Everything you wanted to know about LoRa and LoRaWAN… but were afraid to ask

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About the Talk

- The talk focuses on explaining the operational principles of LoRa (Long Range) technology and LoRaWAN (Long Range Wide Area Network), detailing how LoRa enables long-distance wireless communication with low power consumption and how LoRaWAN provides the network protocol and architecture that allows for efficient, secure, and scalable connectivity in various Internet of Things (IoT) applications.

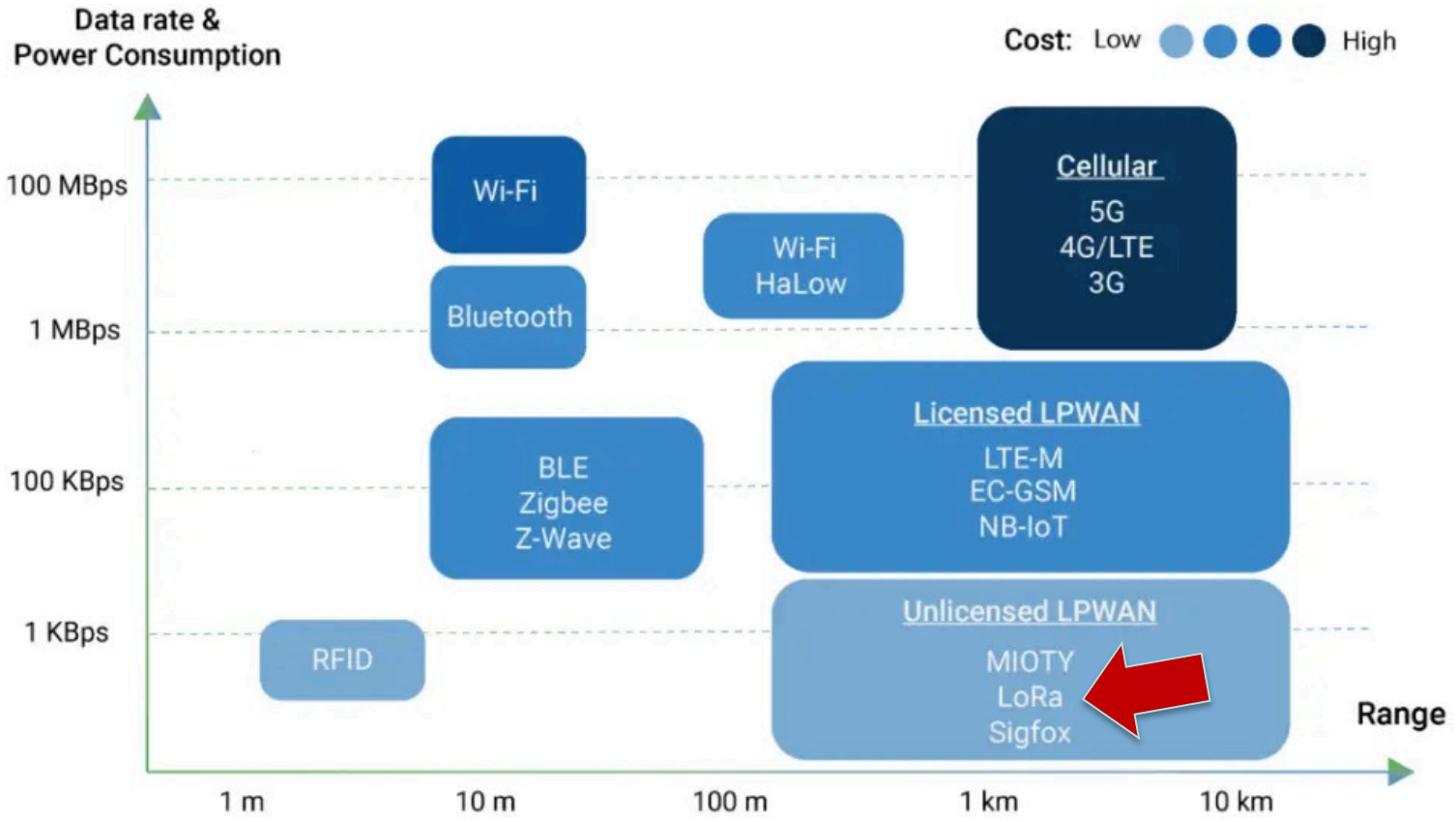
For a copy of these slides ➔

https://bit.ly/aboutLoRa

IoT for rural and extreme environments

- The Internet of Things (IoT) has the potential to collect real-time data from sensors, cameras, and other devices, making it beneficial for various applications.
- However, rural and extreme environments, such as remote areas, deserts, forests, or mountains, **lack reliable communication infrastructure**, presenting several technical challenges that must be overcome to use IoT in such settings successfully.

