From LoRa to the Cloud: Bridging Physical and Digital Worlds

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About the Talk

- 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 ➔

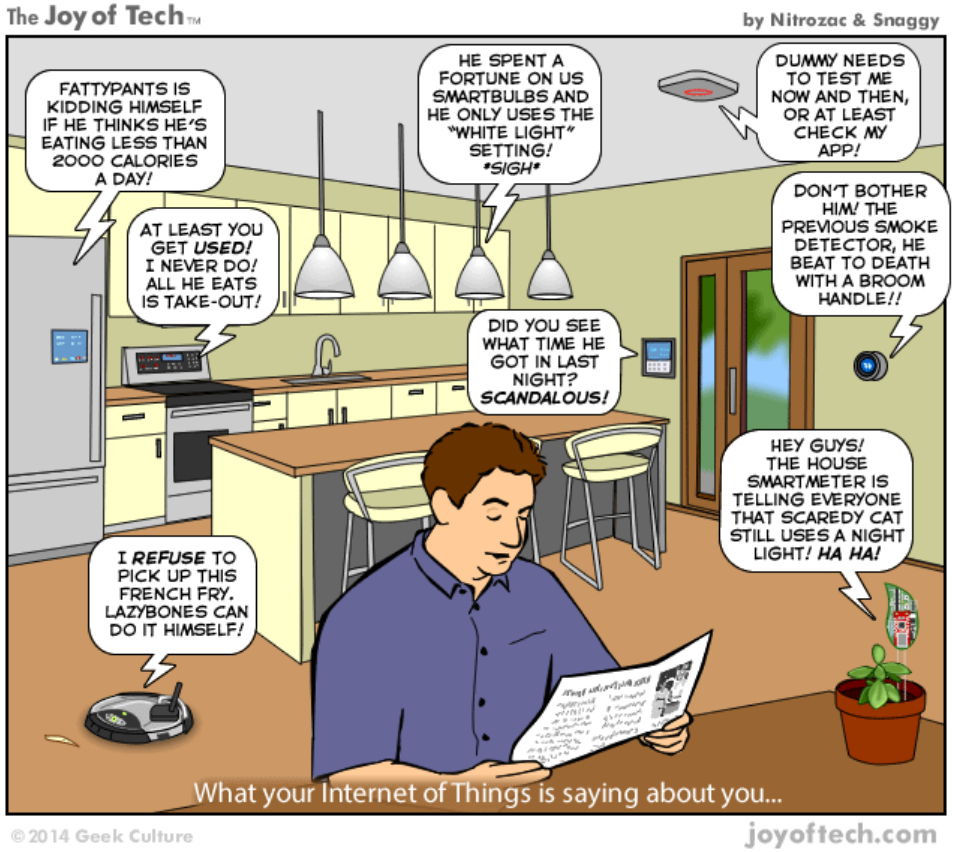
https://bit.ly/lora2cloud

A brief introduction to IoT

Internet of Things (IoT)

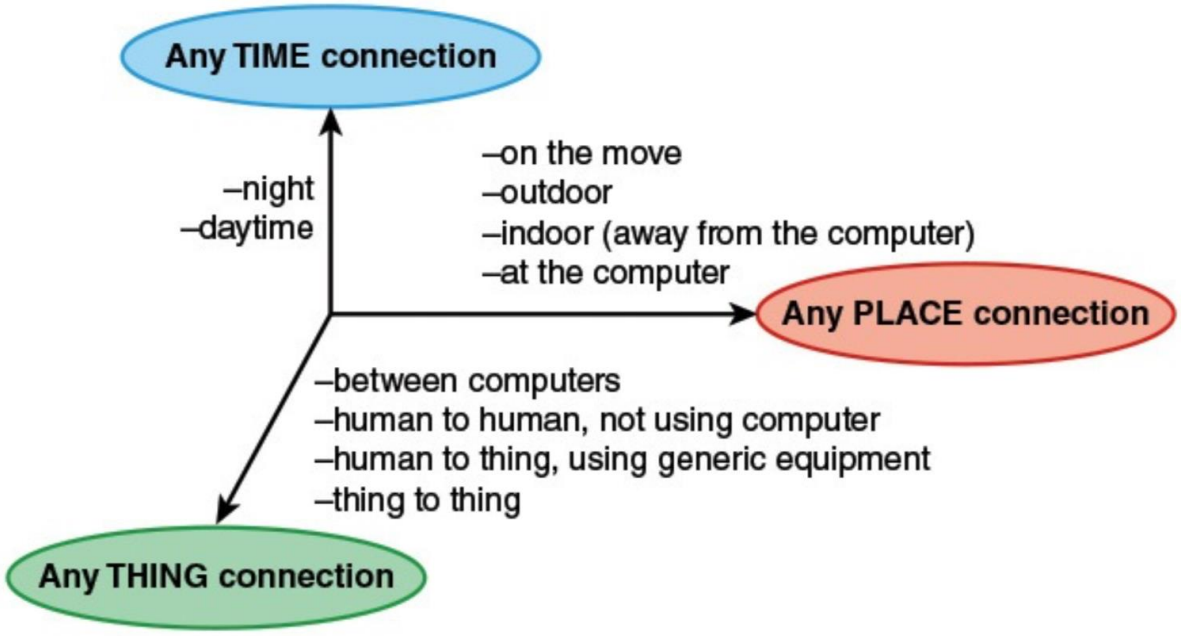
A quick and "physical" definition (https://iot.IEEE.org/definition.html):

"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)."

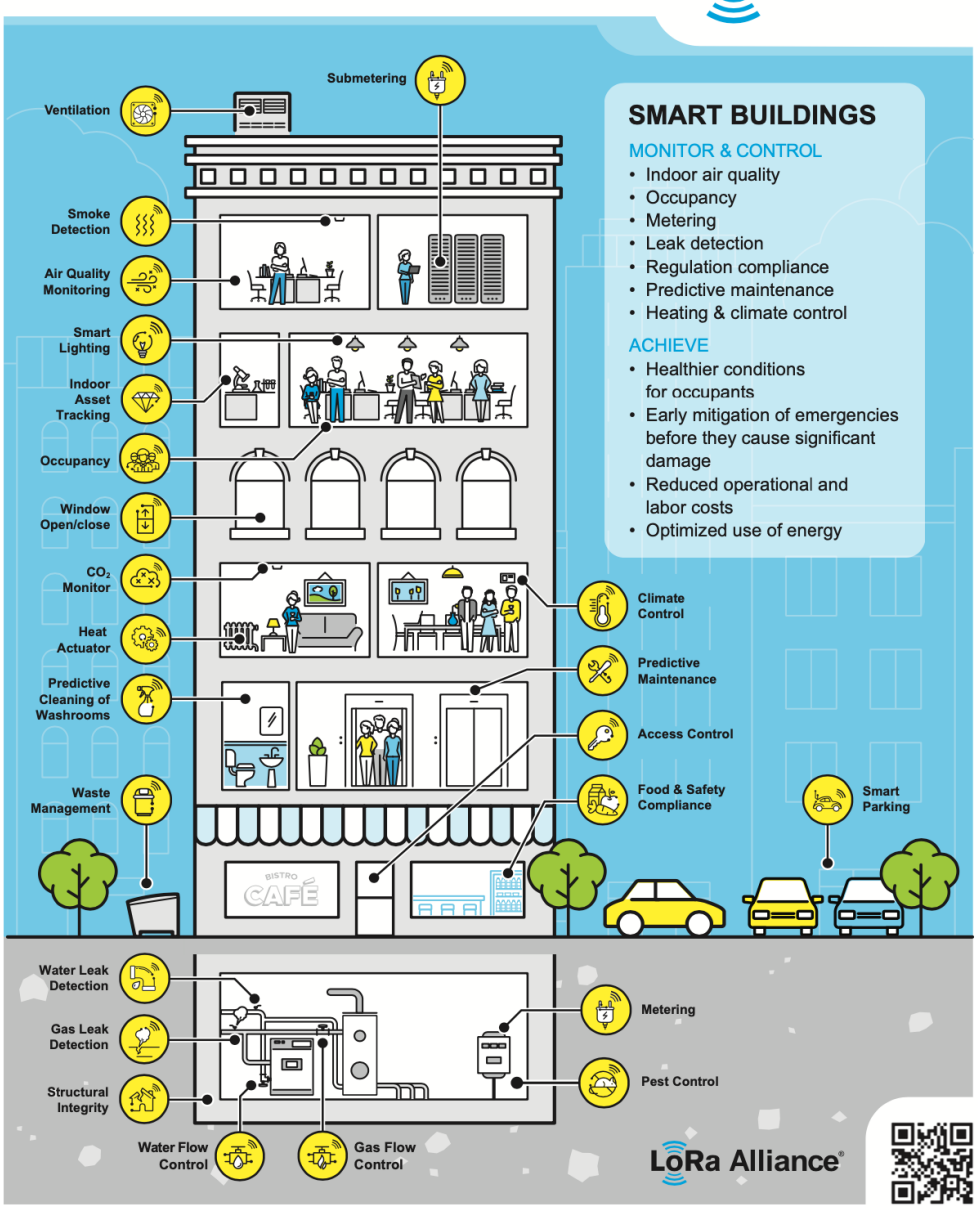


Source: Recommendation ITU-T Y.2060

The IoT landscape

https://www.nffinc.com/

BUILDING INTELLIGENCE WITH LoRaWAN®

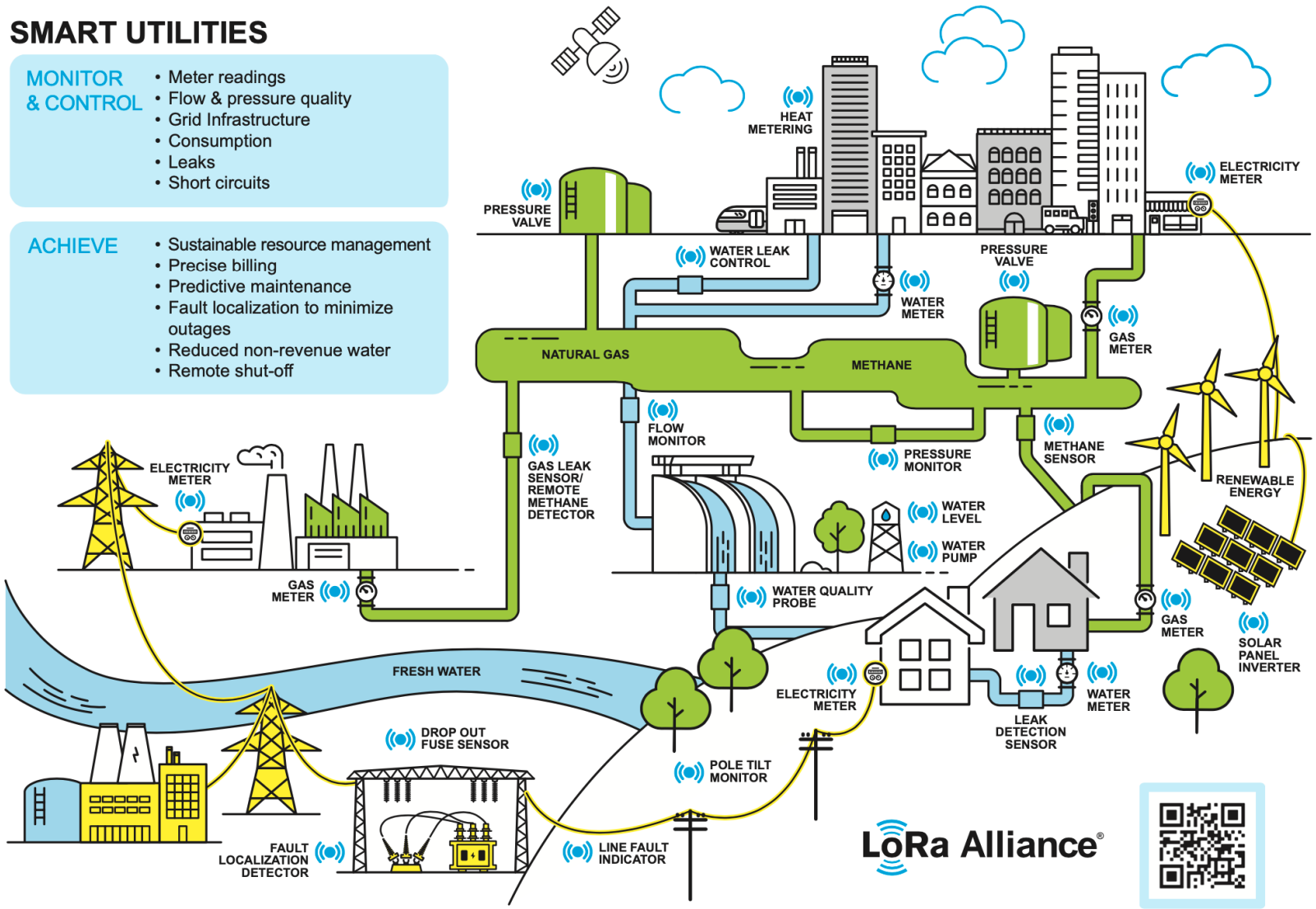


LoRaWAN® FOR PROFITABLE AND EFFICIENT UTILITIES

SMART UTILITIES

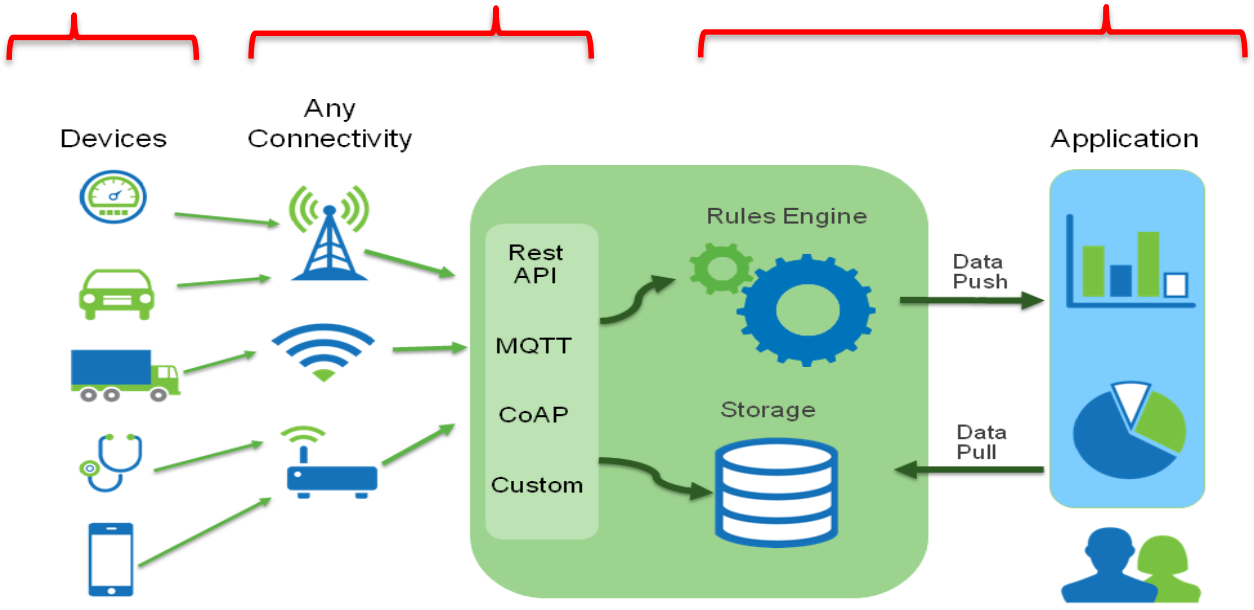
MONITOR & CONTROL
- Meter readings
- Flow & pressure quality
- Grid Infrastructure
- Consumption
- Leaks
- Short circuits

