Sciences,
Biosciences and
Natural Sciences

J. C. Camposano, K. Smolander and T. Ruippo, "Seven Metaphors to Understand Digital Twins of Built Assets," in IEEE Access, vol. 9, pp. 27167-27181, 2021, doi: 10.1109/ACCESS.2021.3058009.

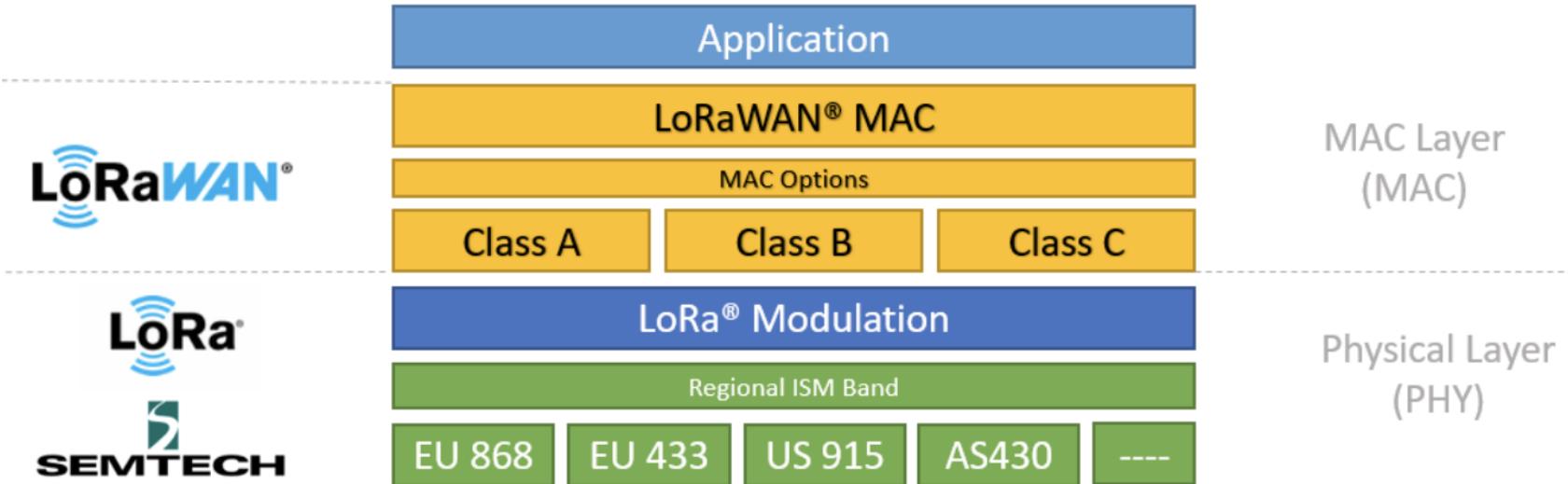
So, what about LoRaWAN?

LPWAN: range vs power



<https://www.mokolora.com/lora-and-wireless-technologies/>

LoRa and LoRaWAN: the big picture



<https://lora-developers.semtech.com/library/tech-papers-and-guides/lora-and-lorawan/> ©

- The LoRa® Alliance is an open, non-profit association of members whose mission is:
 - “..promote and drive the success of the LoRaWAN® protocol as the leading open global standard for secure, carrier-grade IoT LPWAN connectivity...”
 - “To develop and promote LoRaWAN® technology and its ecosystem to deliver massive IoT”
- Specification is free to download:
 - <https://resources.lora-alliance.org/technical-specifications>



LoRaWAN® L2 1.0.4 Specification (TS001-1.0.4)

Authored by the LoRa Alliance Technical Committee

Technical Committee Chair and Vice-Chair:
A.YEGIN (Actility), O.SELLER (Semtech)

Editors:
T.KRAMP (Semtech), O.SELLER (Semtech)

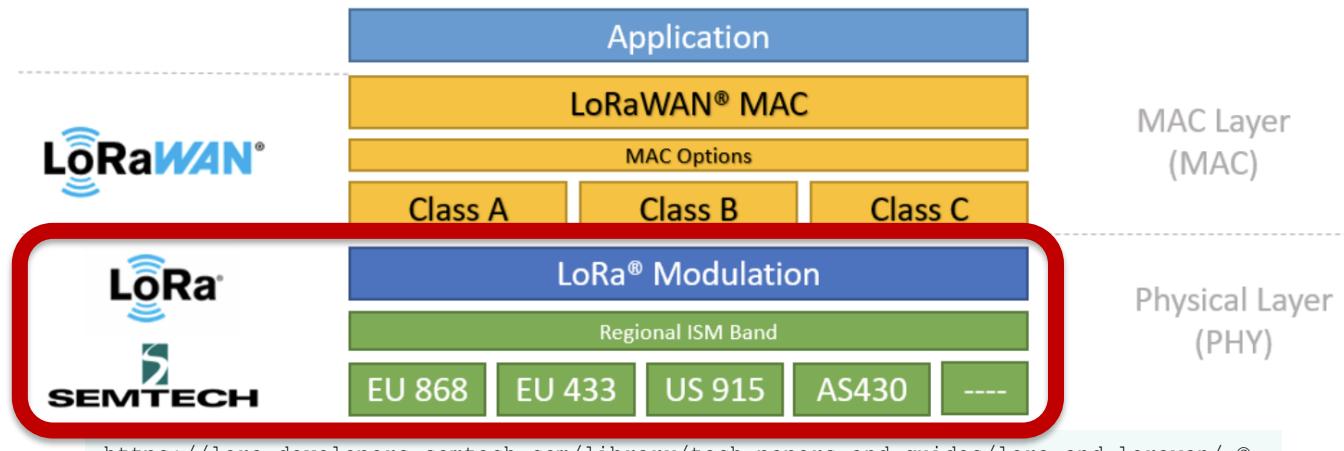
Contributors (in alphabetical order):
A.BERTOLAUD (Gemalto), I.CALABRESE (A2A Smart City), J.CATALANO (Kerlink), J.DELCLEF (ST Microelectronics), V.DELPORT (Microchip Technology), P.DUFFY (Cisco), F.DYDUCH (Bouygues Telecom), T.EIRICH (Semtech), L.FERREIRA (Orange), Y.GAUDIN (Kerlink), S.GHAROUT (Orange), O.HERSENT (Actility), A.KASTTET (Birdz), D.KJENDAL (Senet), V.KLEBAN (Everynet), J.KNAPP (Semtech), T.KRAMP (Semtech), M.KUYPER (Semtech), P.KWOK (Objenious), M.LEGOURIEREC (Sagemcom), C.LEVASSEUR (Bouygues Telecom), M.LUIS (Semtech), M.PAULIAC (Gemalto), P.PIETRI (Orbiwise), O.SELLER (Semtech), D.SMITH (MultiTech), N.SORNIN (Semtech), R.SOSS (Actility), J.STOKKING (The Things Network), T.TASHIRO (M2B Communications), D.THOLL (Tektelic), P.THOMSEN (Orbiwise), A.YEGIN (Actility)