LPWAN: range vs power



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

https://www.rfc-editor.org/rfc/rfc8376

Internet Engineering Task Force (IETF)
Request for Comments: 8376
Category: Informational
ISSN: 2070-1721

S. Farrell, Ed.
Trinity College Dublin

May 2018

Low-Power Wide Area Network (LPWAN) Overview

Abstract

Low-Power Wide Area Networks (LPWANs) are wireless technologies with characteristics such as large coverage areas, low bandwidth, possibly very small packet and application-layer data sizes, and long battery life operation. This memo is an informational overview of the set of LPWAN technologies being considered in the IETF and of the gaps that exist between the needs of those technologies and the goal of running IP in LPWANs.

Status of This Memo

This document is not an Internet Standards Track specification; it is published for informational purposes.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Not all documents approved by the IESG are candidates for any level of Internet Standard; see Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at https://www.rfc-editor.org/info/rfc8376.

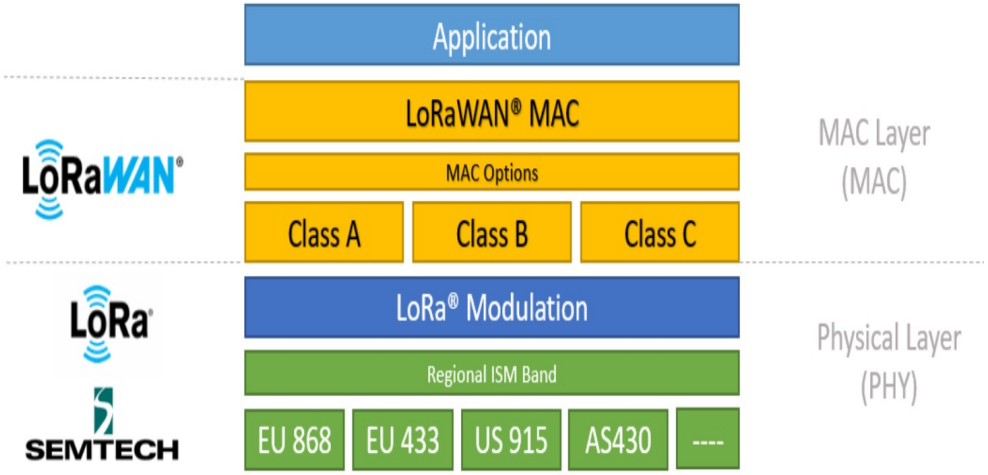
Why LoRaWAN?

- **Ultra low power -** LoRaWAN end devices are optimized to operate in low power mode and can last up to … 10 years on a single coin cell battery.
- **Long range -** LoRaWAN gateways can transmit and receive signals over 10 kilometers in rural areas and up to 3 kilometers in dense urban areas.
- **Deep indoor penetration -** LoRaWAN networks can provide deep indoor coverage, and easily cover multi floor buildings.
- **License free spectrum -** You don't have to pay expensive frequency spectrum license fees to deploy a LoRaWAN network.
- **Public and private deployments -** It is easy to deploy public and private LoRaWAN networks using the same hardware (gateways, end devices, antennas) and software (UDP packet forwarders, Basic Station software, LoRaWAN stacks for end devices).
- **End-to-end security-** LoRaWAN ensures secure communication between the end device and the application server using AES-128 encryption.
- **Low cost -** Minimal infrastructure, low-cost end nodes and open-source software.
- **Ecosystem-** LoRaWAN has a very large ecosystem of device makers, gateway makers, antenna makers, network service providers, and application developers.

https://www.thethingsnetwork.org/docs/lorawan/what-is-lorawan/

A first definition of LoRa and LoRaWAN

- **LoRa** (from "long range") is a physical proprietary (Semtech) radio communication technique. It uses spread spectrum modulation techniques derived from chirp spread spectrum (CSS) technology.
- **LoRaWAN** (Wide Area Network) defines the overall communication protocol and system architecture. LoRaWAN is an official standard of the International Telecommunication Union (ITU), ITU-T Y.4480.
- The continued development of the LoRaWAN protocol is managed by the open, non-profit LoRa Alliance, of which Semtech is a founding member.