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



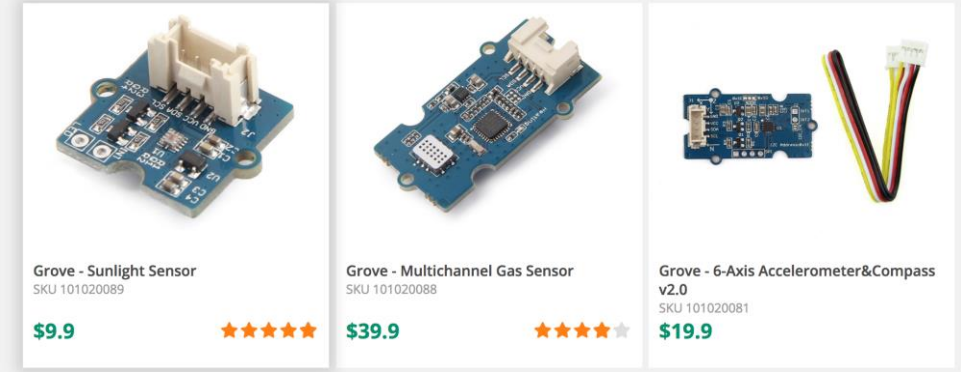
IoT simplified model

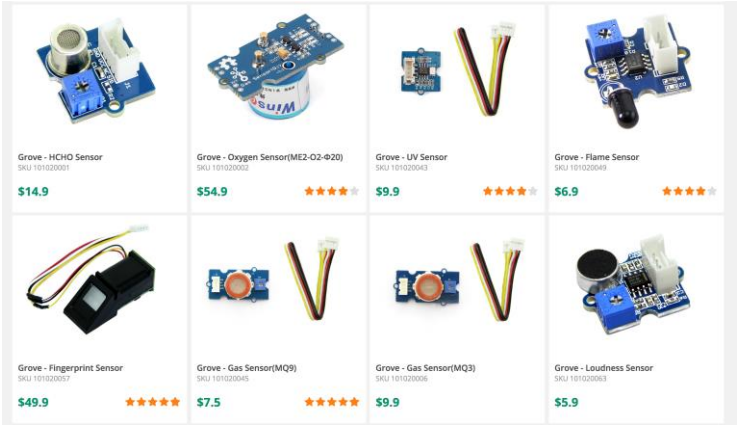
- Devices ("things")
  - These could be sensors, actuators, robots, cars, whatever can be connected.
  - A lot of inheritance from the world of "sensors networks"
- Connectivity
  - To connect things reliably to Internet.
  - Wireless connectivity is central to this task
- Platform
  - the collected data needs to be stored and processed somewhere.
  - Typically cloud-based infrastructures… but the edge is growing



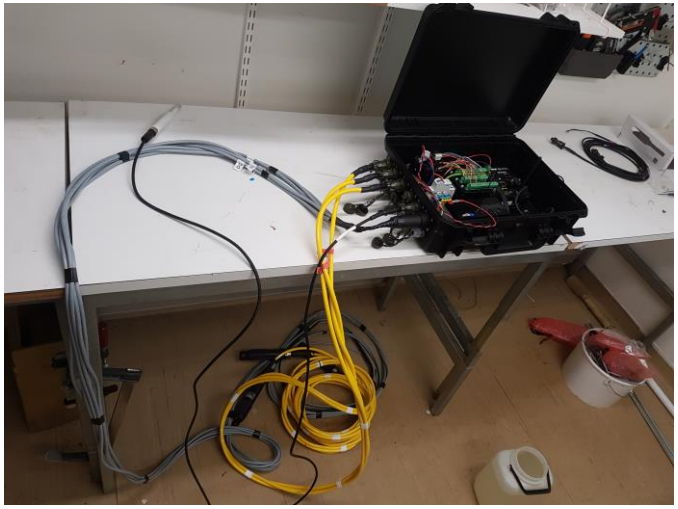
Classic things

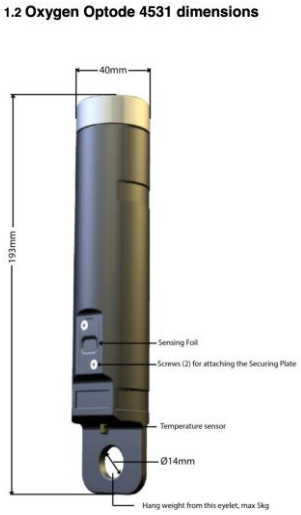
cheap...





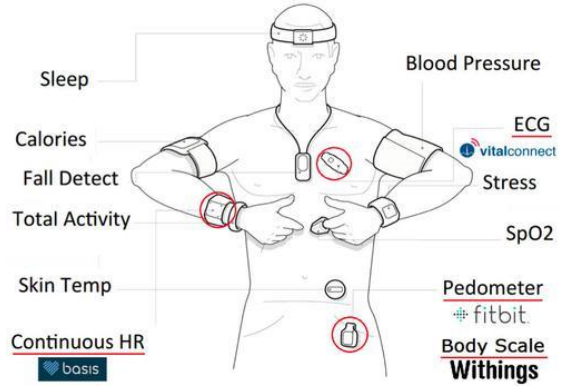
expensive...





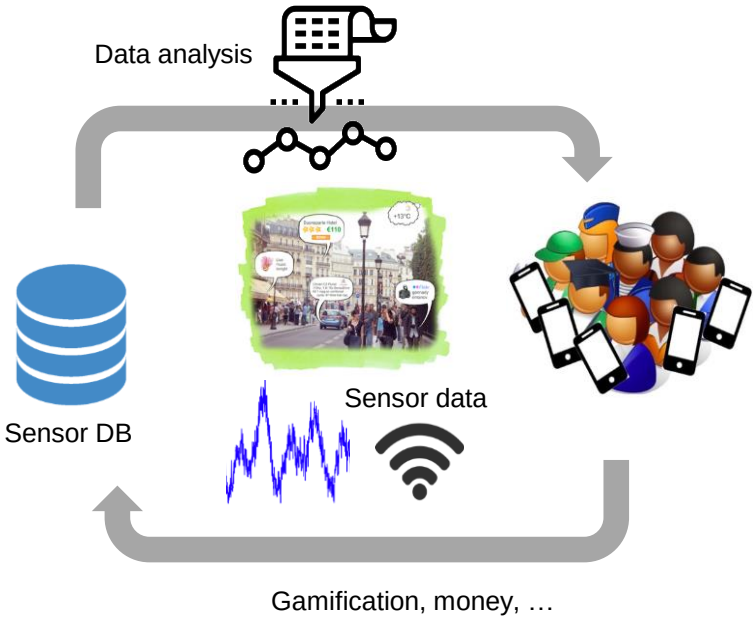
Parameter	Output	Default range[2)]	Calibrated range	Accuracy	Resolution
Oxygen Concentration	0 - 5V	0 to 800µM	0 to 500µM	<8µM or 5% whichever is greater	< 1µM
	4 - 20mA	0 to 800µM	0 to 500µM	<9µM or 5.2% whichever is greater	< 1µM
Oxygen Saturation	0 - 5V	0 – 200%	0 - 120%	<5 %	<0.4%
	4 - 20mA	0 – 200%	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)

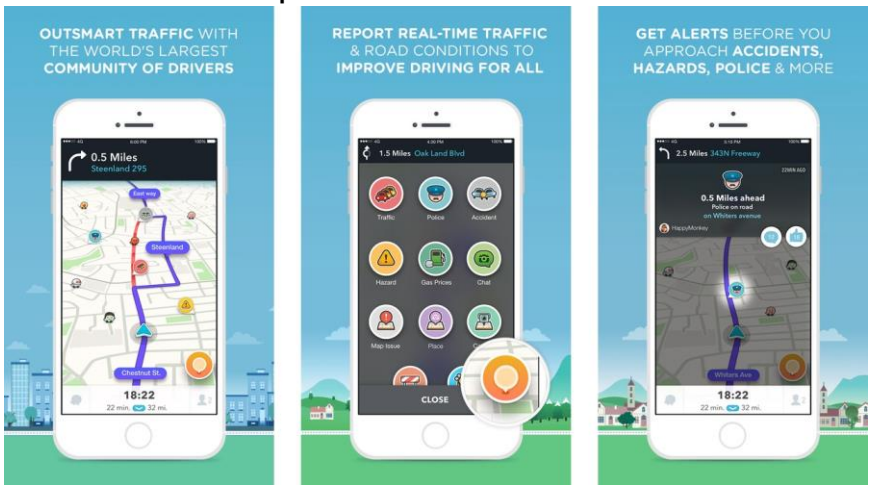


Beyond conventional things

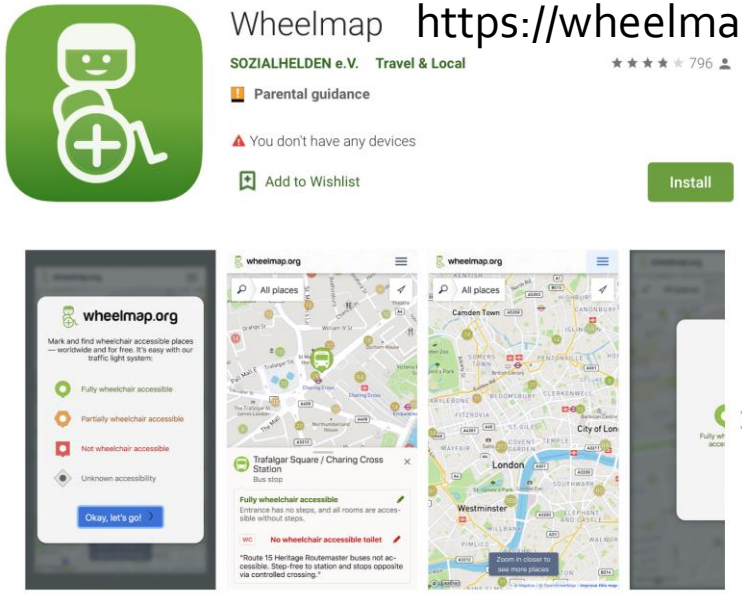
- Humans as a sensor
  - Crowdsensing
  - social sensors: E.g., tweeting real-world data and/or events



https://www.waze.com



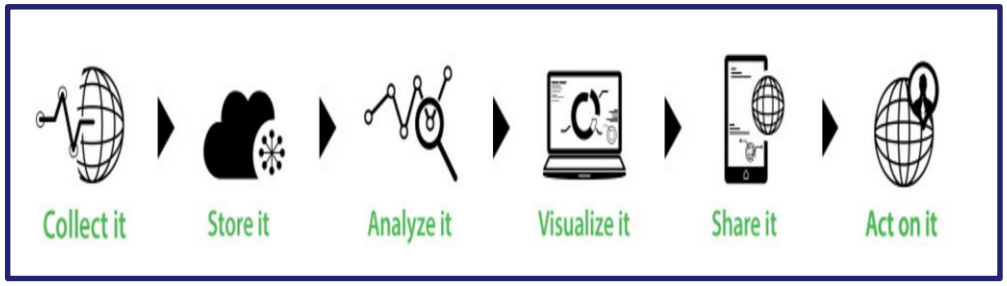
Wheelmap https://wheelmap.org/



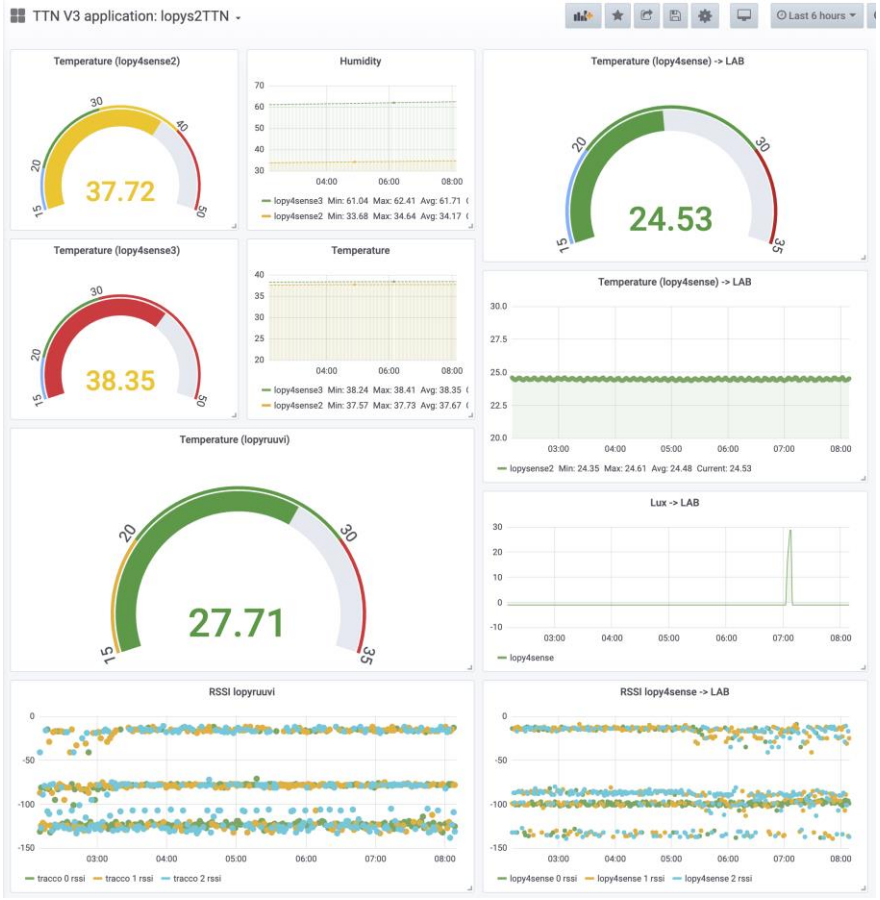
Platforms

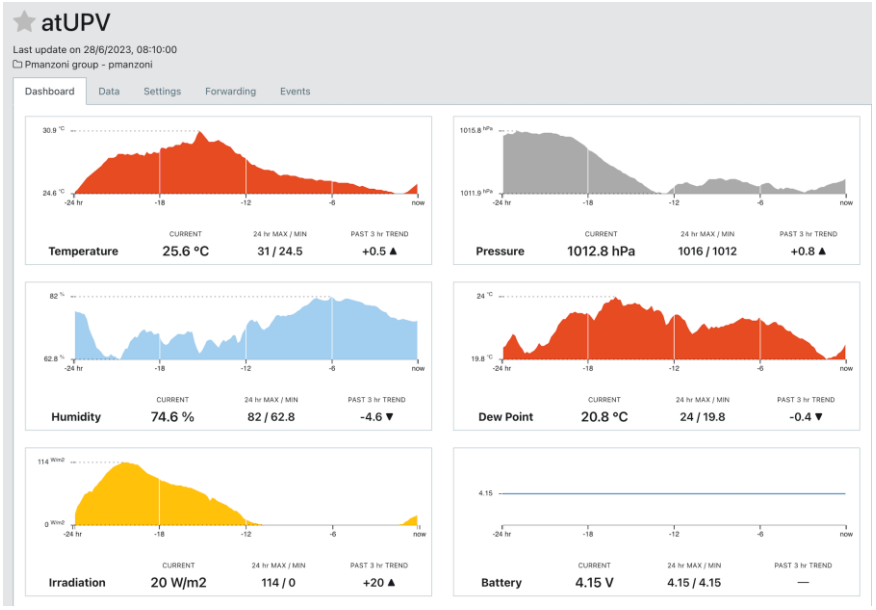
- Microsoft Azure IoT Hub
  - https://azure.microsoft.com/es-es/products/iot-hub
- Amazon AWS IoT
  - https://aws.amazon.com/es/iot/
- ~~Google Cloud IoT~~
  - Maybe
    https://firebase.google.com/
- And Oracle, Cisco, IBM…