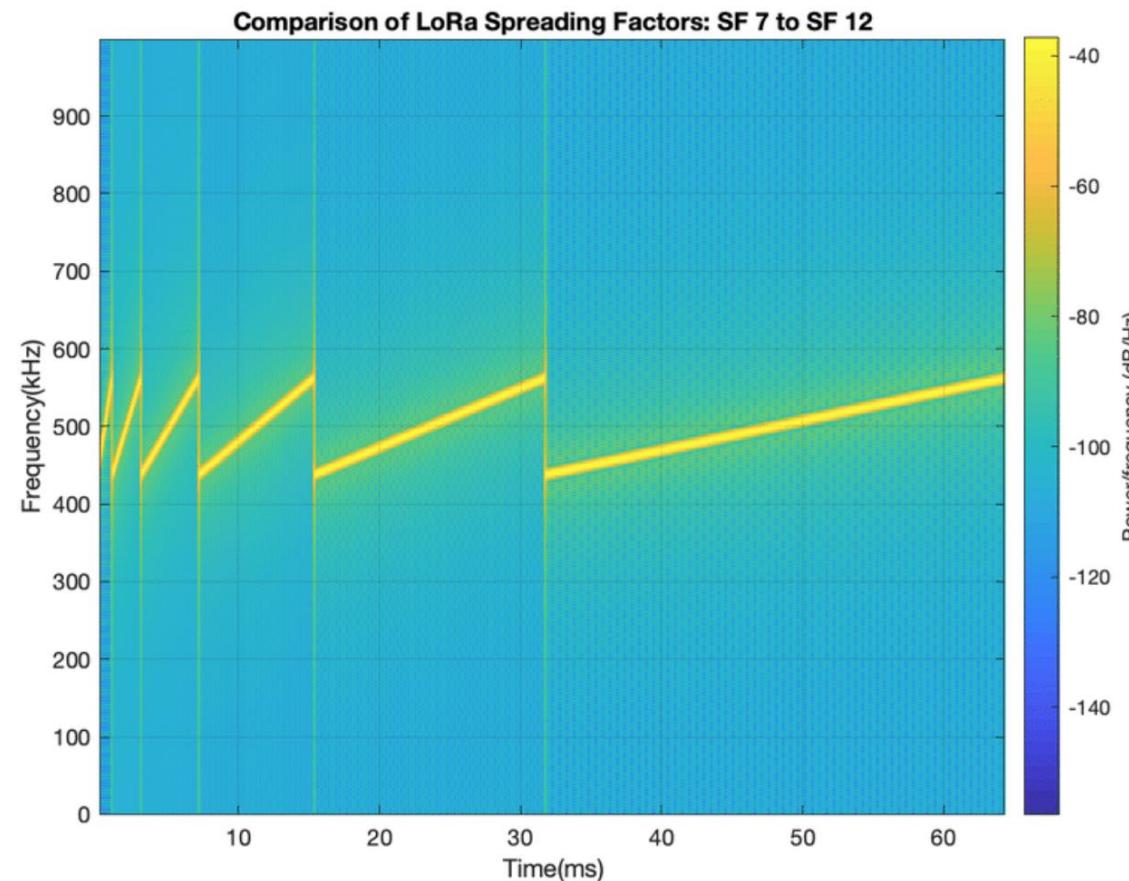
Version: 1.0.4

Date: October 2020

Status: Released

- LoRa® is the physical layer or the wireless modulation utilized to create the long range communication link.
- LoRa® is based on chirp spread spectrum modulation, which maintains the same low power characteristics as FSK modulation but significantly increases the communication range.
- Chirp spread spectrum has been used in military and space communication for decades due to the long communication distances that can be achieved and robustness to interference, but LoRa® is the first low cost implementation for commercial usage.