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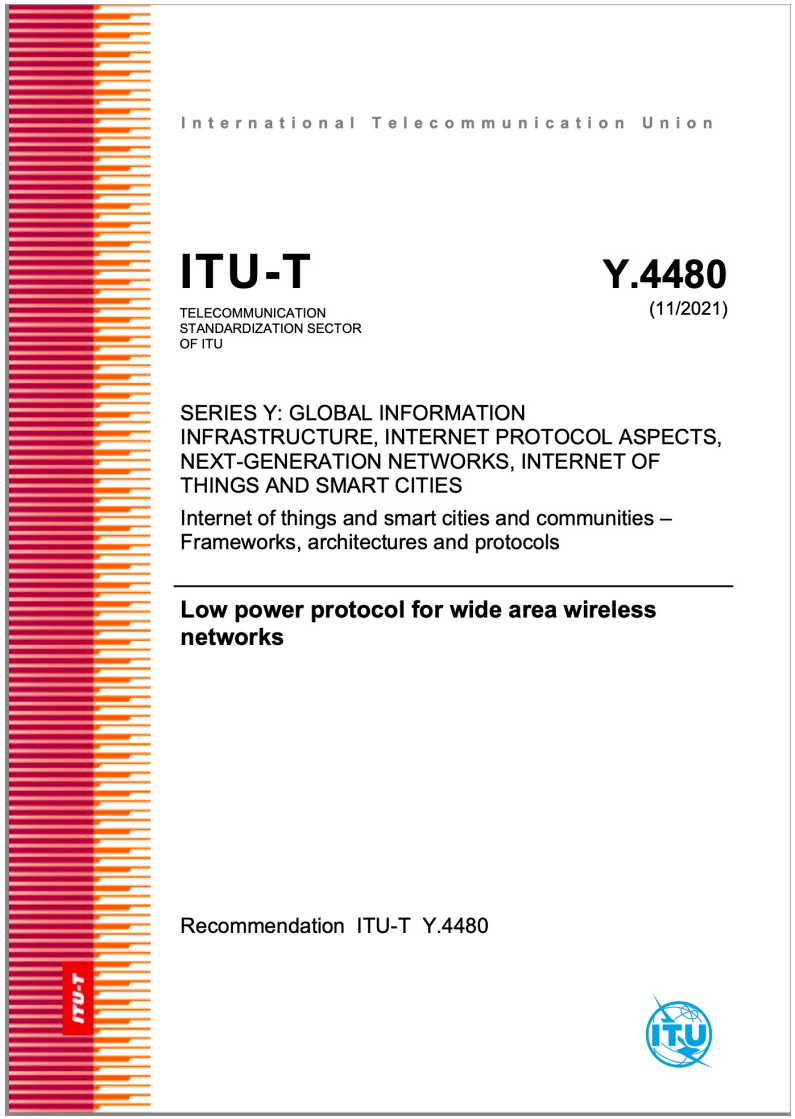
ITU-T Y.4480



International Telecommunication Union

ITU-T

TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

Y.4480

(11/2021)

SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Internet of things and smart cities and communities – Frameworks, architectures and protocols

Low power protocol for wide area wireless networks

Recommendation ITU-T Y.4480

ITU-T

Fremont, California Dec. 7, 2021

The LoRa Alliance … today announced that LoRaWAN was officially approved as a standard by the International Telecommunication Union (ITU), the United Nations specialized agency for information and communication technologies (ICTs).