- 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

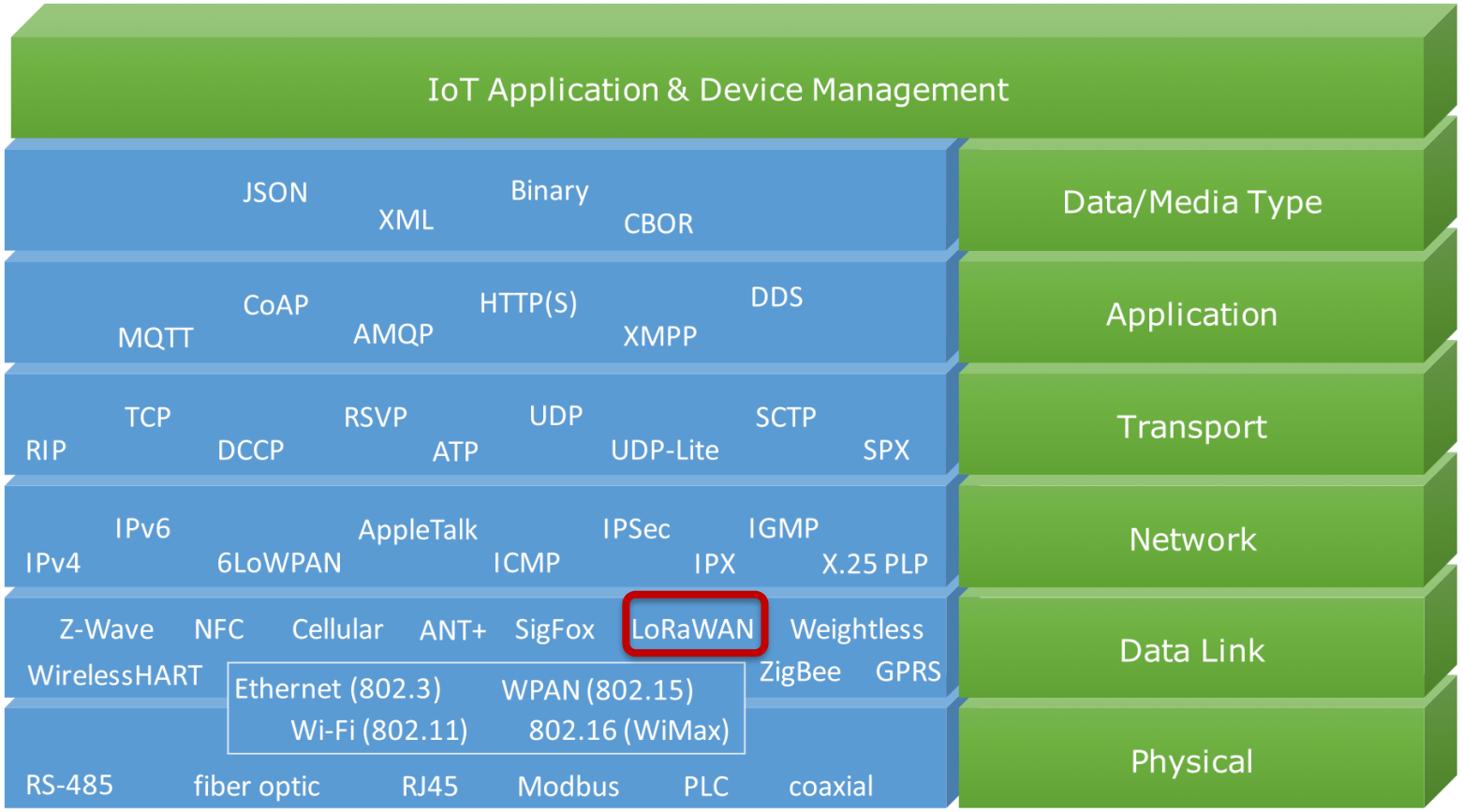


Platforms: data visualization & analysis



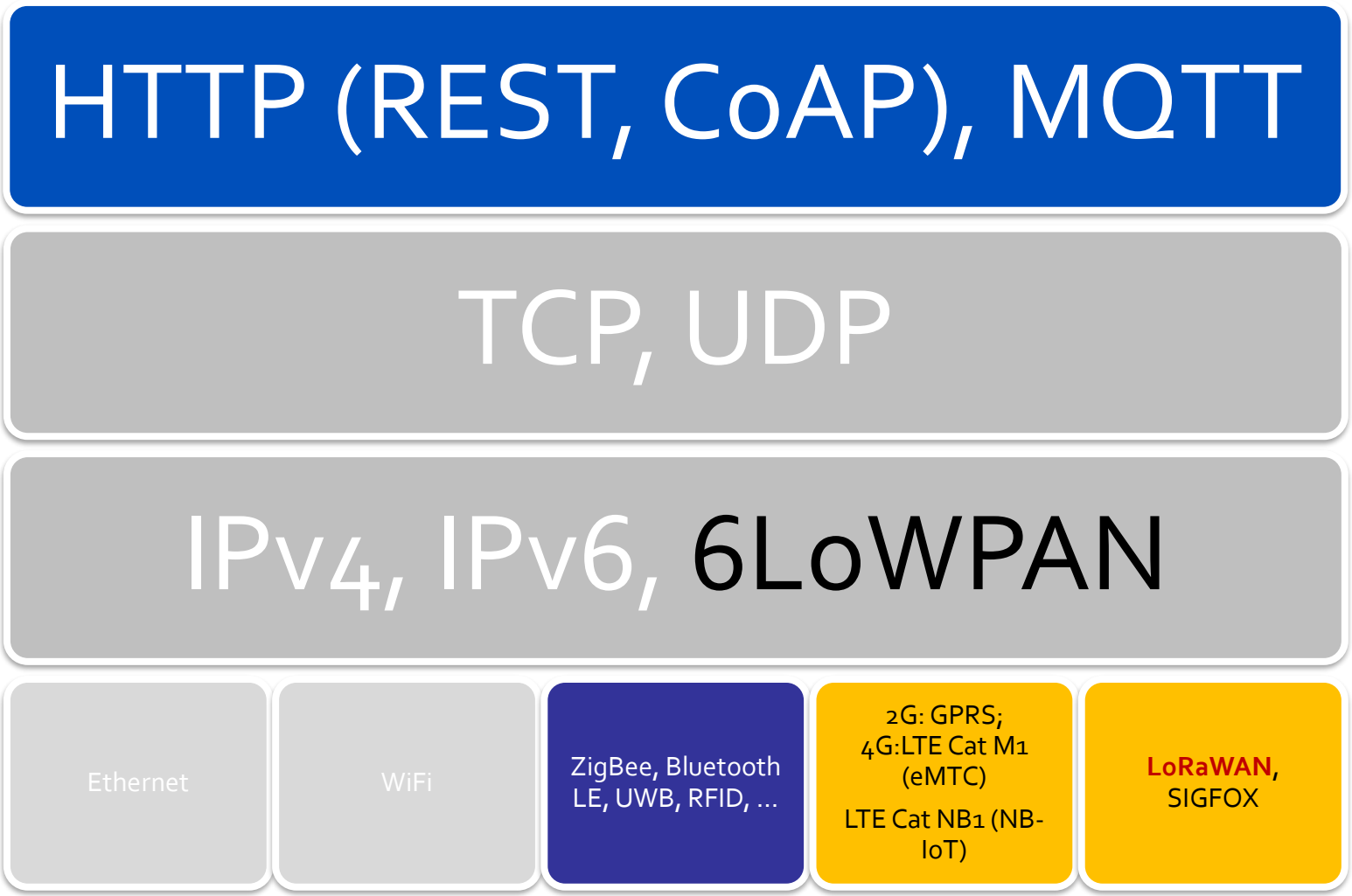


A communication-centric IoT reference model



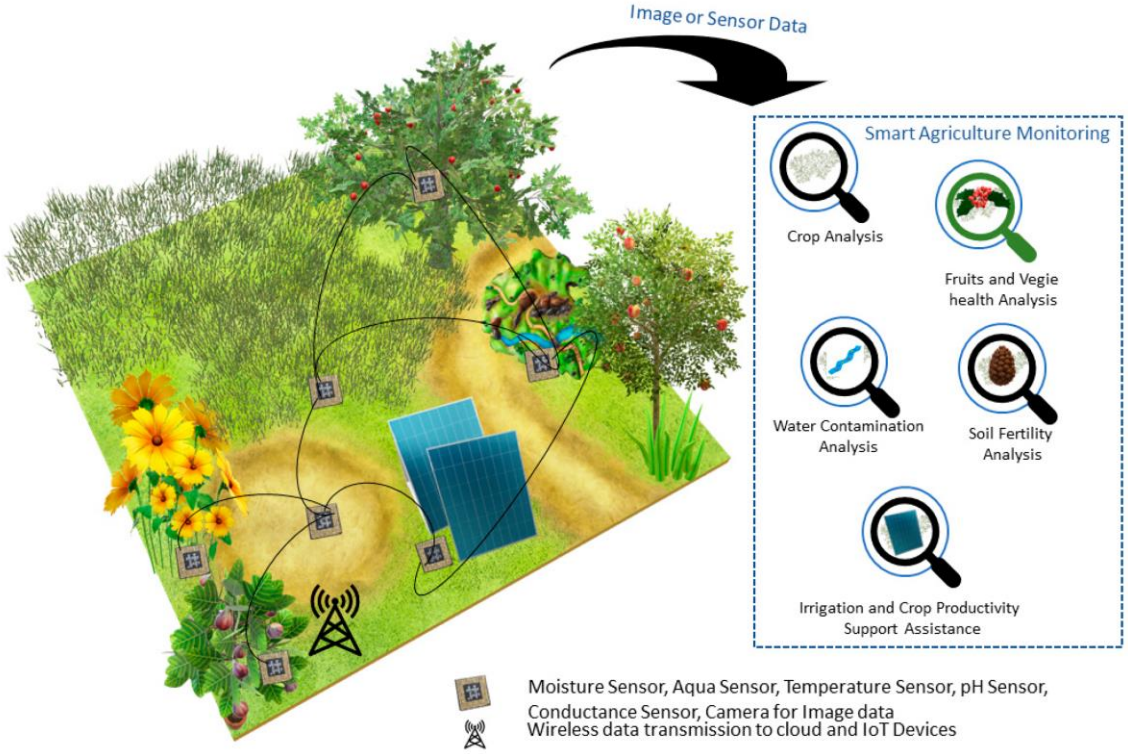
E. Al-Masri et al., "Investigating Messaging Protocols for the Internet of Things (IoT)," in IEEE Access, vol. 8, pp. 94880-94911, 2020, doi: 10.1109/ACCESS.2020.2993363.

Connectivity: a simplified view



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.

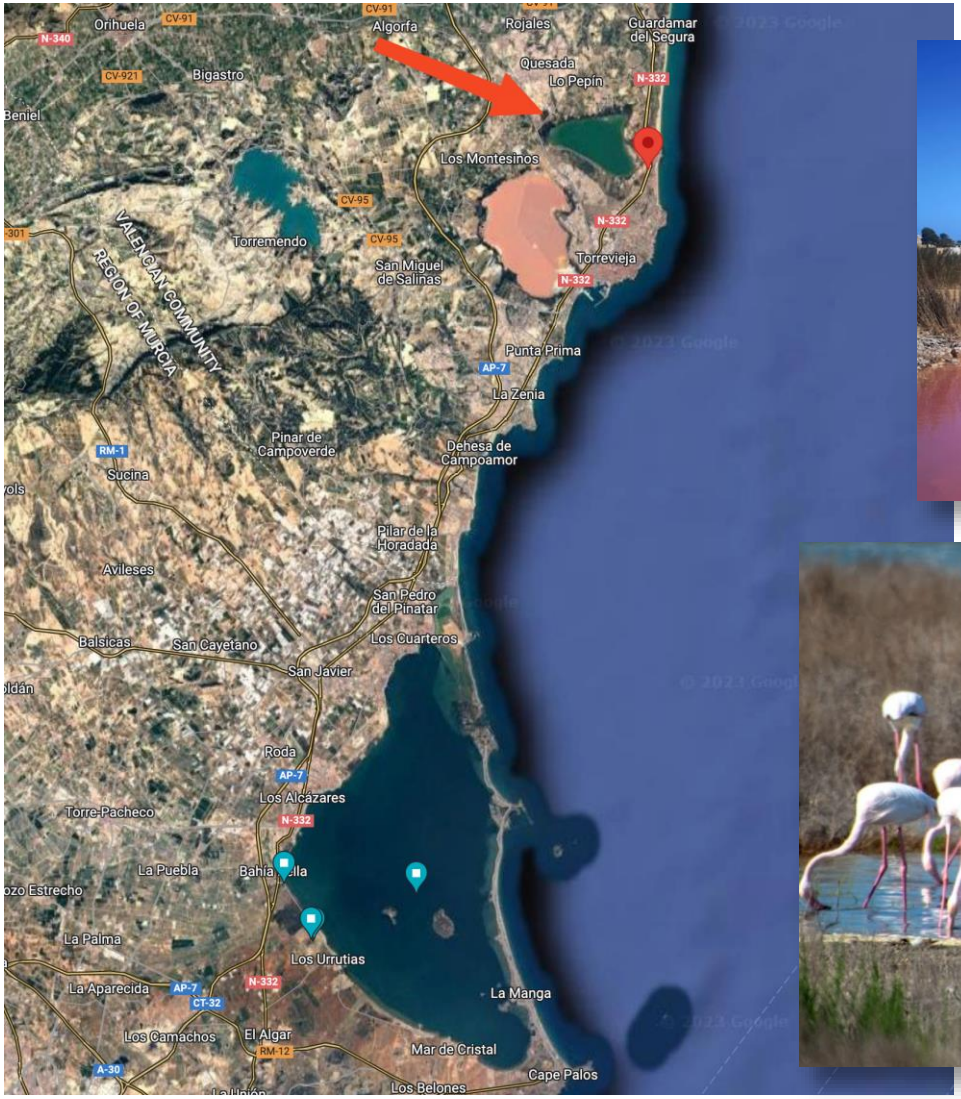
Ullo, S.L.; Sinha, G.R. Advances in Smart Environment Monitoring Systems Using IoT and Sensors. *Sensors* **2020**, *20*, 3113. https://doi.org/10.3390/s20113113

IoT for Environmental sensing

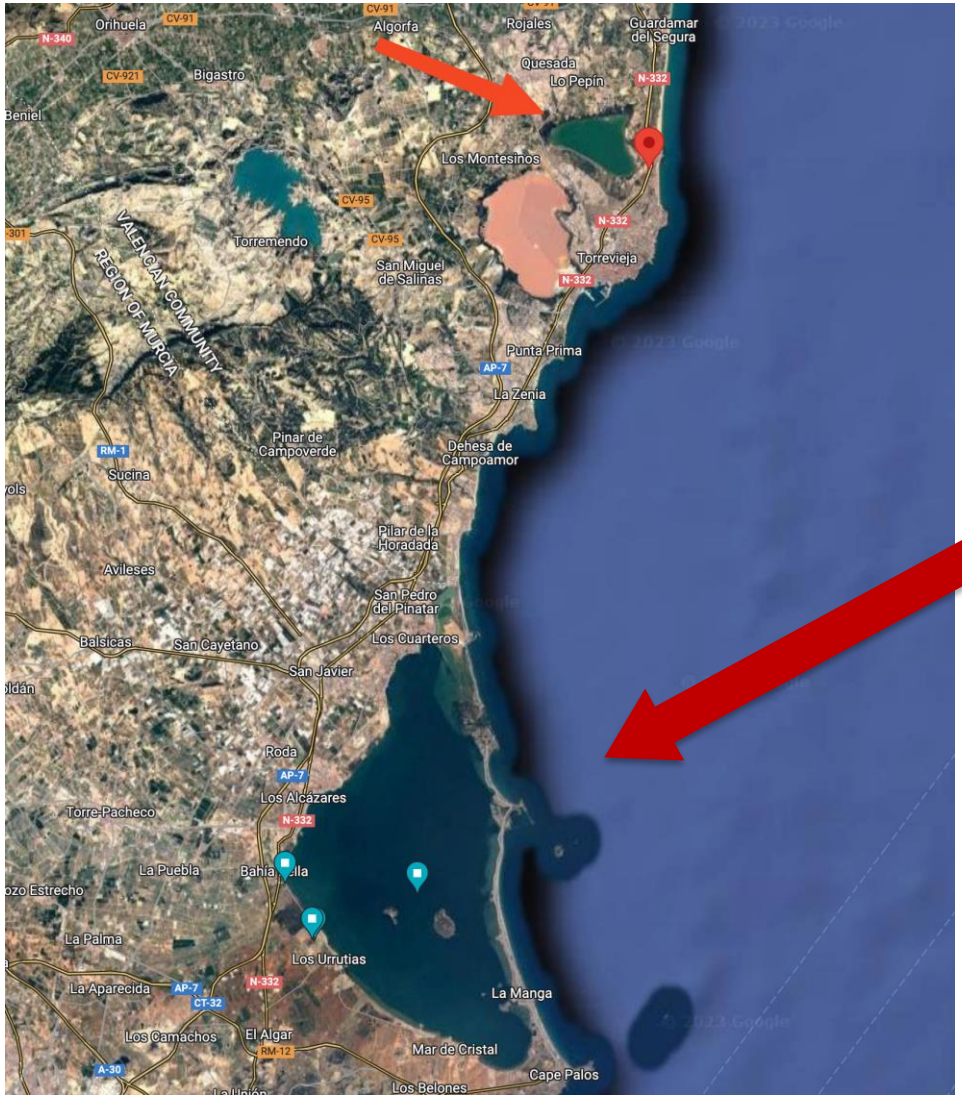
- Environmental sensing typically deals with rural and extreme environments such as remote areas, deserts, forests, or mountains.