<https://www.youtube.com/watch?v=dxYY097QNs0>

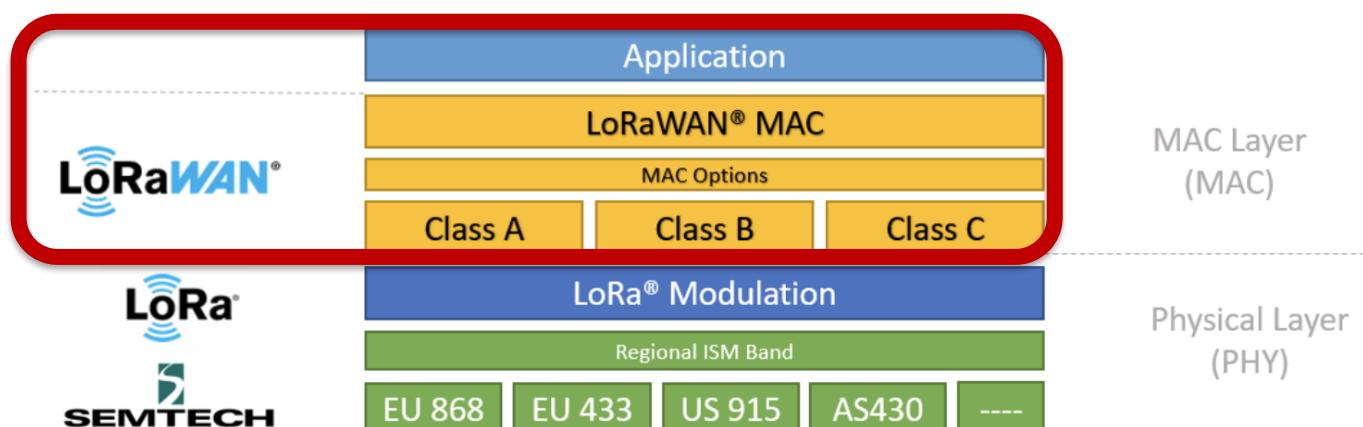
Kim, Dong-Hoon & Lee, Eun-Kyu & Kim, Jibum. (2019). Experiencing LoRa Network Establishment on a Smart Energy Campus Testbed. Sustainability. 11. 1917. 10.3390/su11071917.

Spreading Factors (SF) versus data rate and time-on-air

Spreading factor (at 125 kHz)	Bitrate	Range (indicative value, depending on propagation conditions)	Time on Air (ms) For 10 Bytes app payload
SF7	5470 bps	2 km	56 ms
SF8	3125 bps	4 km	100 ms
SF9	1760 bps	6 km	200 ms
SF10	980 bps	8 km	370 ms
SF11	440 bps	11 km	740 ms
SF12	290 bps	14 km	1400 ms

(with coding rate 4/5 ; bandwidth 125Khz ; Packet Error Rate (PER): 1%)

- LoRaWAN defines the communication protocol and system architecture for the network while the LoRa® physical layer enables the long-range communication link.
- The protocol and network architecture have the most influence in determining the battery lifetime of a node, the network capacity, the quality of service, the security, and the variety of applications served by the network.



<https://lora-developers.semtech.com/library/tech-papers-and-guides/lora-and-lorawan/> ©

Can I use LoRa alone?

Yes! For example → AIoRa

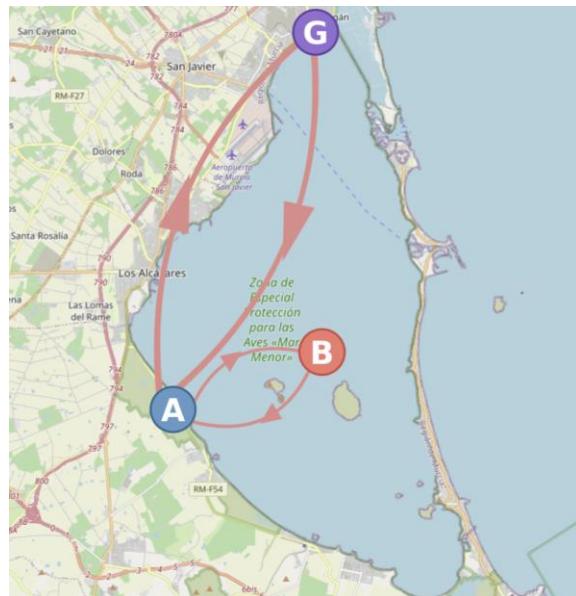
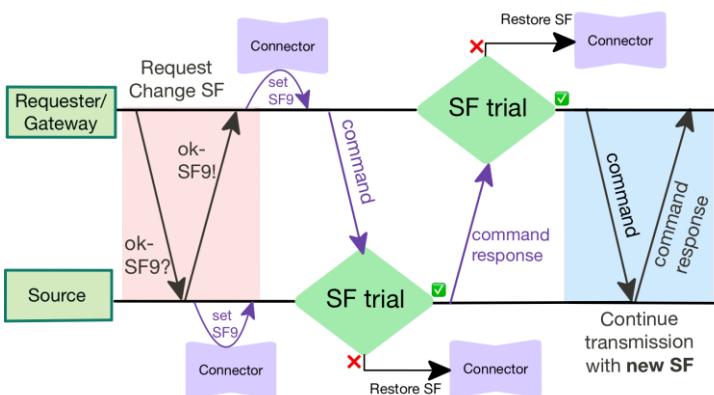
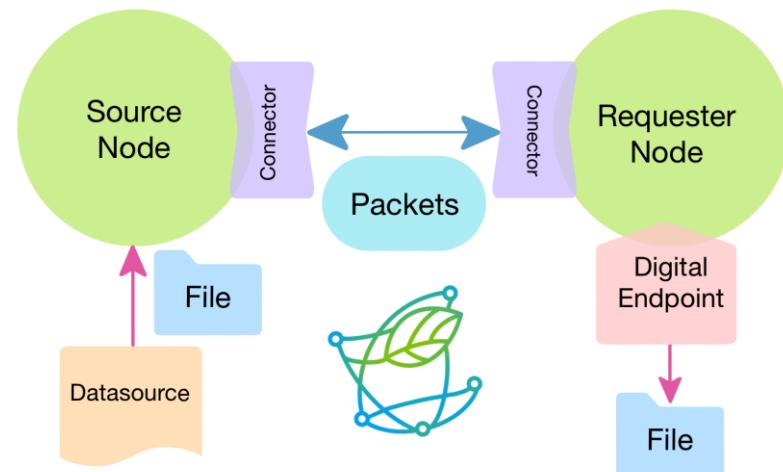
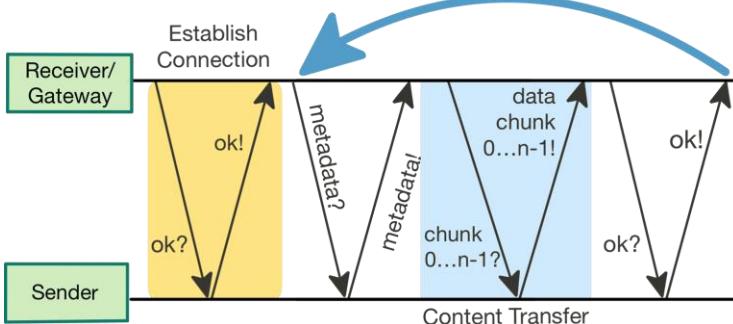