The standard is titled Recommendation ITU-T Y.4480 Low power protocol for wide area wireless networks and is under the responsibility of Study Group 20 of the ITU Telecommunication Standardization Sector (ITU-T), ITU standardization expert group for Internet of Things and smart cities and communities.

https://www.itu.int/rec/T-REC-Y.4480-202111-I/en

https://lora-alliance.org/

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…"

LoRa Alliance®

LoRa Alliance®

LoRaWAN® L2 1.0.4 Specification (TS001-1.0.4)

Authored by the LoRa Alliance Technical Committee

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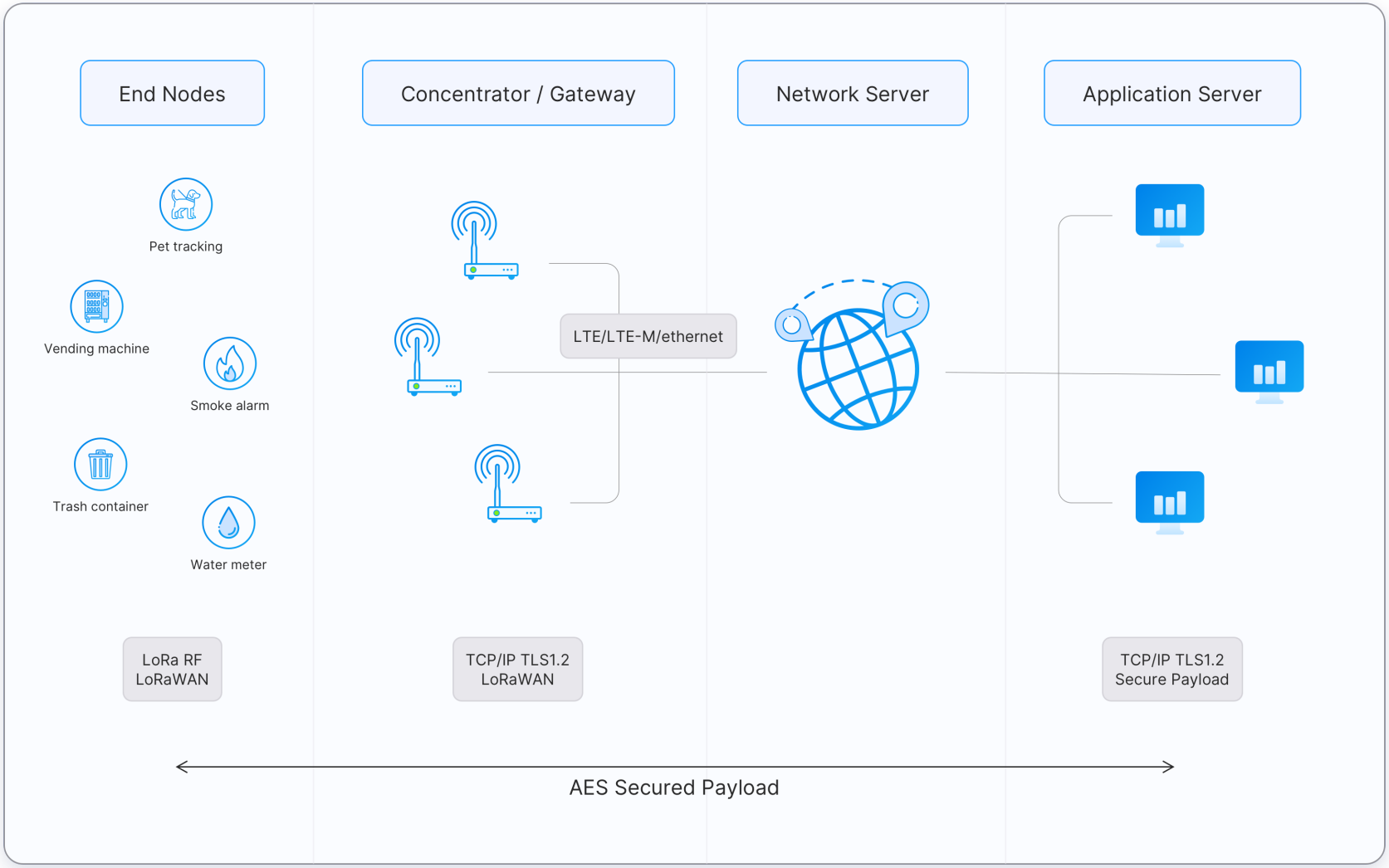
Version: 1.0.4
Date: October 2020
Status: Released

Specification is free to download:
https://resources.lora-alliance.org/technical-specifications