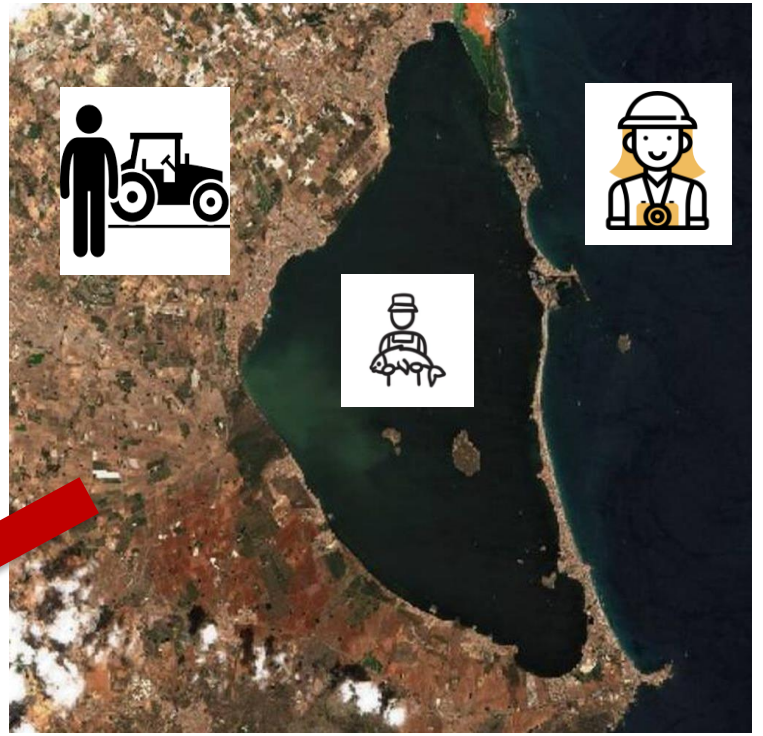
- These areas generally present several technical challenges
  - lack of reliable communication infrastructure.
  - power supply constraints
  - atmospheric agents
  - device maintenance and servicing
  - …

Natural Park of Las Lagunas de La Mata y Torrevieja



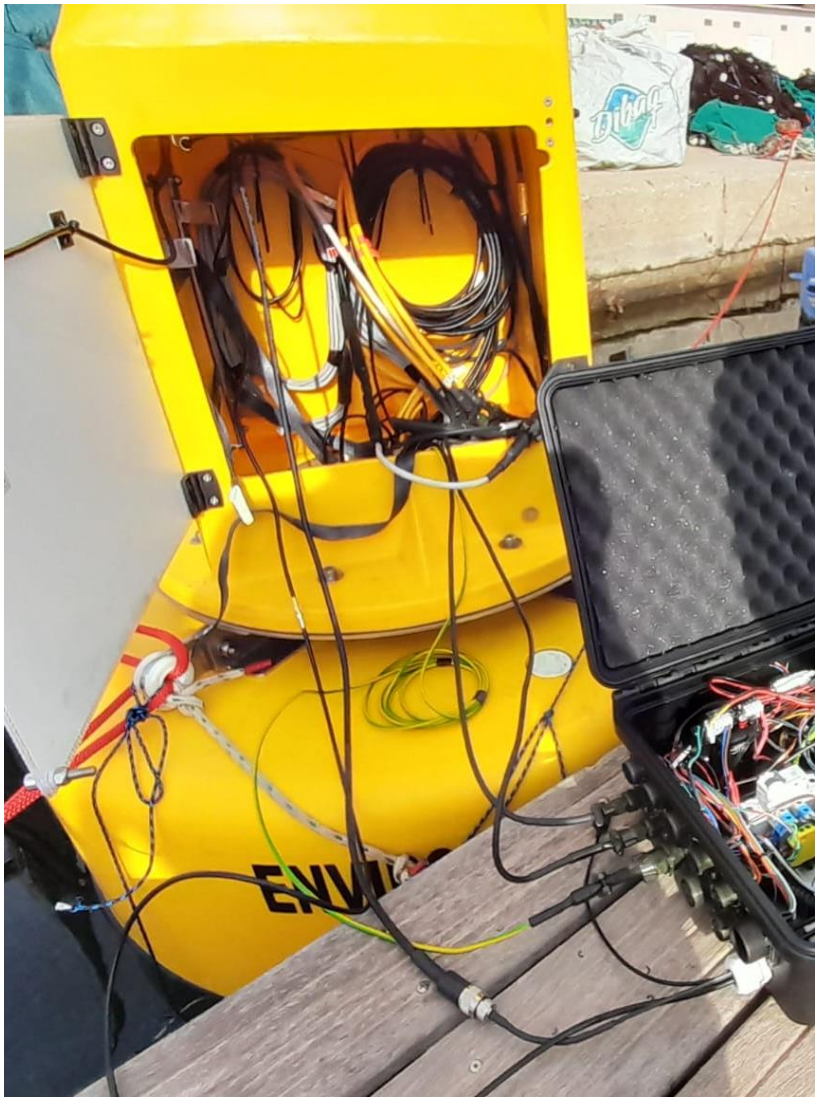
Mar Menor lagoon



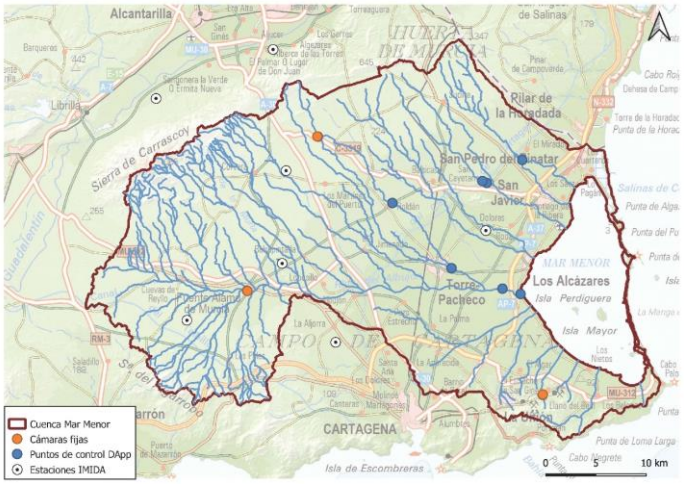


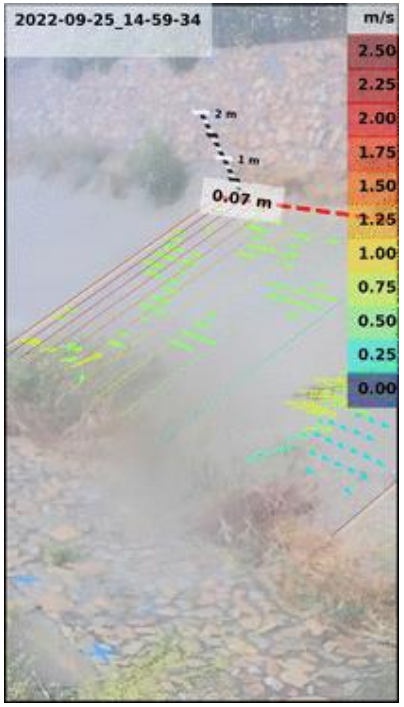
The Mar Menor is the largest saltwater lagoon in Europe, with a surface area of 135 km², a coastline of 73 km and a maximum depth of 7 meters.

Buoy



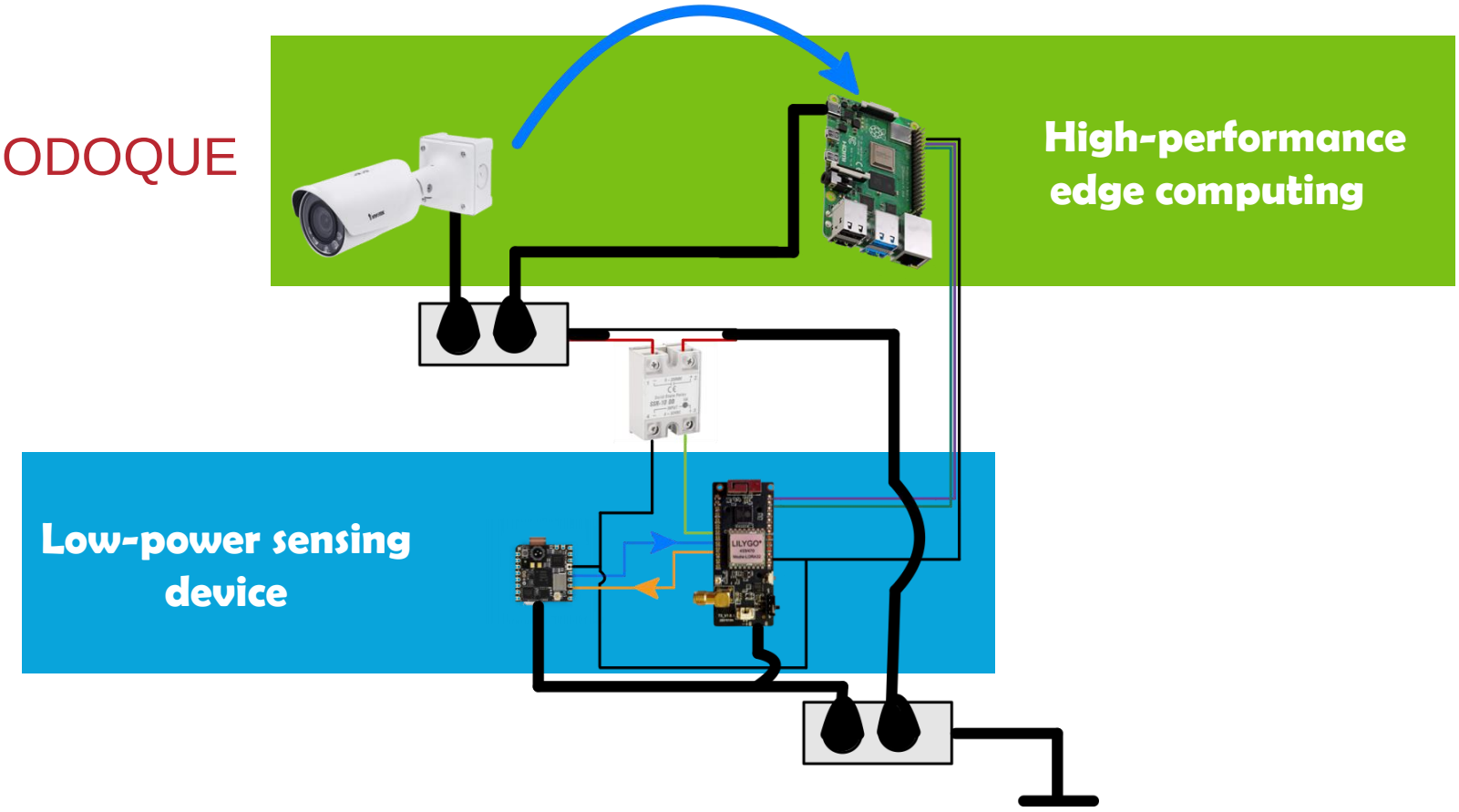
Cameras


Alcantarilla
Librilla
Sierra de Carrascoy
Pilar de la Horadada
San Pedro del Pinatar
San Javier
Torre-Pacheco
Los Alcázares
Isla Perdiguera
Isla Mayor
MAR MENOR
CARTAGENA
Isla de Escombreras
Cuenca Mar Menor
Cámaras fijas
Puntos de control DApp
Estaciones IMIDA
0
5
10 km

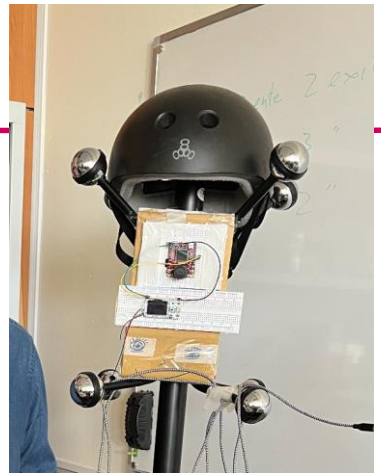

2022-09-25_14-59-34
m/s
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
2 m
1 m
0.07 m