AIoRa: modular, mesh, multi-device LoRa
Content Transfer Protocol

<https://github.com/SMARTLAGOON/AIoRa>

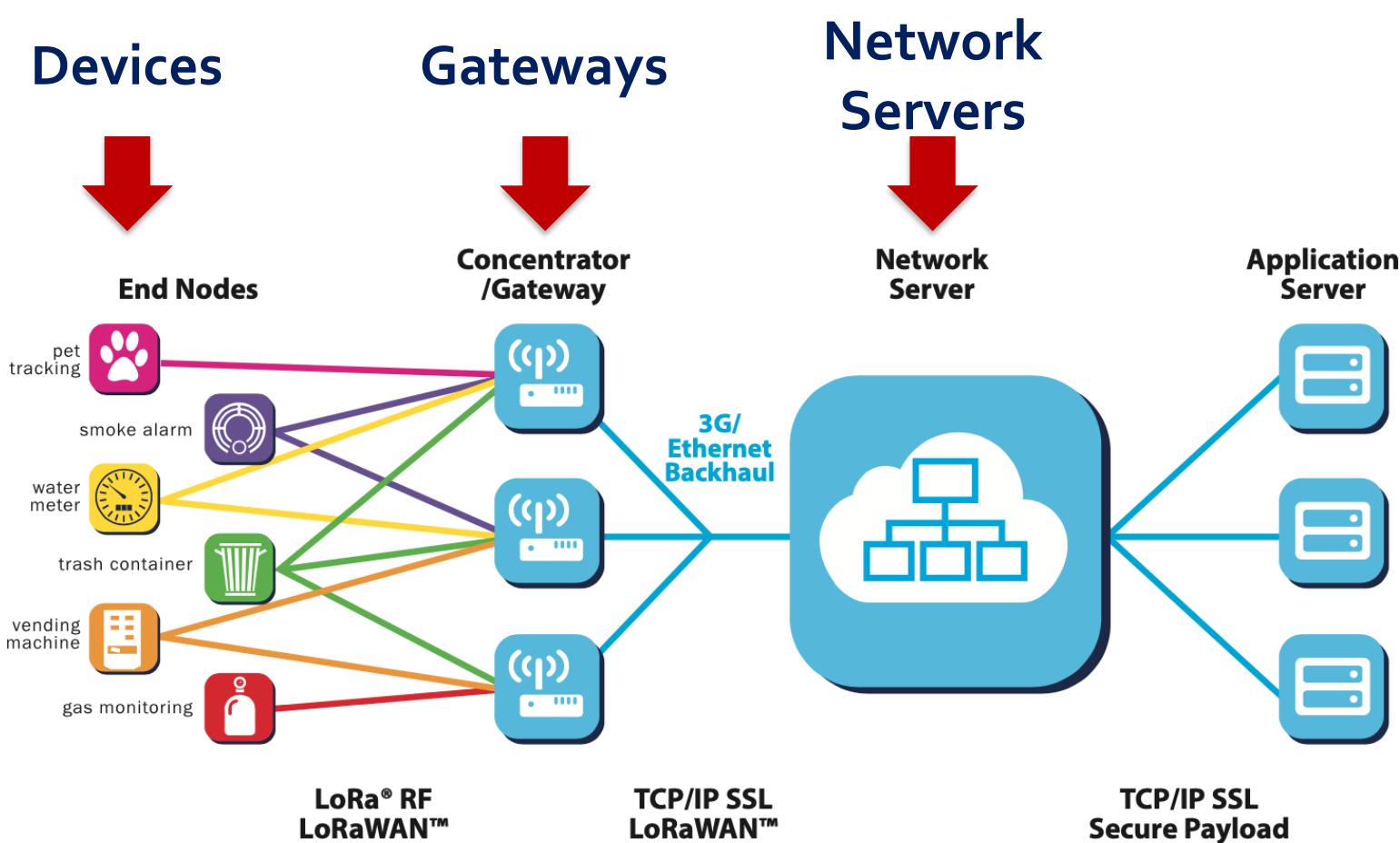


AILoRa: modular, mesh, multi-device...