LoRaWAN network architecture



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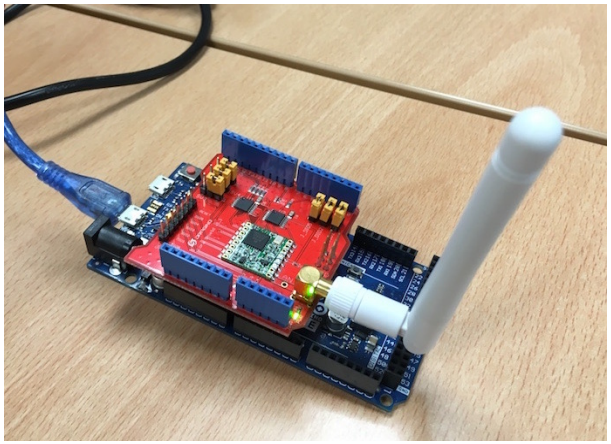
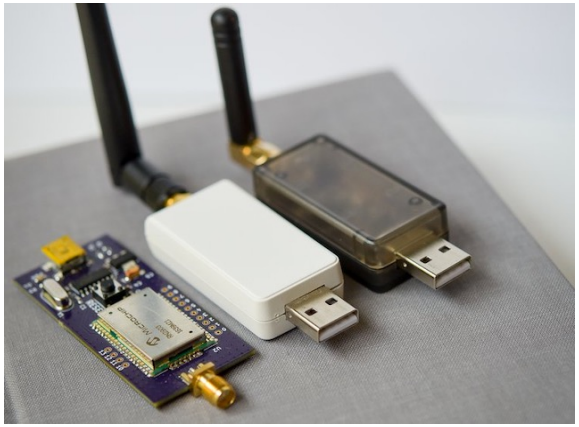
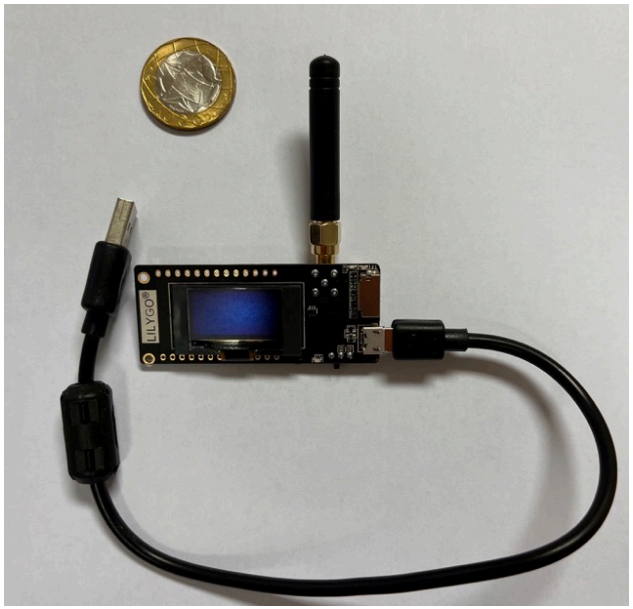
Some devices