Cameras and some TinyML

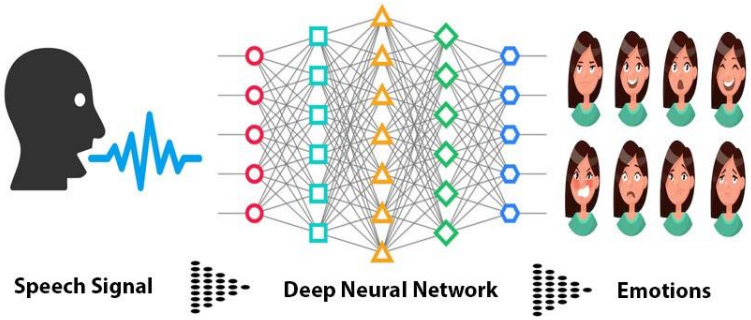
BODOQUE

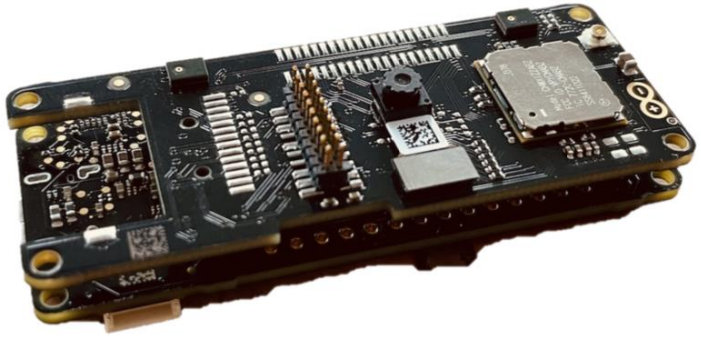


Person counting and classification



More TinyML: sentiment analysis

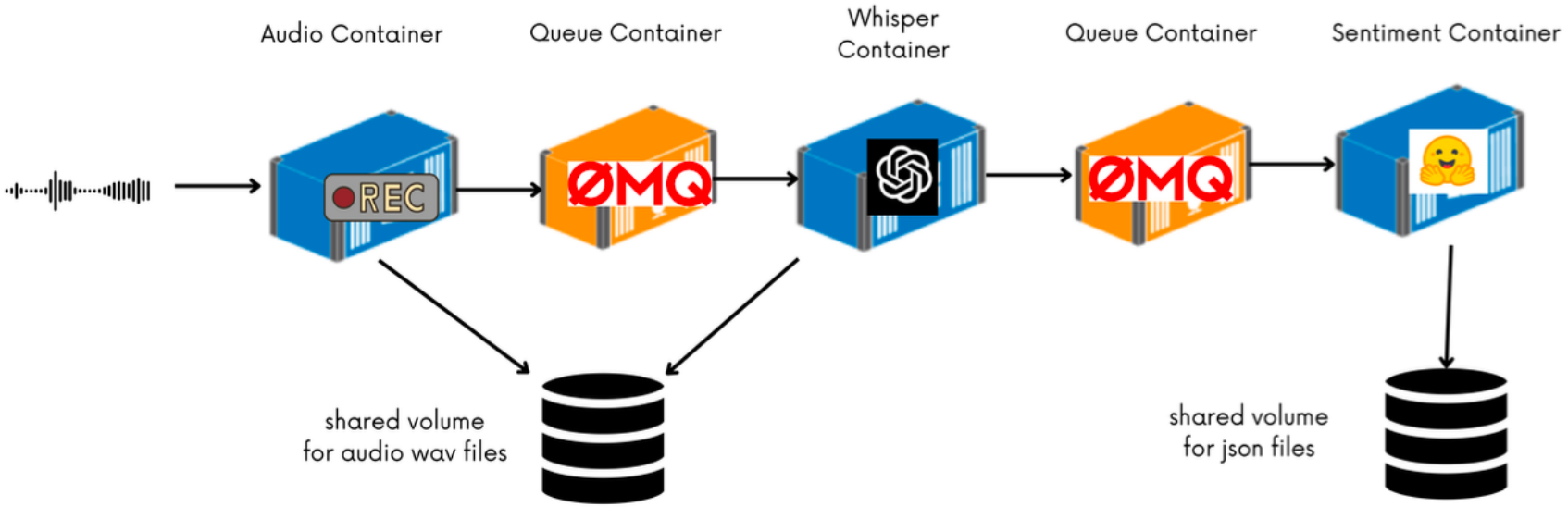




Portenta H7

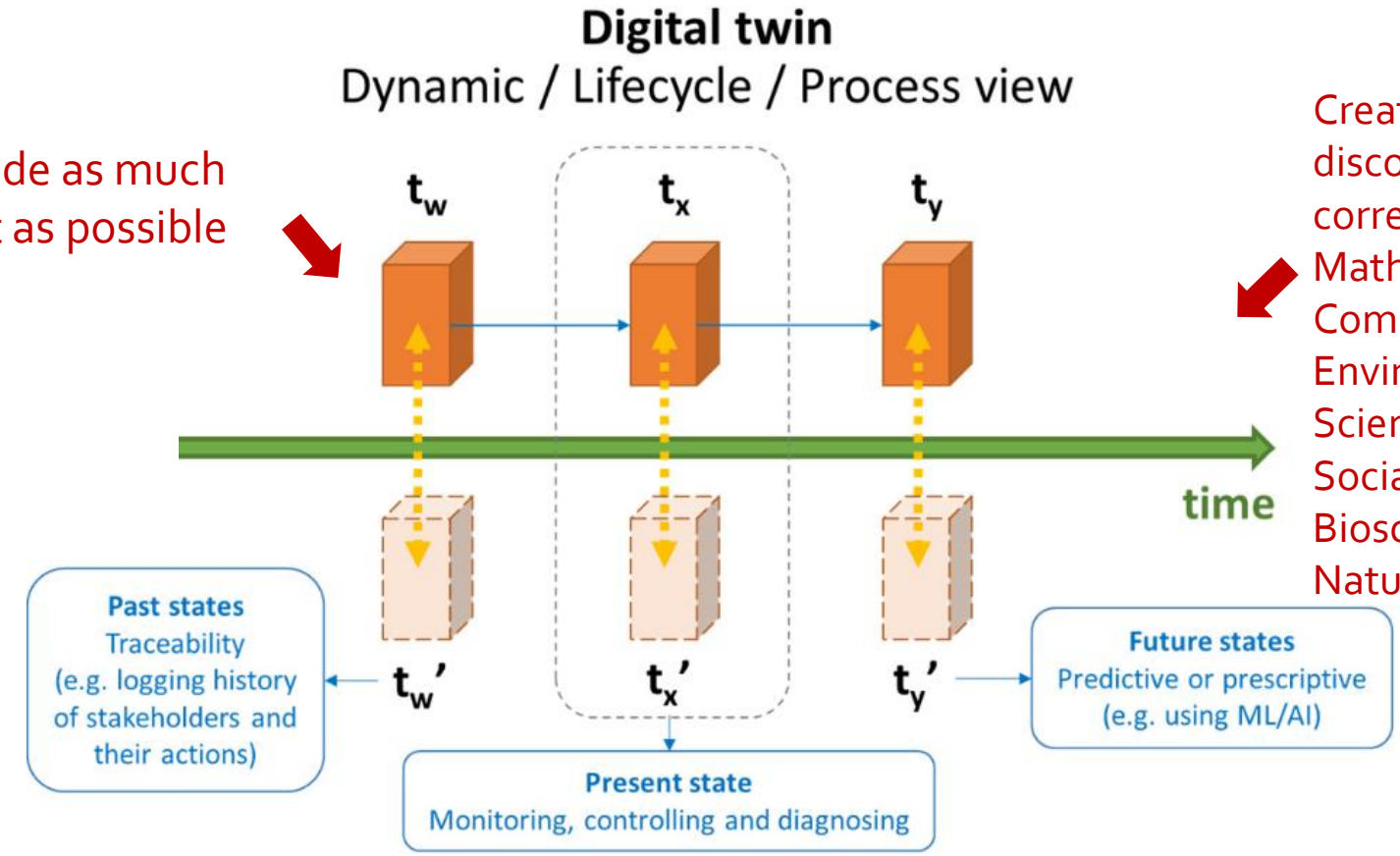
	1c	1d	2c	3c	5c	8c
Bello	90.2%	93.4%	95.1%	91.8%	94.3%	90.2%
	0.93	0.94	0.94	0.94	0.93	0.93
Bonito	100%	95.4%%	96.9%	98.5%	92.3%	98.5%
	0.95	0.89	0.98	0.98	0.94	0.98
Brutto	92.9%	86.7%	93.9%	96.9%	95.9%	92.9%
	0.95	0.91	0.96	0.97	0.97	0.94
Carino	93.4%	86.9%	93.4%	96.7%	95.%	91.8%
	0.94	0.92	0.94	0.97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

More «TinyML»: sentiment analysis



How about platforms? → Digital Twins

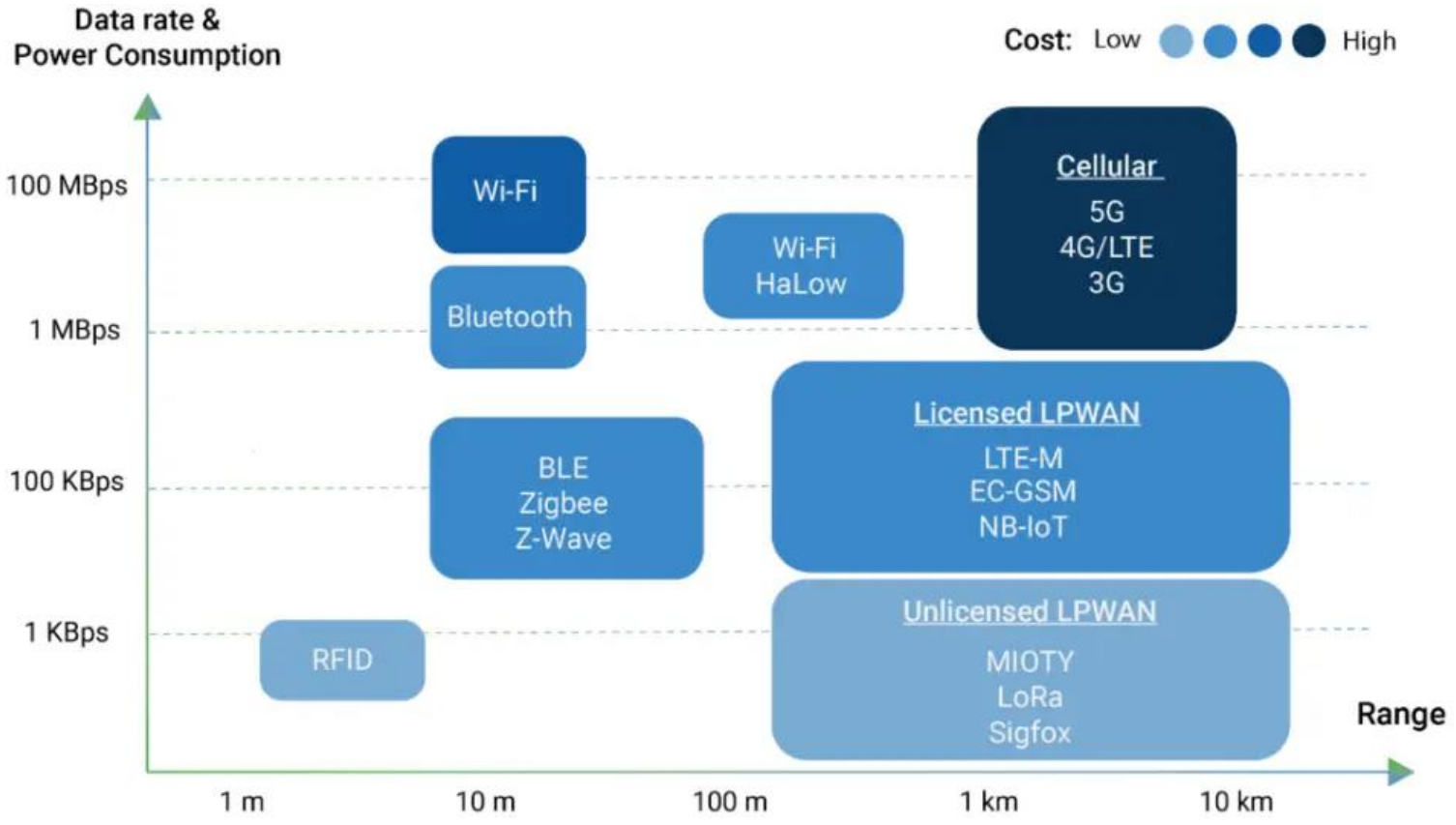
A digital twin is a virtual representation or model of a physical object or system. Digital twins are used in various contexts for simulation, analysis, and control. They can help predict issues before they happen, develop new opportunities, and even plan for the future.



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.

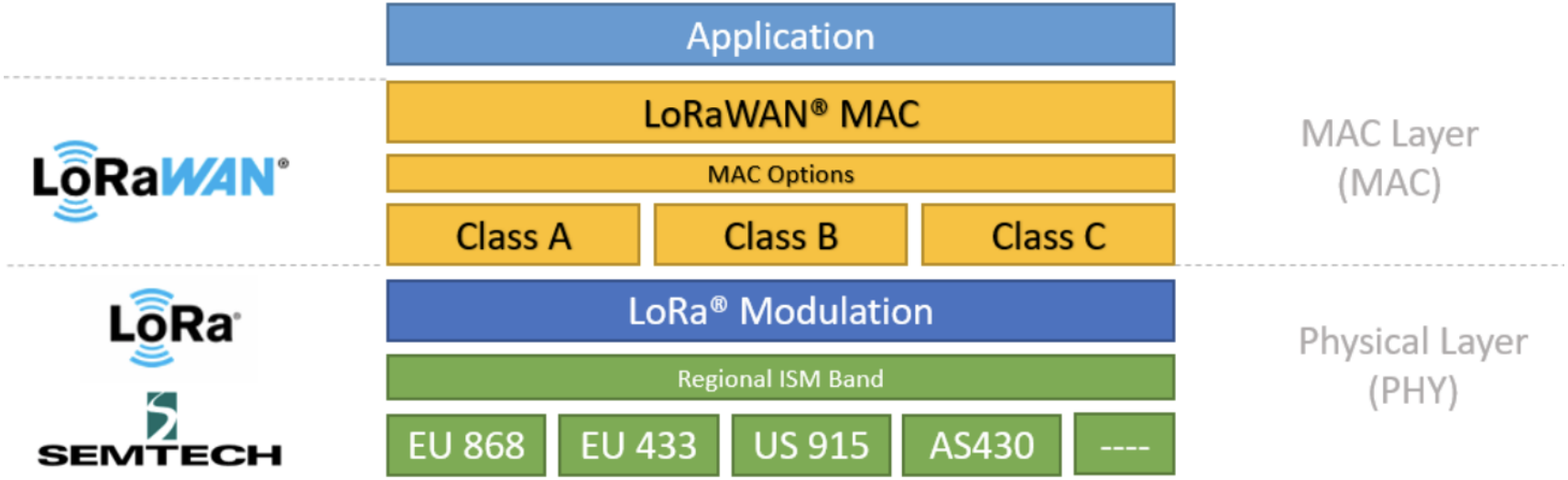
So, what about LoRaWAN?

LPWAN: range vs power



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

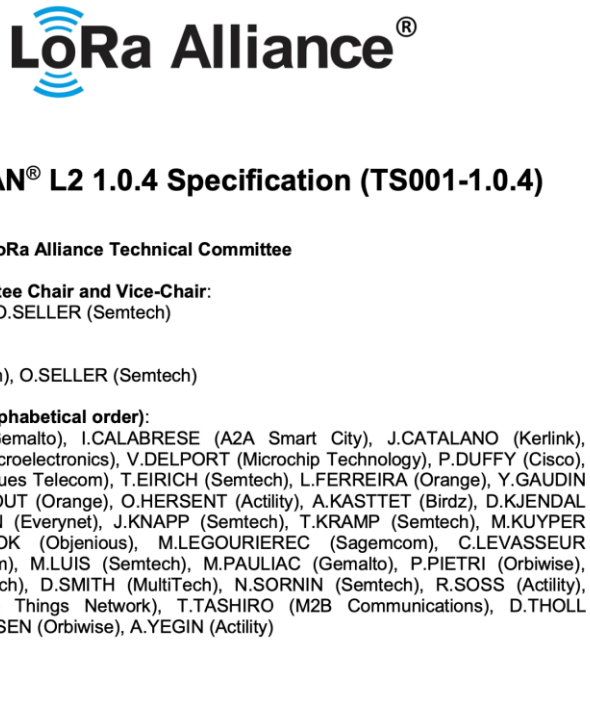
LoRa and LoRaWAN: the big picture



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

LoRa® Alliance

- 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


LoRa Alliance®

LoRaWAN® L2 1.0.4 Specification (TS001-1.0.4)

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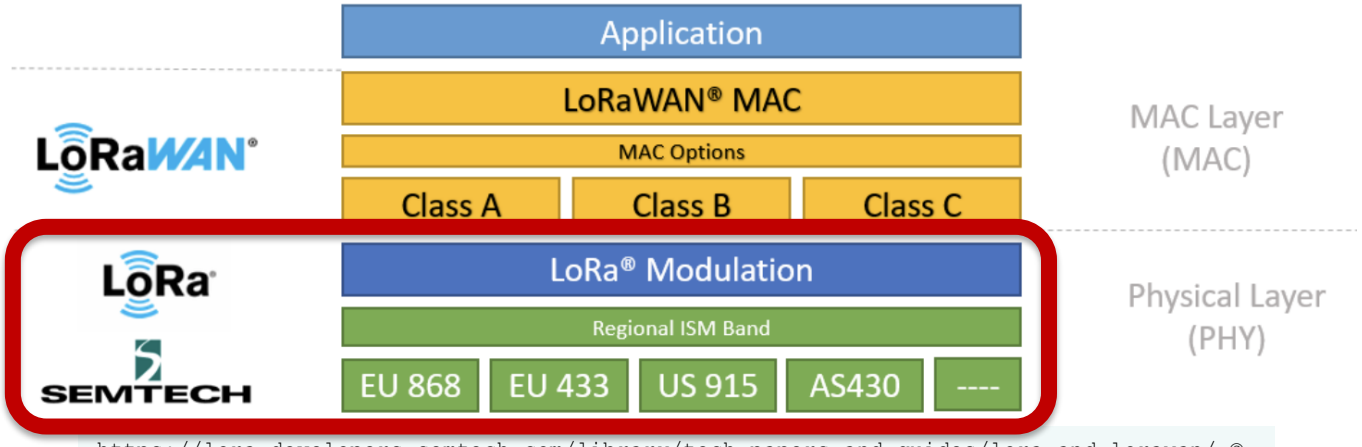
Version: 1.0.4
Date: October 2020
Status: Released

What is LoRa?

- 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.