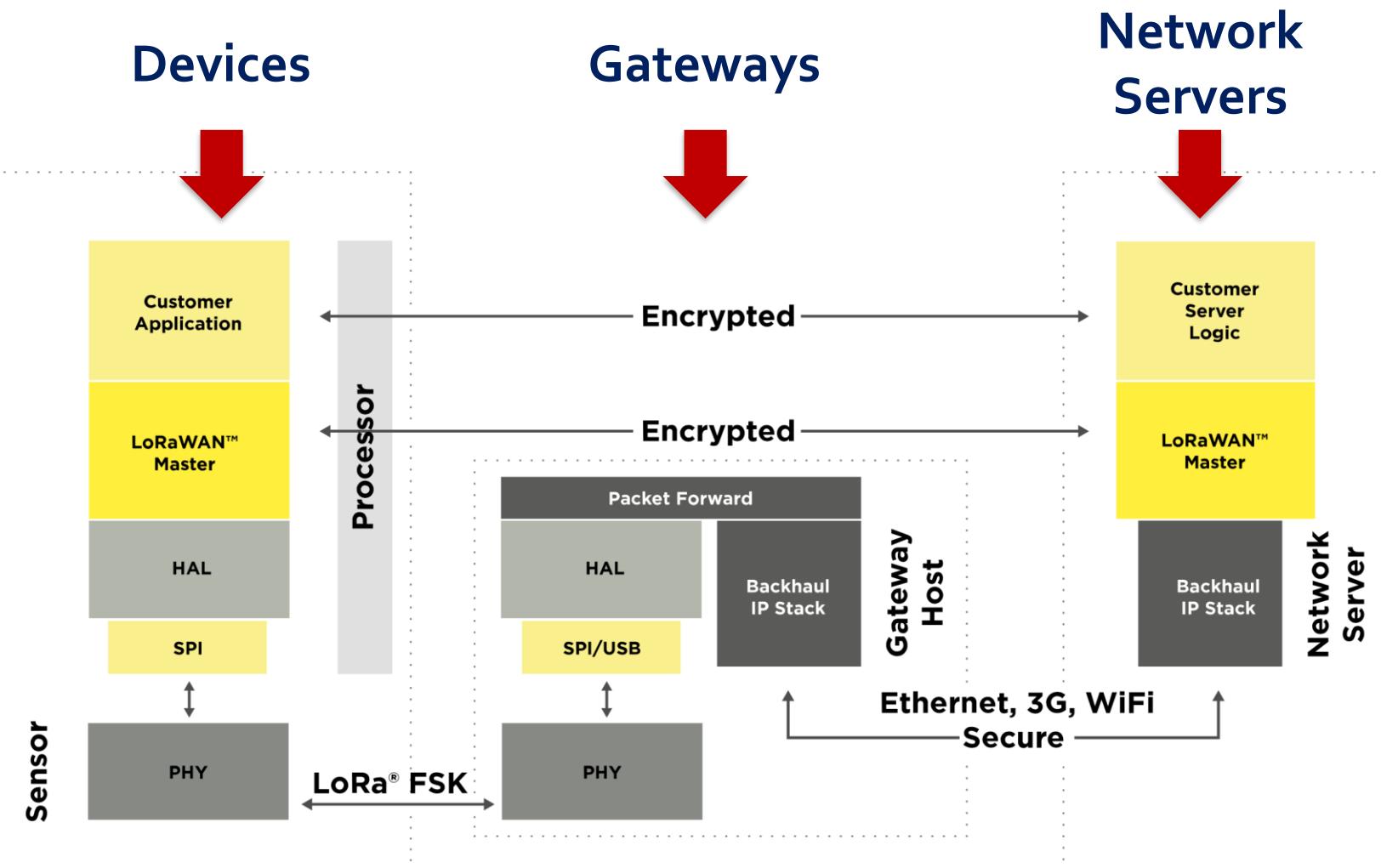
Let's continue with LoRaWAN

LoRaWAN network architecture



LoRa Alliance ©

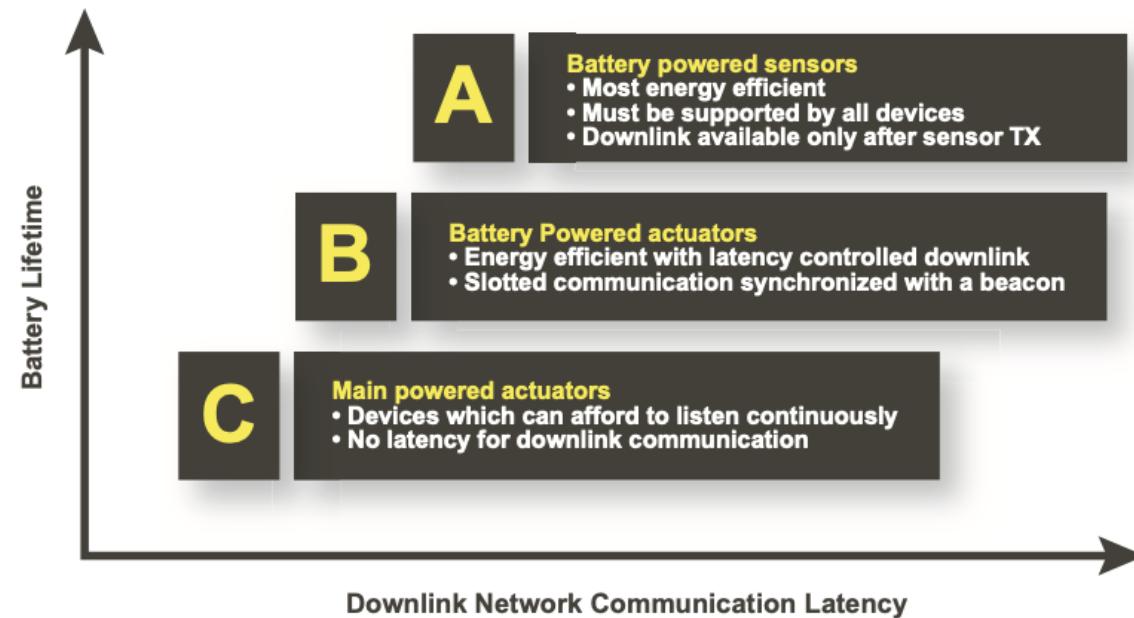
LoRaWAN data flow



HAL: Hardware Abstraction Layer

Three types of devices

- LoRaWAN has three different classes of end-point devices to address the different needs reflected in the wide range of applications:



LoRa® Alliance Technical Marketing Workgroup

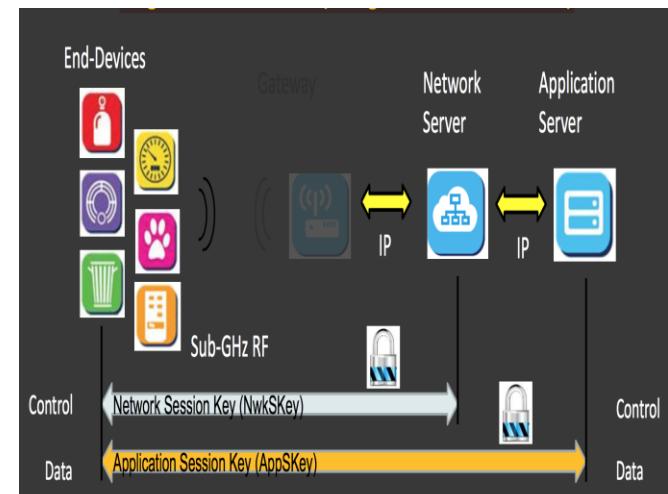
Edge ML University Program 2023:

Workshop on Widening Access to TinyML Network by Establishing Best Practices in Education



UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA

- LoRaWAN devices have a 64-bits unique identifier (DevEUI) that is assigned to the device by the chip manufacturer.
- All communication is done with a dynamic 32 bit device address (DevAddr) of which 7 bits are fixed (Network Server), leaving 25 bits that can be assigned to individual devices with a procedure called **Activation**.
 - Over-the-Air Activation (OTAA)
 - Devices perform a join-procedure with the network, during which a dynamic DevAddr is assigned and security keys are negotiated with the device
 - Activation By Personalization (ABP)
 - Hardcode the DevAddr as well as the security keys in the device.



- The **duty cycle of radio devices is often regulated by government**. In Europe, duty cycles are regulated by section 7.2.3 of the ETSI EN300.220 standard.

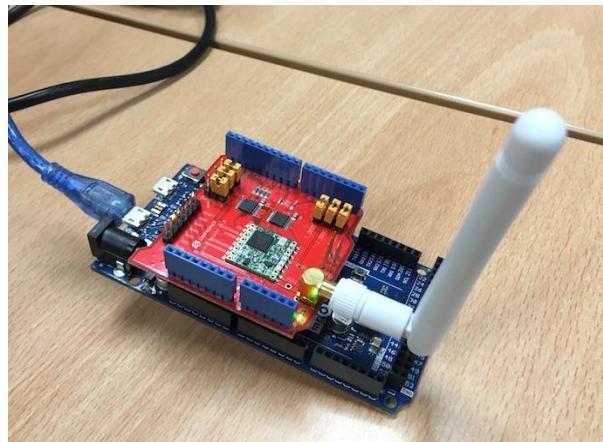
Duty Cycle indicates the fraction of time a resource is busy.

When a single device transmits on a channel for 2 time units every 10 time units, this device has a duty cycle of 20%.

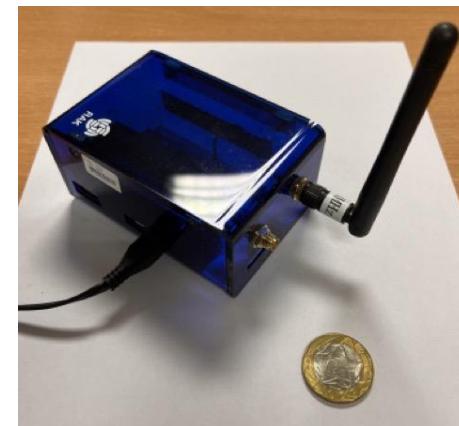


- On “community network” like TTN there typically is a **Fair Access Policy** that limits the uplink airtime to 30 seconds per day (24 hours) per node and the downlink messages to 10 messages per day (24 hours) per node.

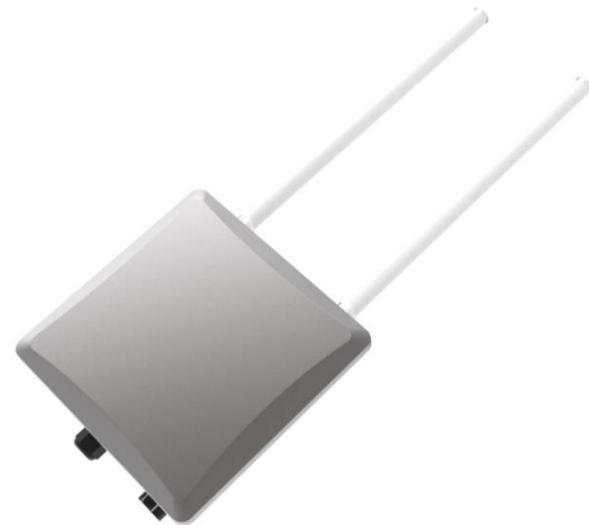
Some devices



Gateways: examples



Gateways: examples



LoRaWAN Network Servers



LORIOT AG is a global IoT company, founded in Switzerland in 2015. Our core product today is software for scalable, distributed, resilient operation of LoRaWAN® networks and end-to-end applications, which we offer under a variety of business models.