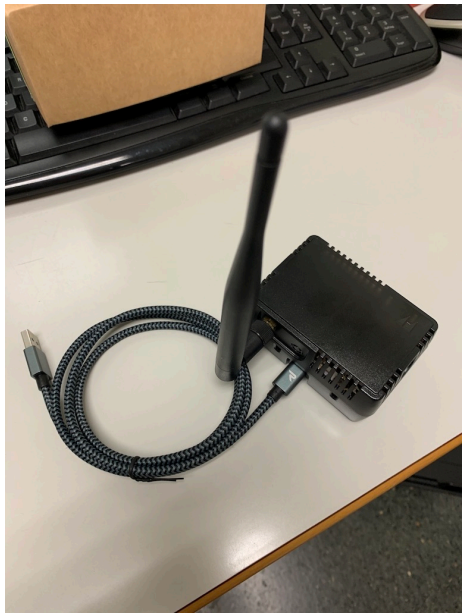


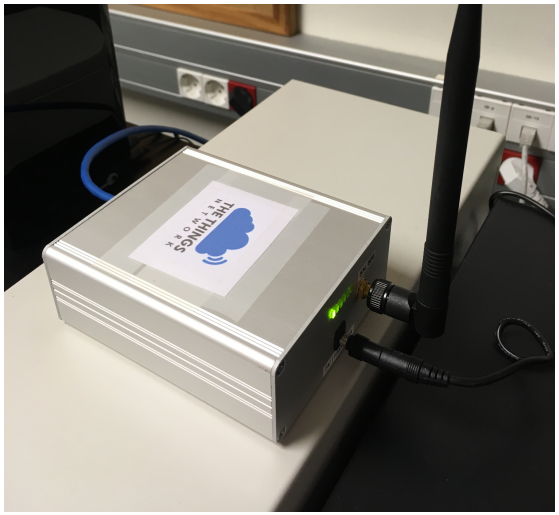


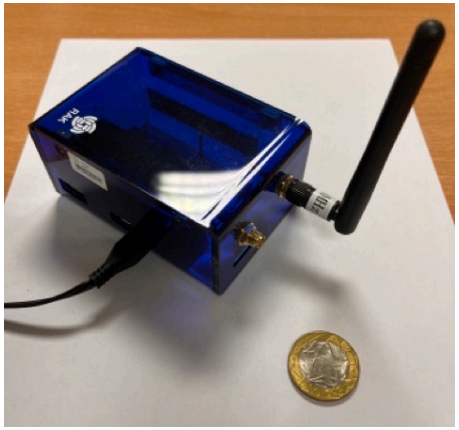


LoRaWAN tracking devices

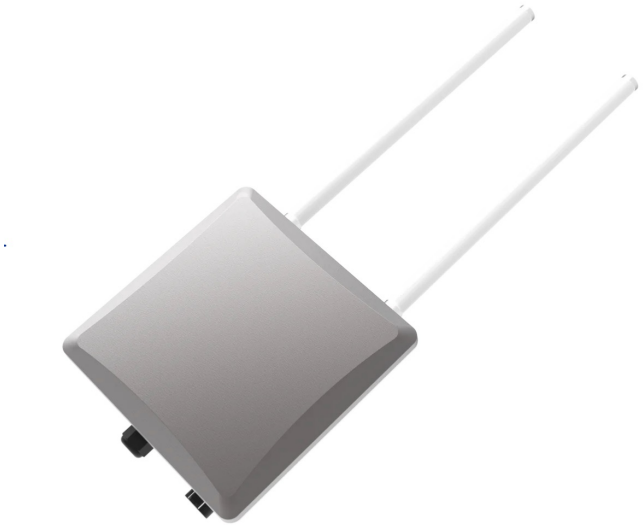
Gateways: examples







Gateways: examples



… not only for extreme environments…

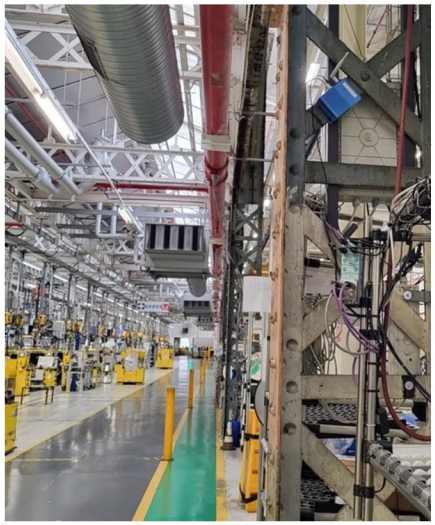
Story

Volvo Group implements a new Internet of Things (IoT) network to make factories smarter

2023-03-22

Reducing operational costs and improving maintenance service is a huge concern for automobile manufacturers, and for the Volvo Group manufacturing facility in Lyon, Franc is no exception.