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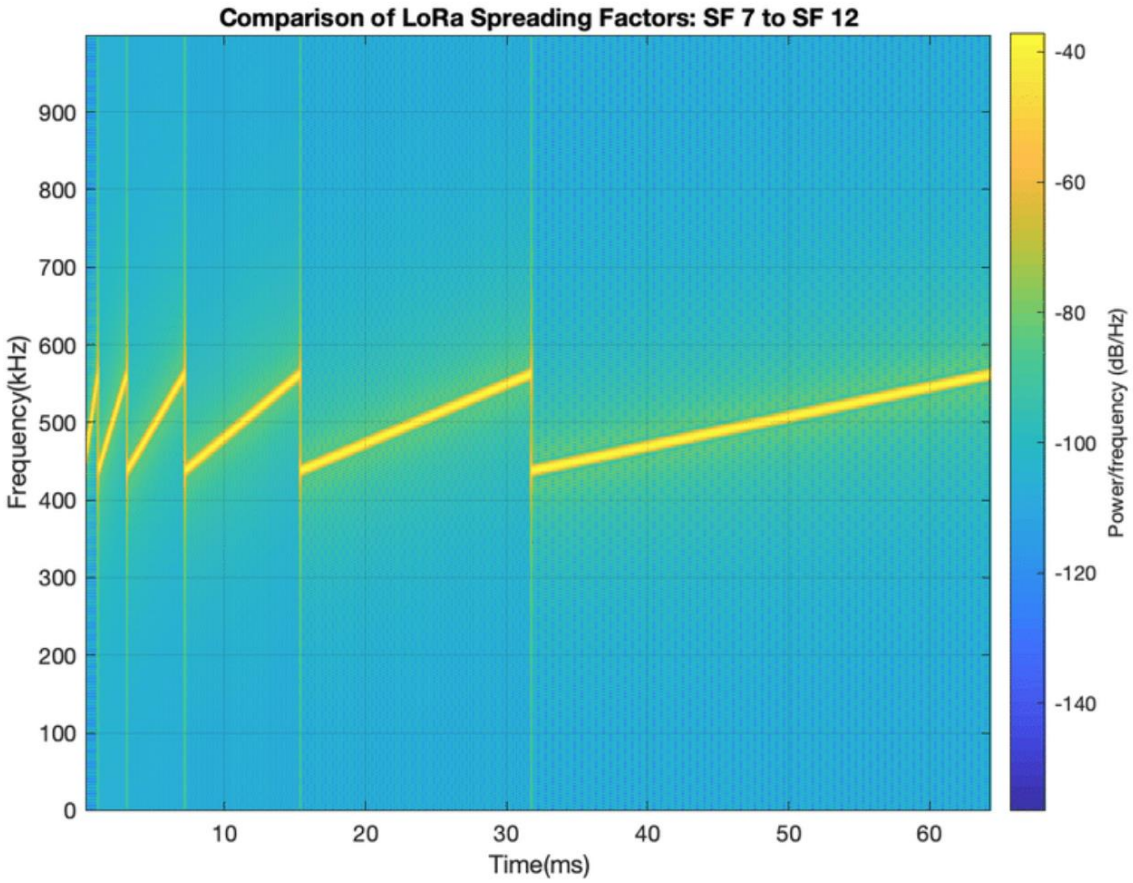
Chirp Modulation



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.

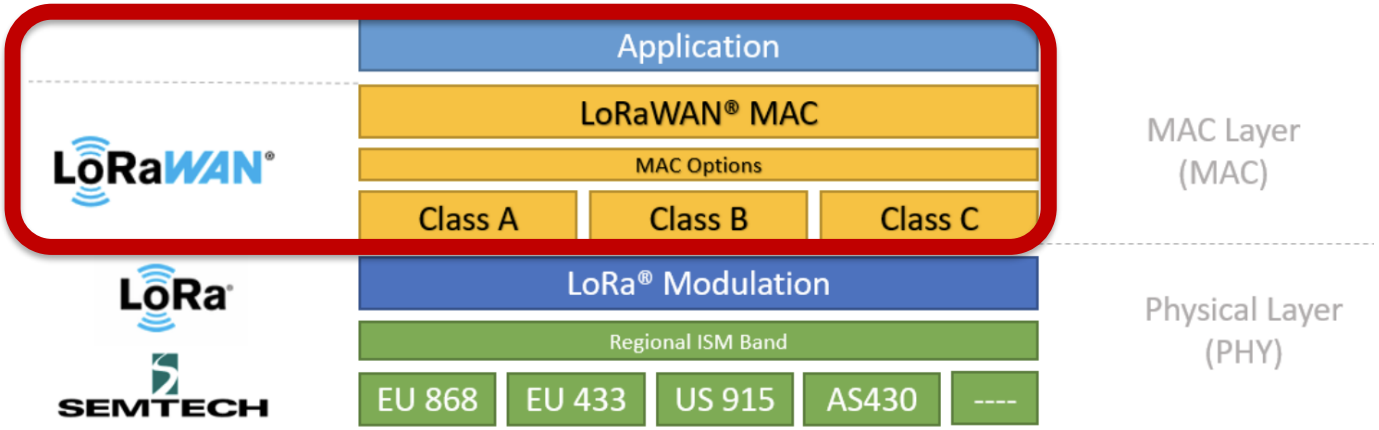
Spreading Factors (SF) versus data rate and time-on-air

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%)

What is LoRaWAN?

- 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.



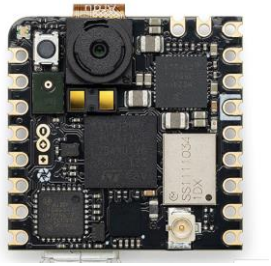
https://lora-developers.semtech.com/library/tech-papers-and-guides/lora-and-lorawan/ ©

Can I use LoRa alone?

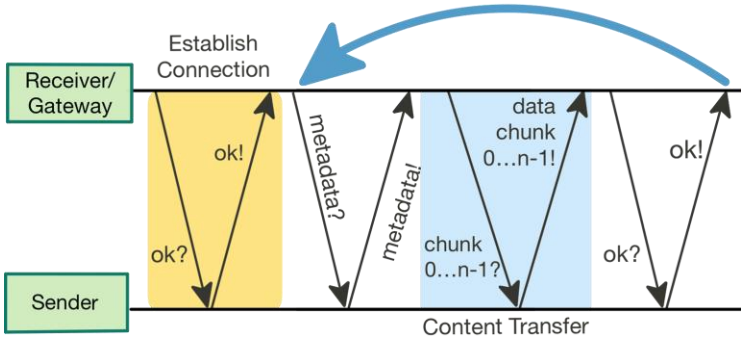
Yes! For example →AlLoRa

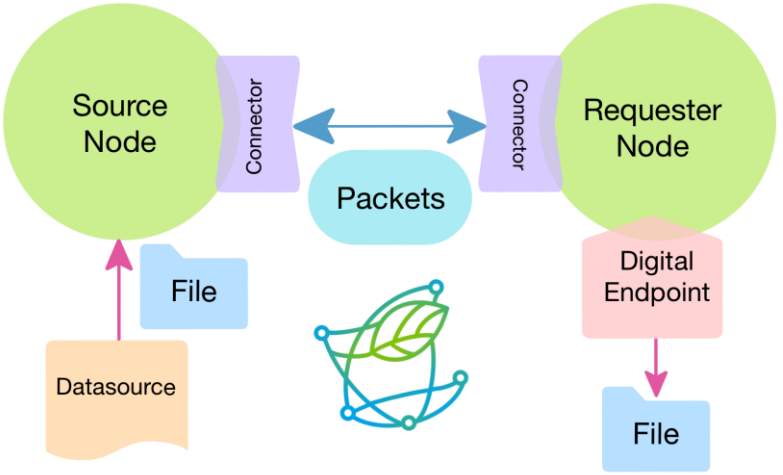
AlLoRa: modular, mesh, multi-device LoRa Content Transfer Protocol

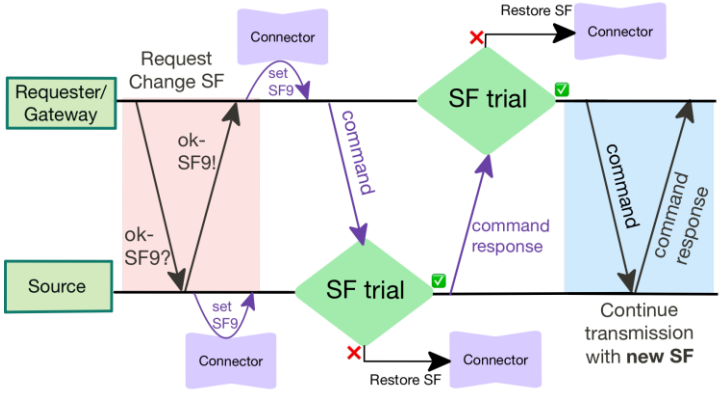
https://github.com/SMARTLAGOON/AlLoRa

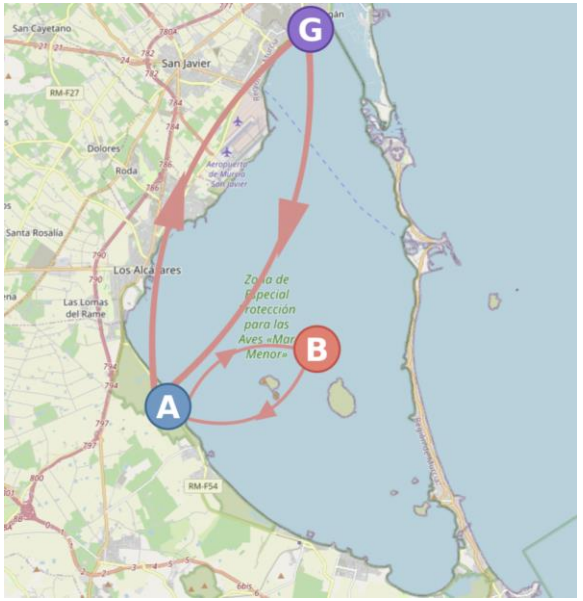


AlLoRa: modular, mesh, multi-device...