<https://www.loriot.io/>



Chirpstack v4 is out and brings many improvements! [Read the announcement on the forum.](#)

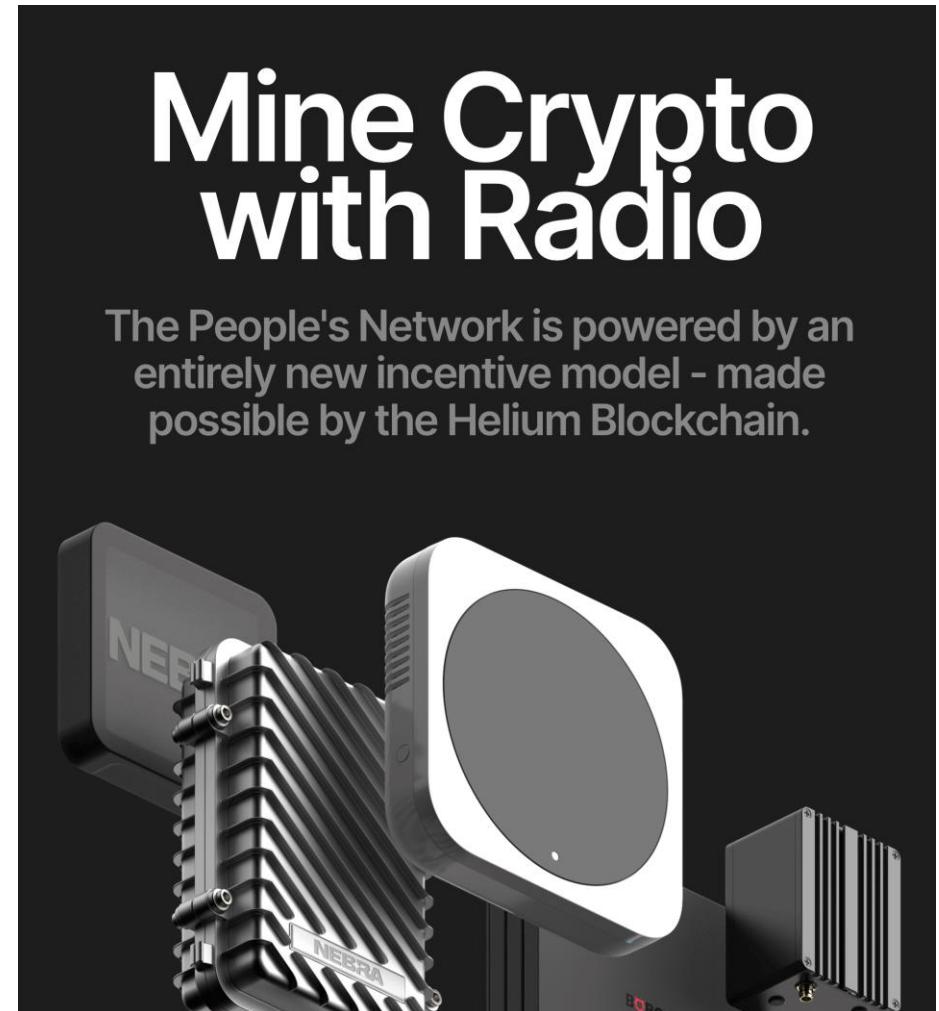
ChirpStack, open-source LoRaWAN® Network Server

ChirpStack is an open-source LoRaWAN Network Server which can be used to setup LoRaWAN networks. ChirpStack provides a web-interface for the management of gateways, devices and tenants as well as to setup data integrations with the major cloud providers, databases and services commonly used for handling device data. ChirpStack provides a gRPC based API that can be used to integrate or extend ChirpStack.

[Documentation](#)

A screenshot of the ChirpStack web interface. The left sidebar shows a navigation tree with "ChirpStack" at the top, followed by "Network Server" (with "Dashboard", "Tenants", "Users", "API keys", "Device-profile templates"), "Tenant" (with "Dashboard", "Users", "API keys", "Device profiles", "Gateways"), and "Applications" (which is currently selected). The main content area is titled "Applications" and lists three entries: "Air quality" (Description: Air quality application), "Parking sensor" (Description: Parking sensor application), and "Weather station" (Description: Weather station application). There is a "Search..." input field, a "Add application" button, and a "10 / page" dropdown at the bottom right of the table.

Helium's network is referred to as The People's Network. It is powered by an entirely new incentive model – made possible by the Helium Blockchain. Installing a LoRa Hotspot means you are rewarded in HNT crypto coins as soon as you have "Proof-of-Coverage".



The Things Network (TTN) is a global collaborative Internet of Things ecosystem that creates networks, devices and solutions using LoRaWAN®.