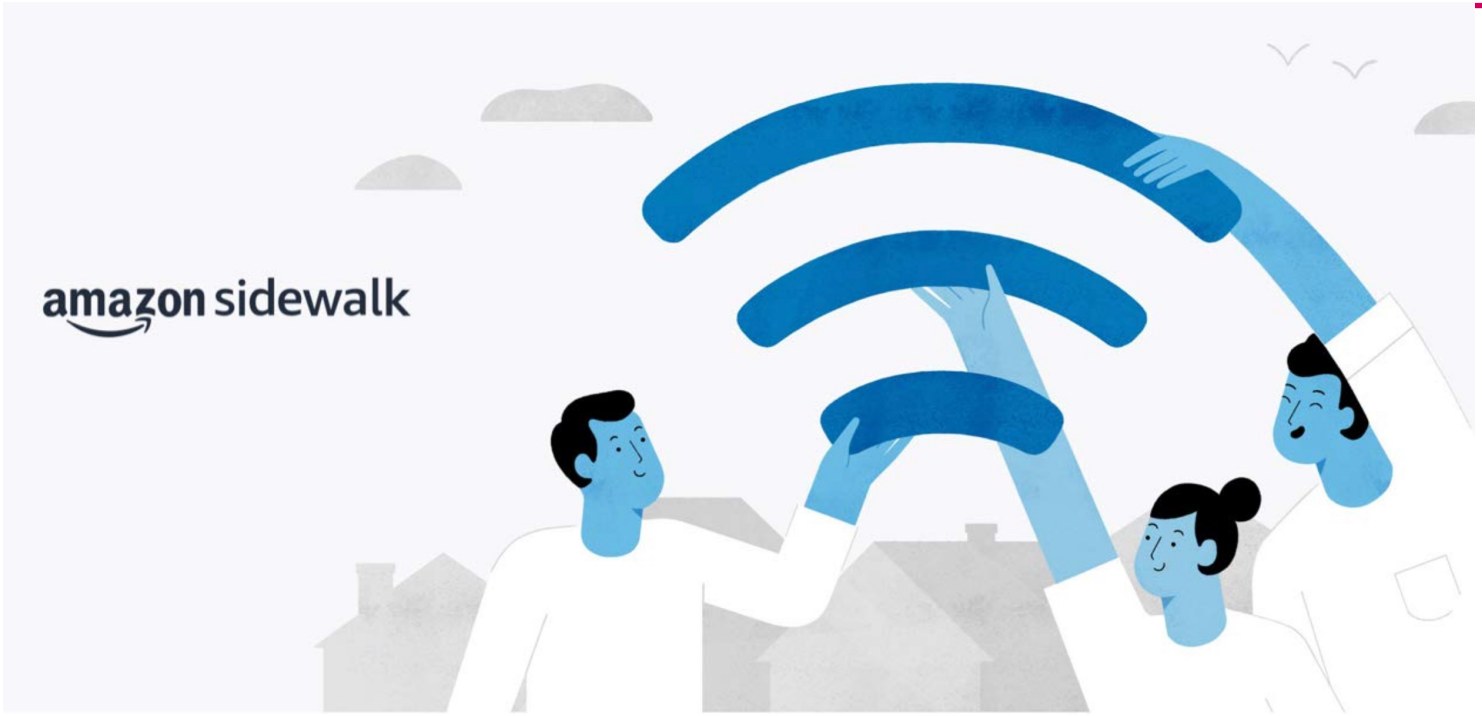
To proactively monitor the health of the AGVs and prevent their shutdown, the IoT team at Volvo Group Digital & IT, supporting the factory in Lyon, envisioned a wireless system for predictive maintenance. The team initially looked at WIFI technology, but the WIFI 2.4GHz band was already being used for critical processes in the production line. Faced with this challenge, the IoT teamlooked toward LoRaWAN, a LPWAN protocol designed to connect battery-operated 'things' to the internet for powering the large fleet of AGVs. LoRaWAN is ideally suited to the manufacturing process as it provides long-range capability, good resistance to interferences, and a secured and flexible network architecture.



MultiTech gateway installed in the factory

The team also installed their own LoRaWAN sensor on every AVG to receive periodic voltage data of the battery levels (<23V) or battery failures. With the new system, the maintenance team receives regular notifications, providing more time to move the AVGs to the charge point, without blocking the production line. They can also organize interventions in cases of battery failure.