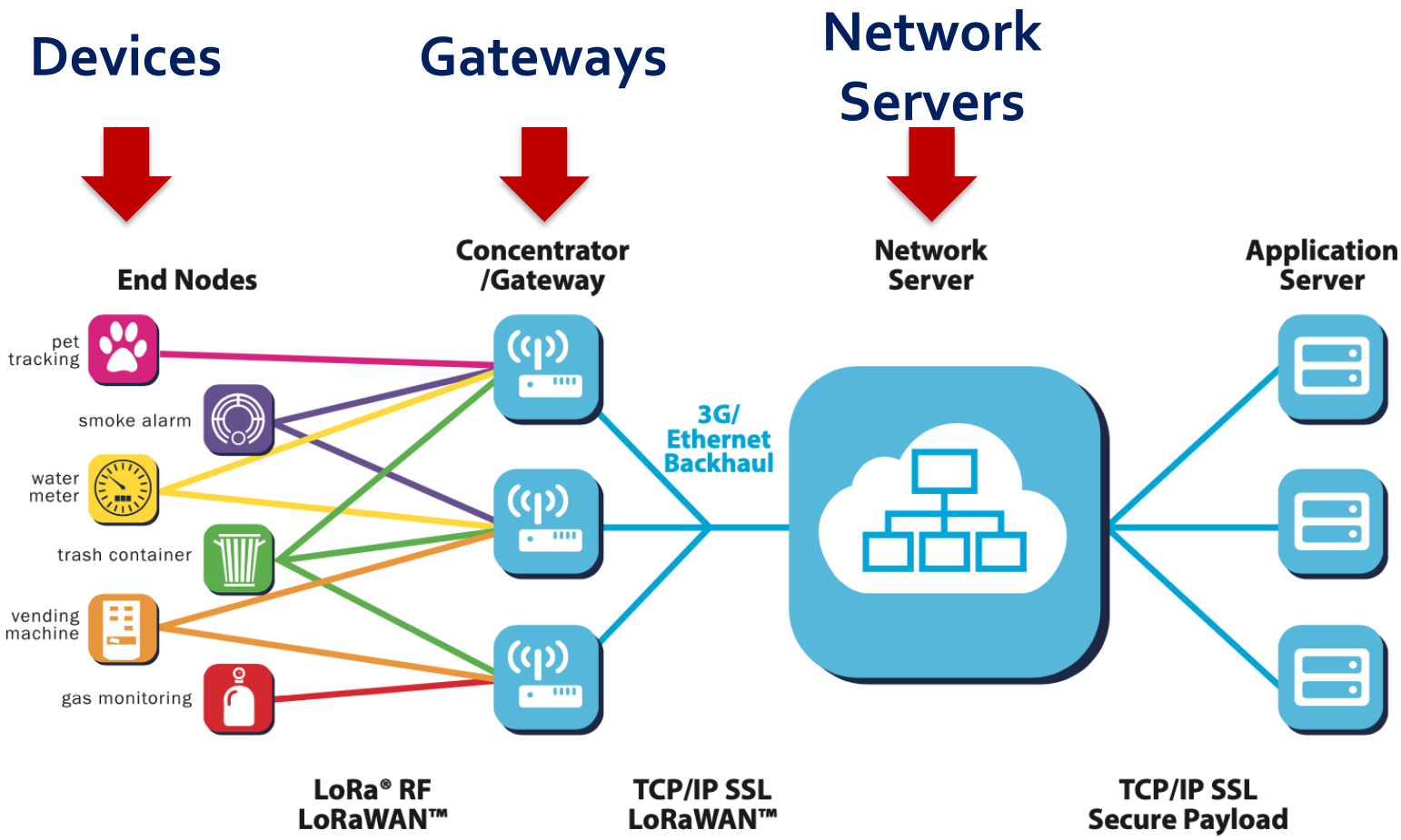






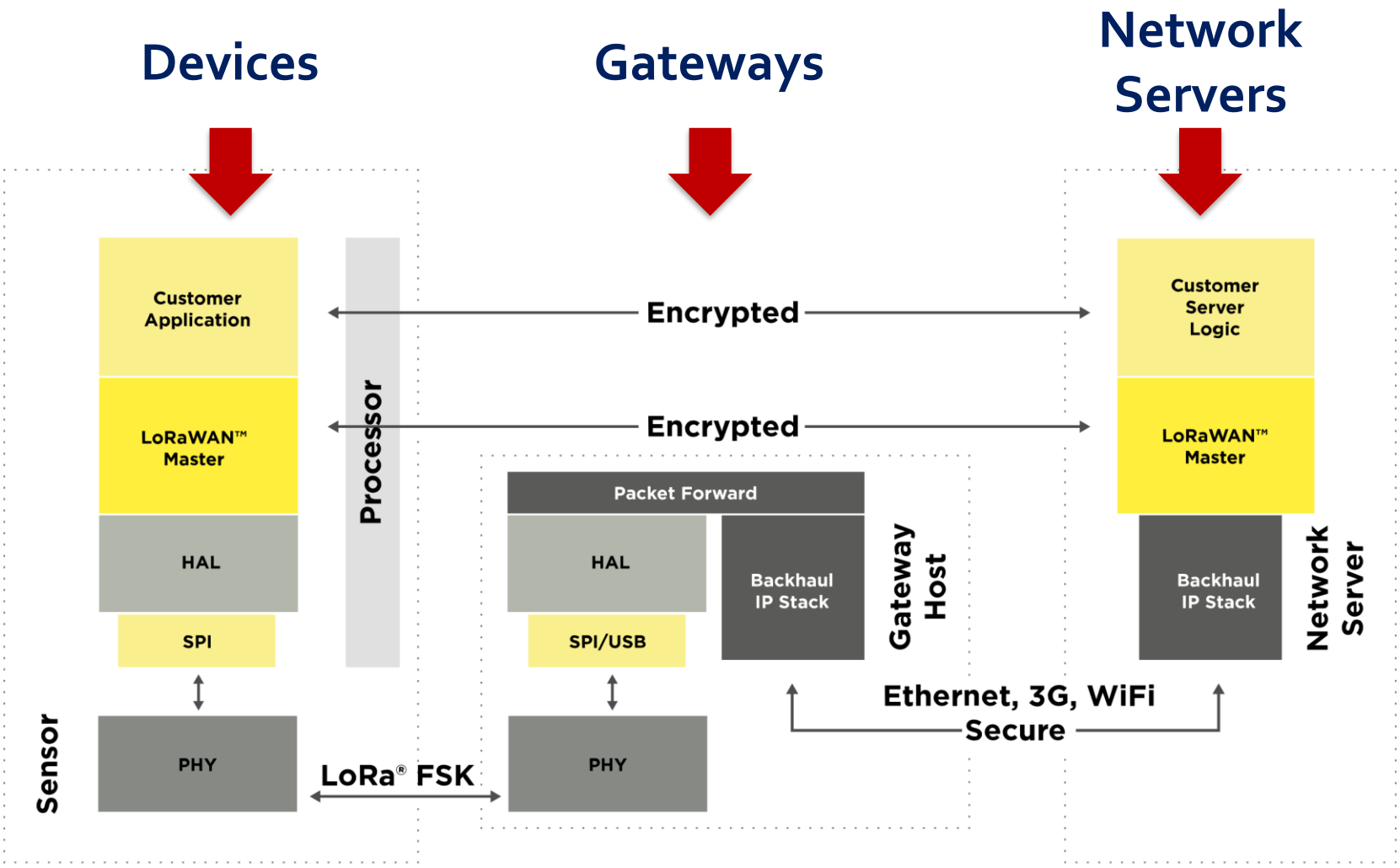
Let's continue with LoRaWAN

LoRaWAN network architecture



LoRa Alliance ©

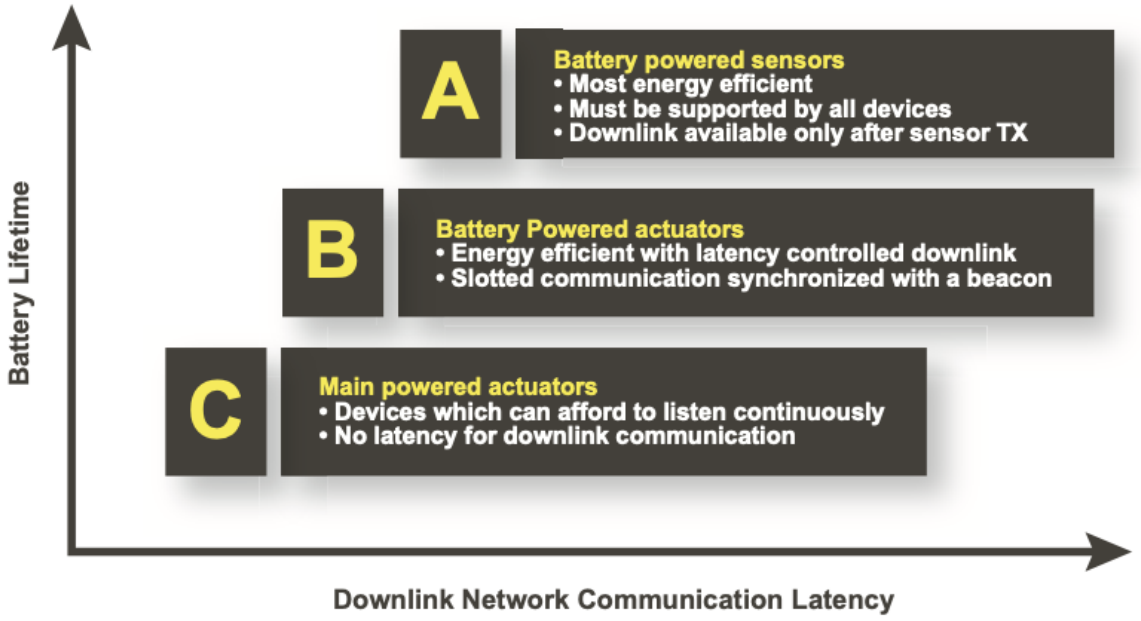
LoRaWAN data flow



HAL: Hardware Abstraction Layer

Three types of devices

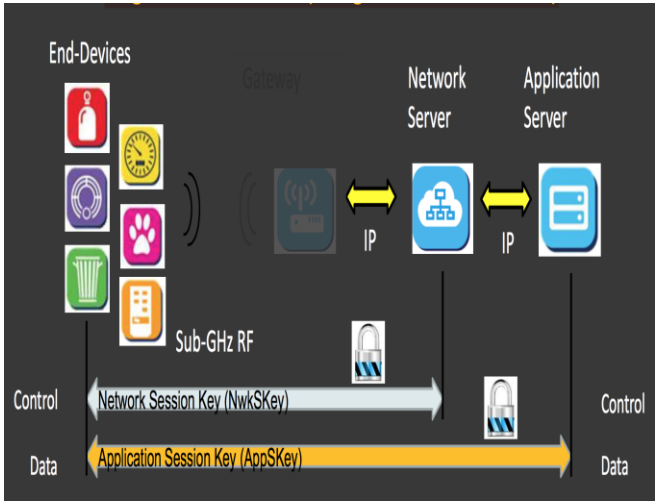
- LoRaWAN has three different classes of end-point devices to address the different needs reflected in the wide range of applications:



LoRa® Alliance Technical Marketing Workgroup

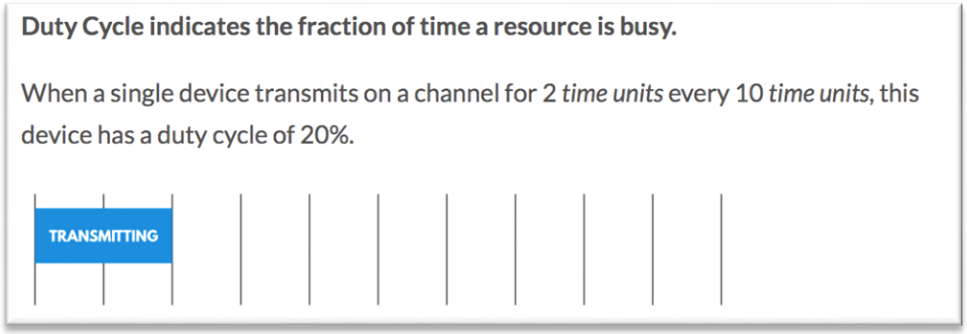
Devices activation

- 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.



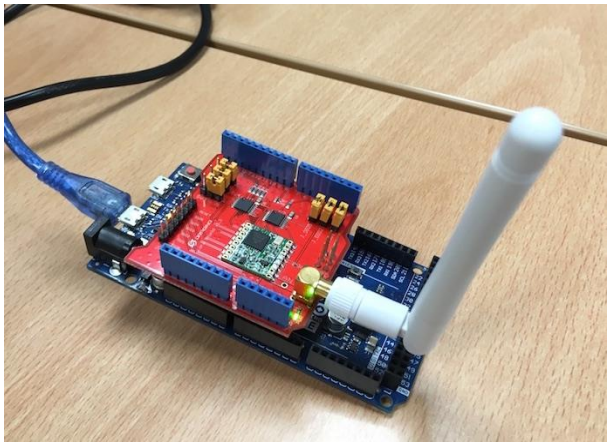
Maximum Duty Cycle

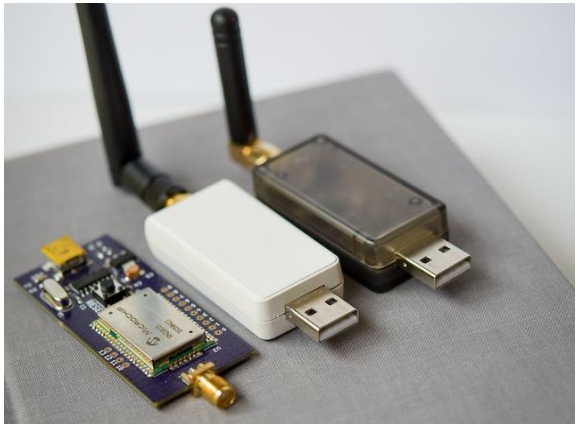
- The **duty cycle of radio devices is often regulated by government**. In Europe, duty cycles are regulated by section 7.2.3 of the ETSI EN300.220 standard.

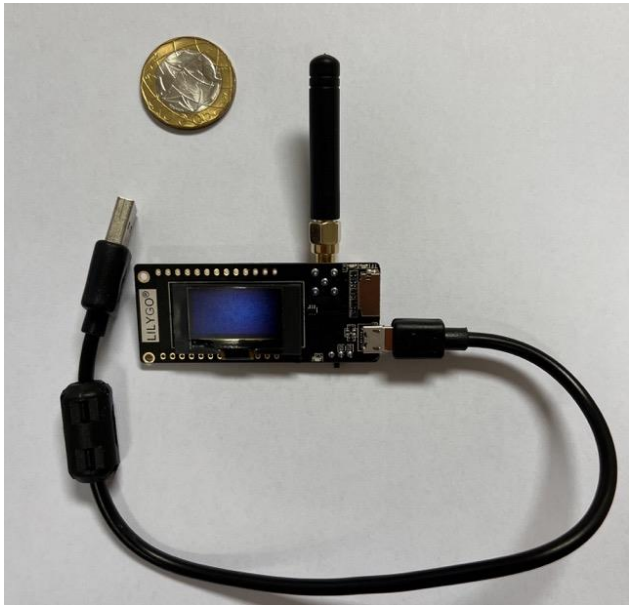


- On "community network" like TTN there typically is a **Fair Access Policy** that limits the uplink airtime to 30 seconds per day (24 hours) per node and the downlink messages to 10 messages per day (24 hours) per node.

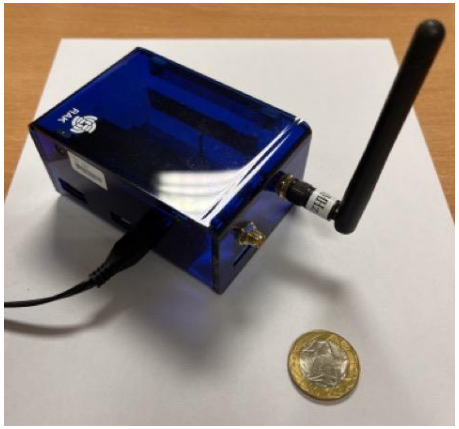
Some devices



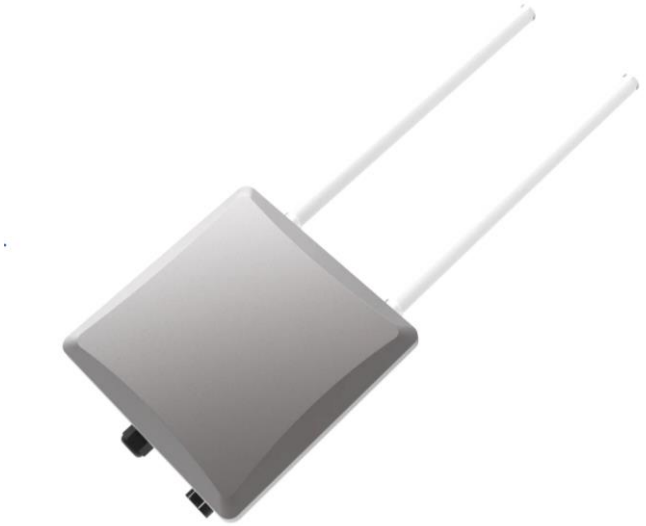




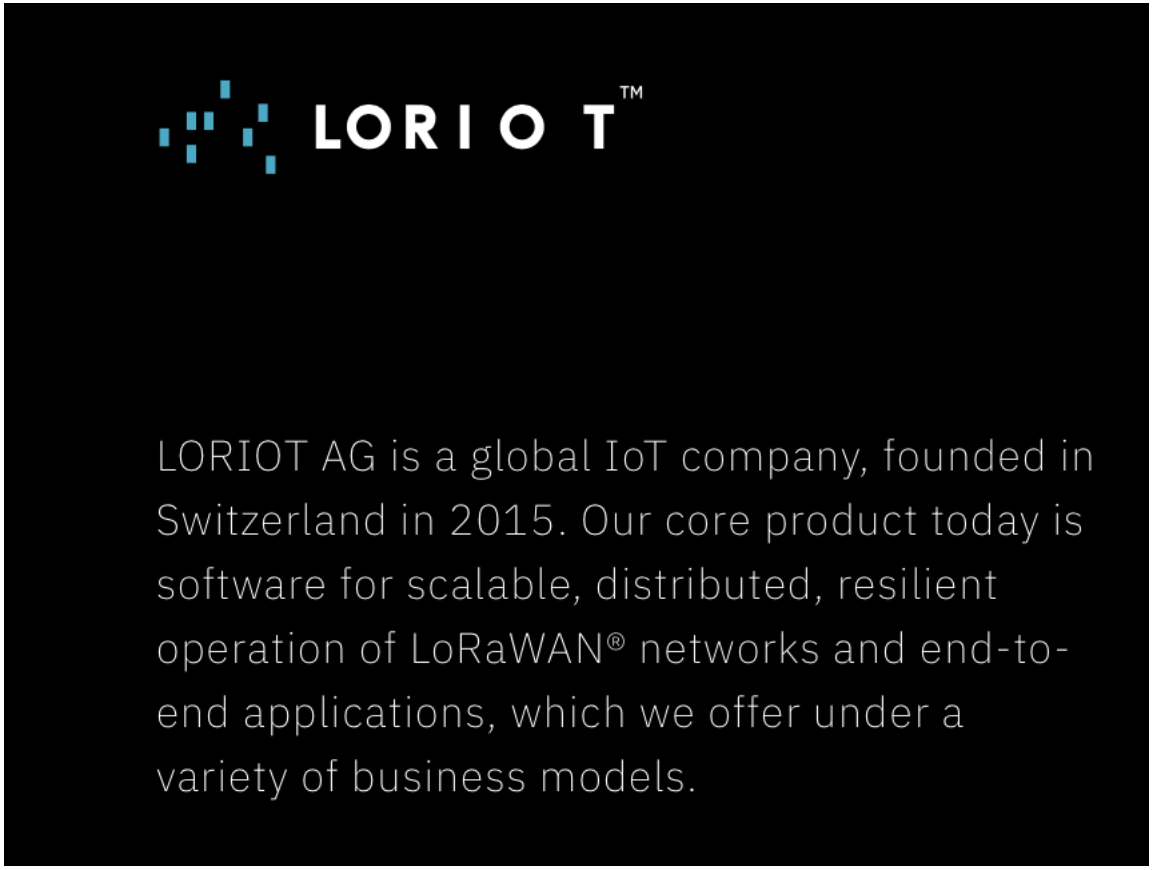
Gateways: examples



Gateways: examples



LoRaWAN Network Servers



https://www.loriot.io/

https://www.chirpstack.io/

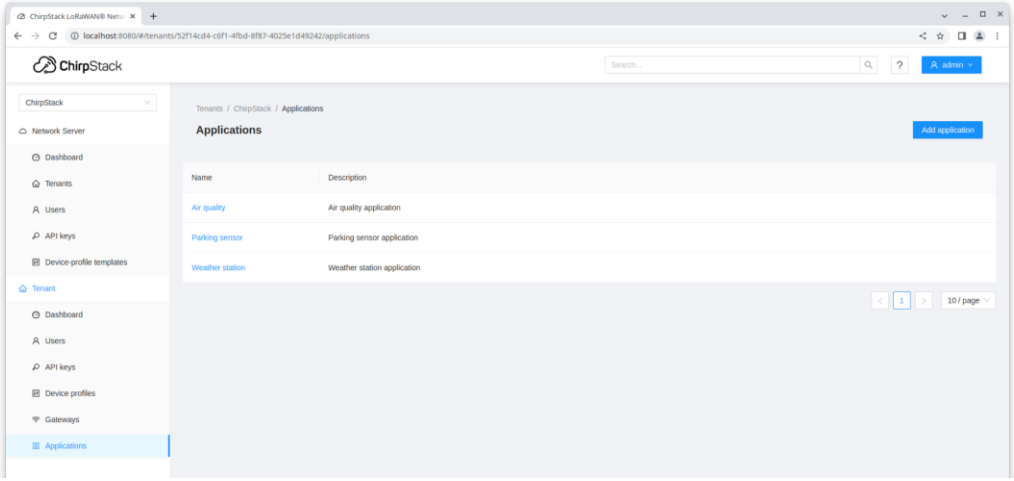
ChirpStack

Chirpstack v4 is out and brings many improvements! **Read the announcement on the forum**.