Start building Learn more

27.2M
Messages today

151
Countries

970
Certified developers

154.6K
Members

21.3K
Gateways

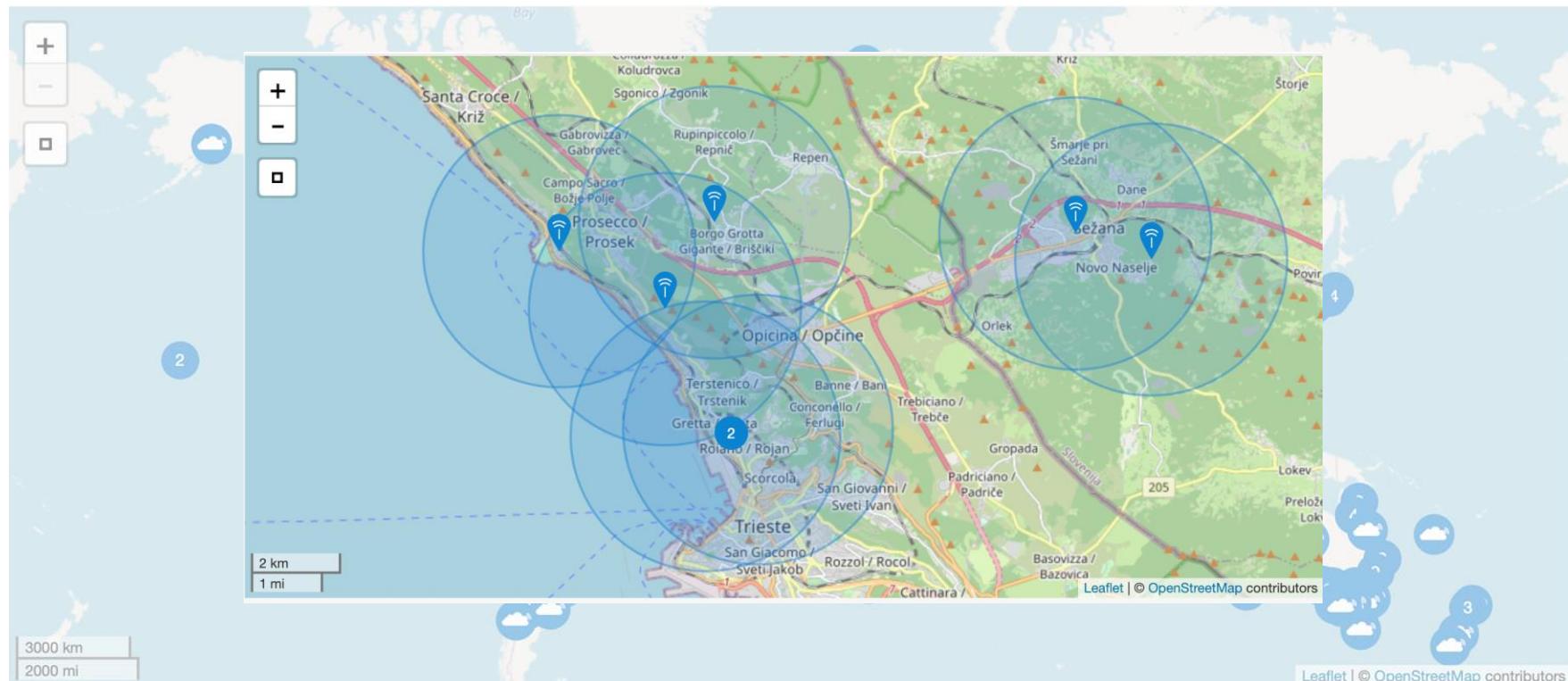
The Things Network (TTN)

Currently (June 2023) approx. 21.200 gateways active worldwide



The Things Network (TTN)

Currently (June 2023) approx. 21.200 gateways active worldwide



<https://eu1.cloud.thethings.network/console/>

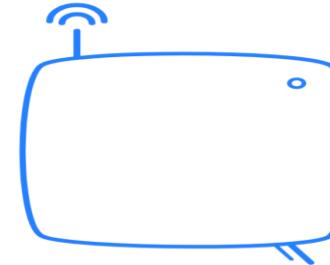
Welcome back, Pietro Manzoni! 

Walk right through to your applications and/or gateways.

Need help? Have a look at our [Documentation](#) or [Get support](#).



Go to applications

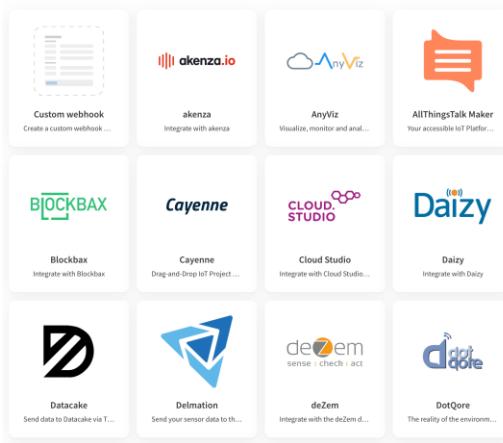


Go to gateways



«Integrations»

Choose webhook template



↑ Integrations



MQTT



Webhooks



Storage Integration

Storage Integration

The Storage Integration allows storing received upstream messages in a persistent database, and retrieving them at a later time. This integration is implemented as an [Application Package](#) and can be enabled per application or per end device.

Further resources

[Storage Integration](#) | [Application Packages](#)

Status

- The Storage Integration is currently activated

You can use the endpoints below to retrieve data from the storage. For detailed API description, see

[Storage Integration API](#).

GET
<https://eu1.cloud.thethings.network/api/v3/as/applications/lopy52ttn/packages/storage/{type}>

GET
https://eu1.cloud.thethings.network/api/v3/as/applications/lopy52ttn/devices/{device_id}/packages/storage/{type}

[Deactivate Storage Integration](#)



AWS IoT



Azure IoT



LoRa Cloud



<https://aws.amazon.com/es/iot/>

<https://azure.microsoft.com/en-us/solutions/iot/>

[https://www.loracloud.com/documentation/modem_services?url#](https://www.loracloud.com/documentation/modem_services?url=)

MQTT Demo with...



<http://mqtt-explorer.com>



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<https://bit.ly/lora2cloud>