ChirpStack, open-source LoRaWAN® Network Server

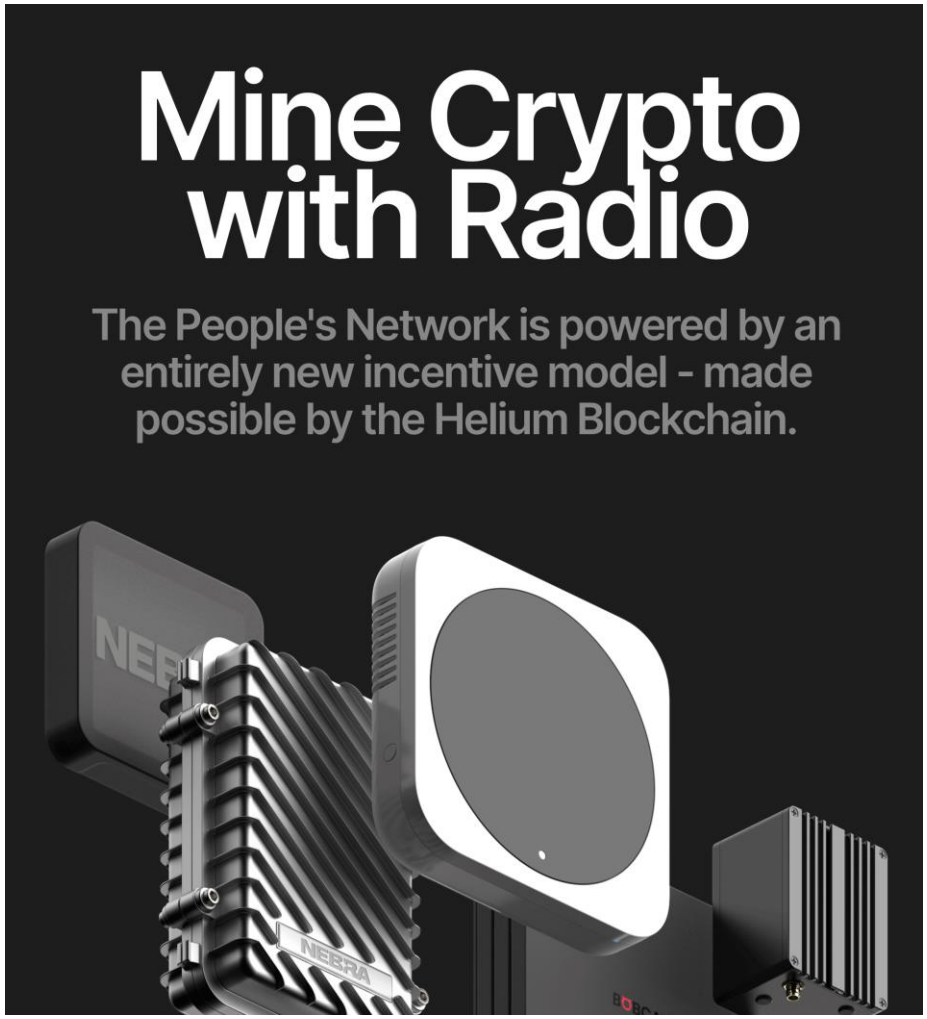
ChirpStack is an open-source LoRaWAN Network Server which can be used to to setup LoRaWAN networks. ChirpStack provides a web-interface for the management of gateways, devices and tenants as well to setup data integrations with the major cloud providers, databases and services commonly used for handling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

Documentation



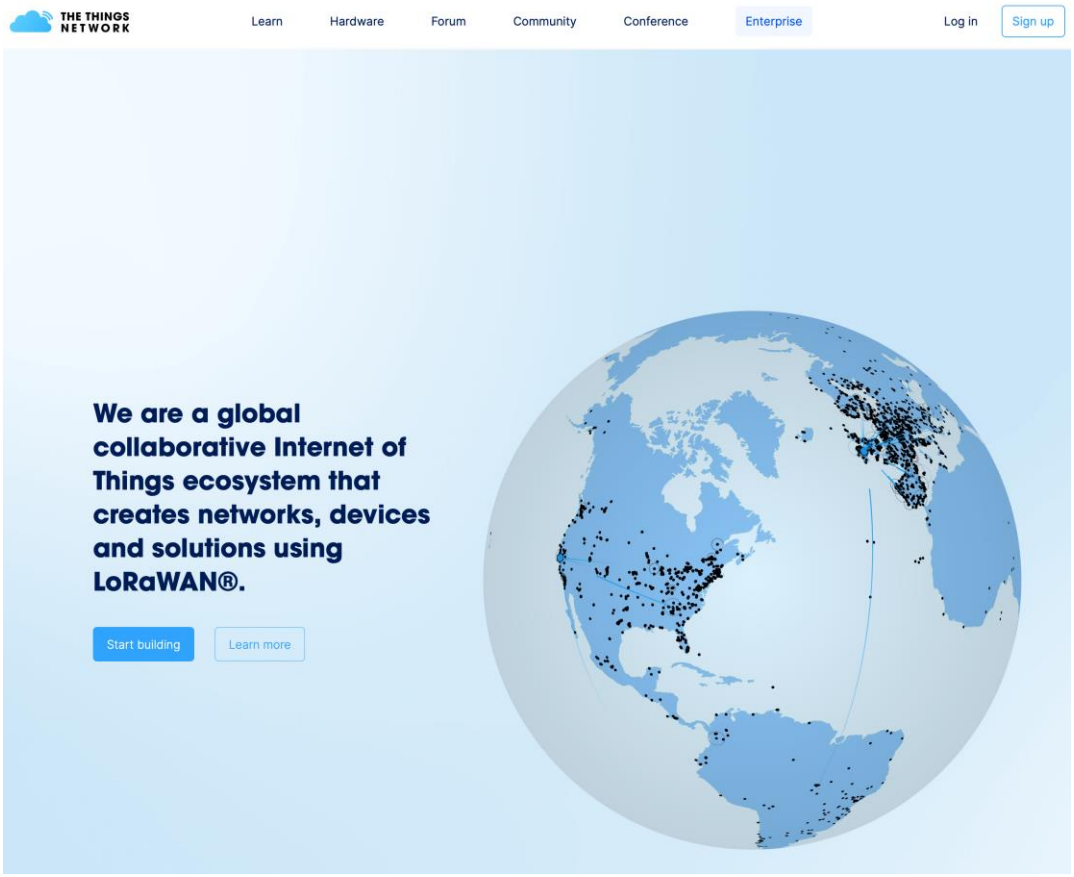
https://www.helium.com

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".



https://www.thethingsnetwork.org

The Things Network (TTN)



27.2M	151	970	154.6K	21.3K
Messages today	Countries	Certified developers	Members	Gateways

The Things Network (TTN)

Currently (June 2023) approx. 21.200 gateways active worldwide

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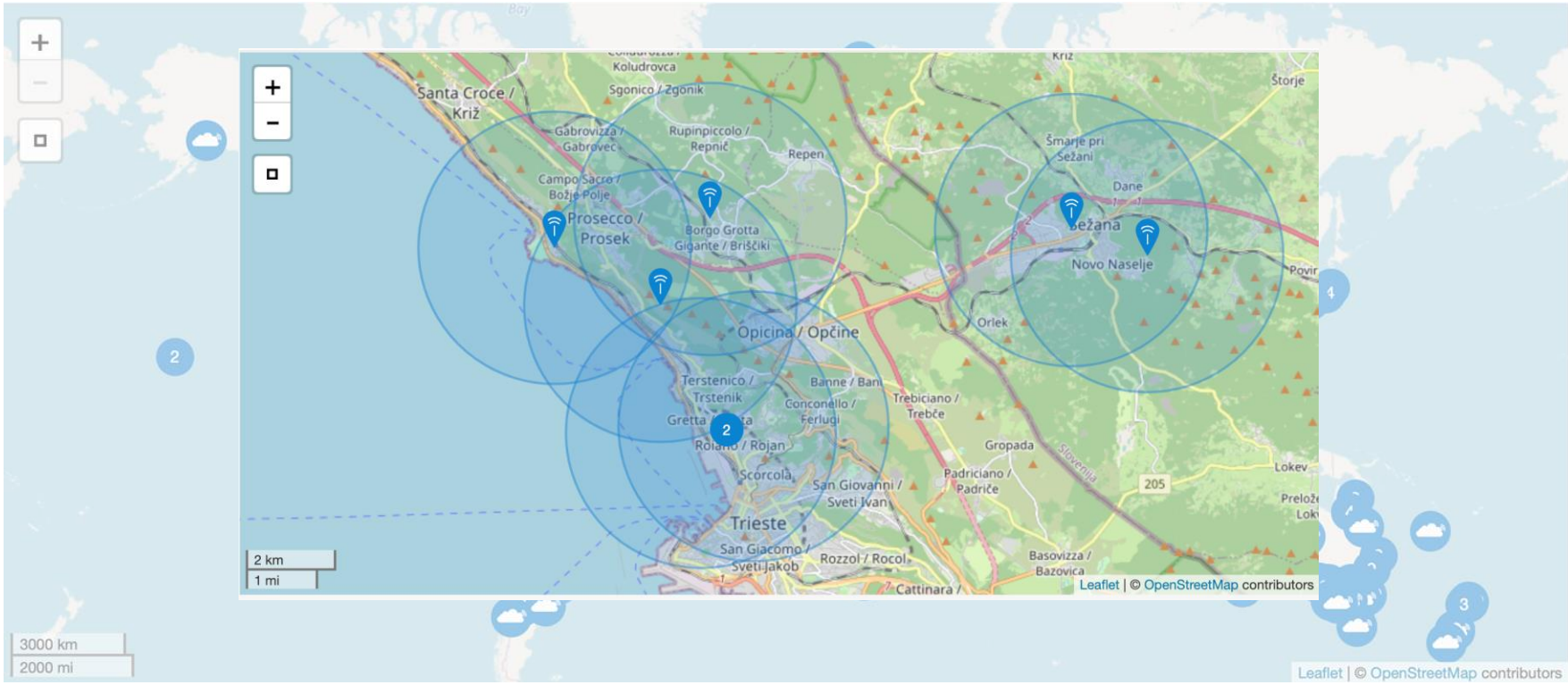
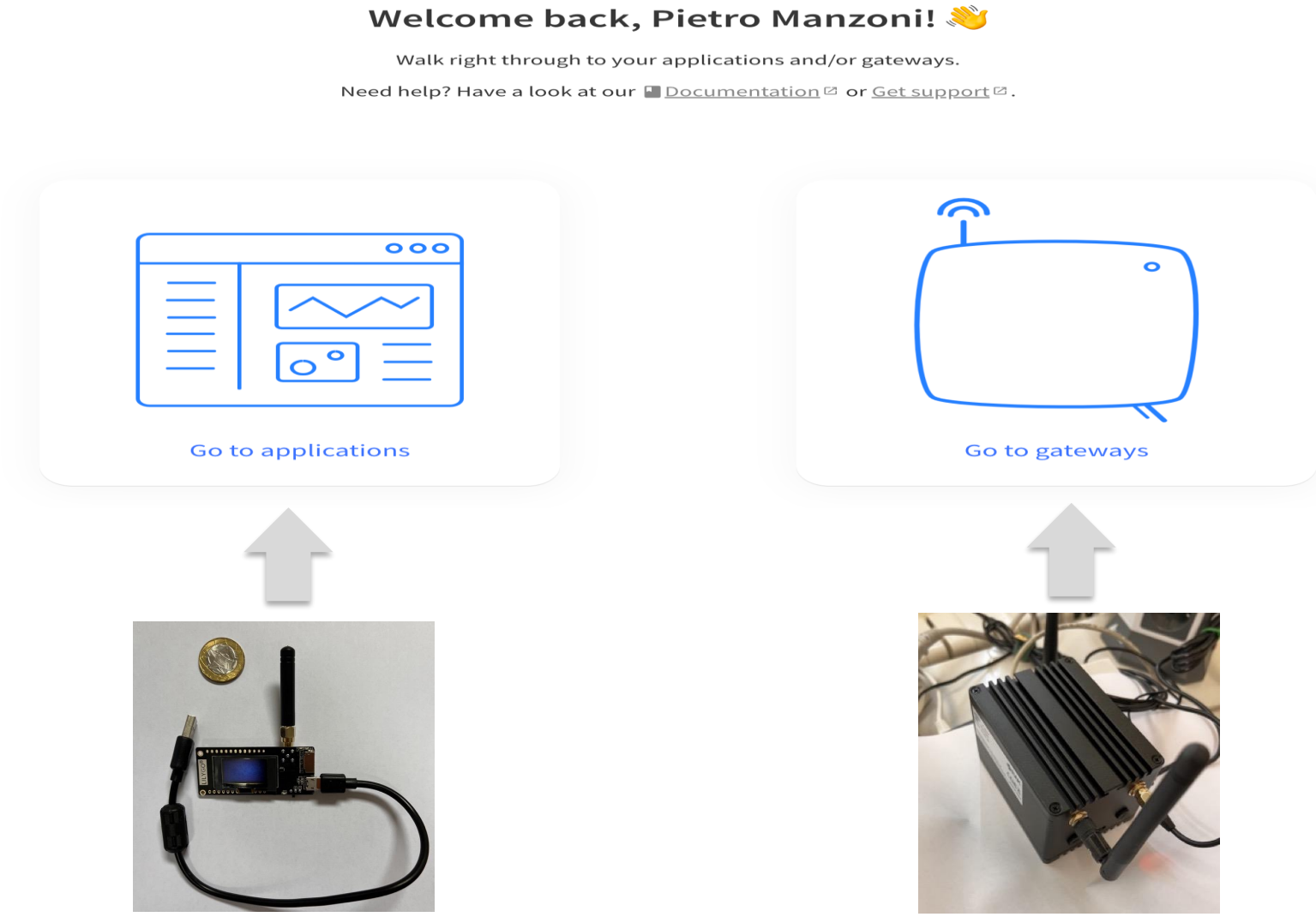
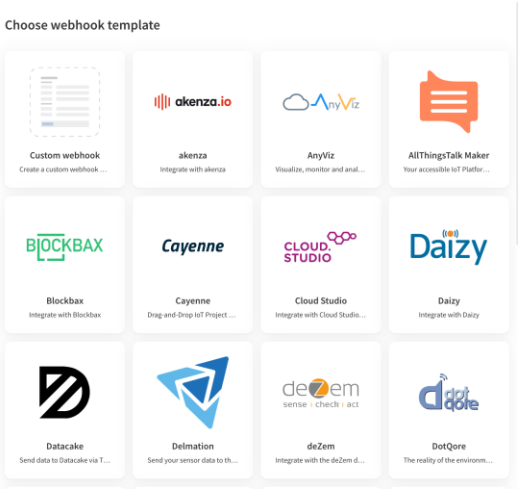
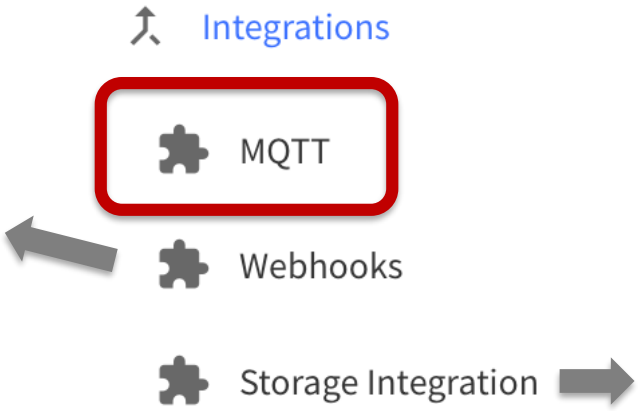


https://eu1.cloud.thethings.network/console/



«Integrations»

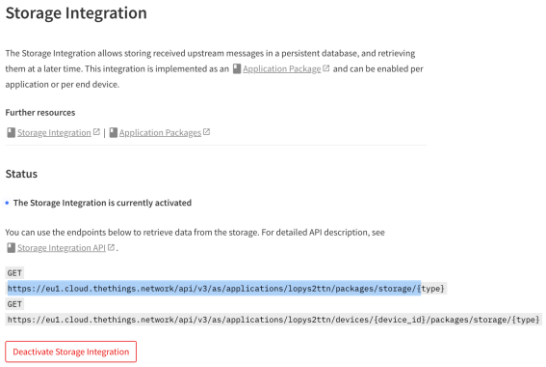




https://aws.amazon.com/es/iot/

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

https://www.loracloud.com/documentation/modem_services?url=#



MQTT Demo with…

http://mqtt-explorer.com

Any questions?

Pietro Manzoni

- Universitat Politècnica de València (UPV)
- pmanzoni@disca.upv.es

https://bit.ly/lora2cloud