… not only for extreme environments…



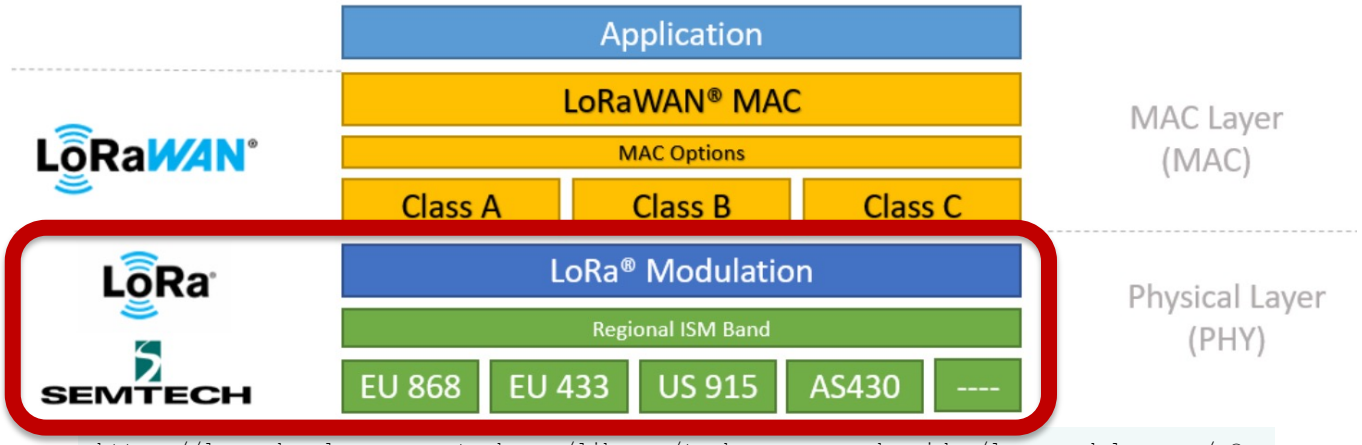
Welcome to Amazon Sidewalk

Amazon has released this data in conjunction with the official opening of Sidewalk to developers. First announced in 2019, Amazon Sidewalk is a new low-power, wide-area network (LPWAN) that Amazon believes will help enable the next wave of connected devices. It's not designed to replace cellular data for high-bandwidth devices but to be used instead of expensive LTE or 5G connectivity on gadgets that don't need that much data and where paying $10 or more a month for data is excessive.

Let's start with LoRa

LoRa basics

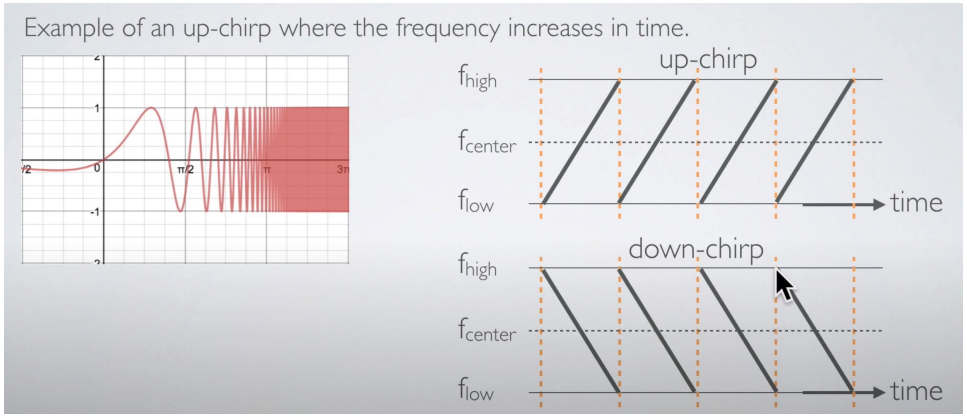
- LoRa is the physical layer, or the wireless modulation used to create the long-range communication link.
- LoRa modulation uses Spread Spectrum to transmit its data. Instead of using "codes", it uses "Chirps" and that is why it is called Chirp Spread Spectrum (CSS) modulation.
- Chirp spread spectrum 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.
  - *Chirp: Compressed High Intensity Radar Pulse*

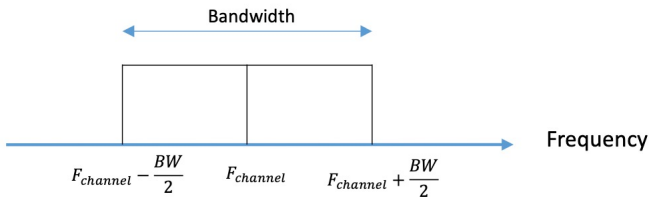


https://lora-developers.semtech.com/library/tech-papers-and-guides/lora-and-lorawan/ ©

Chirp Modulation

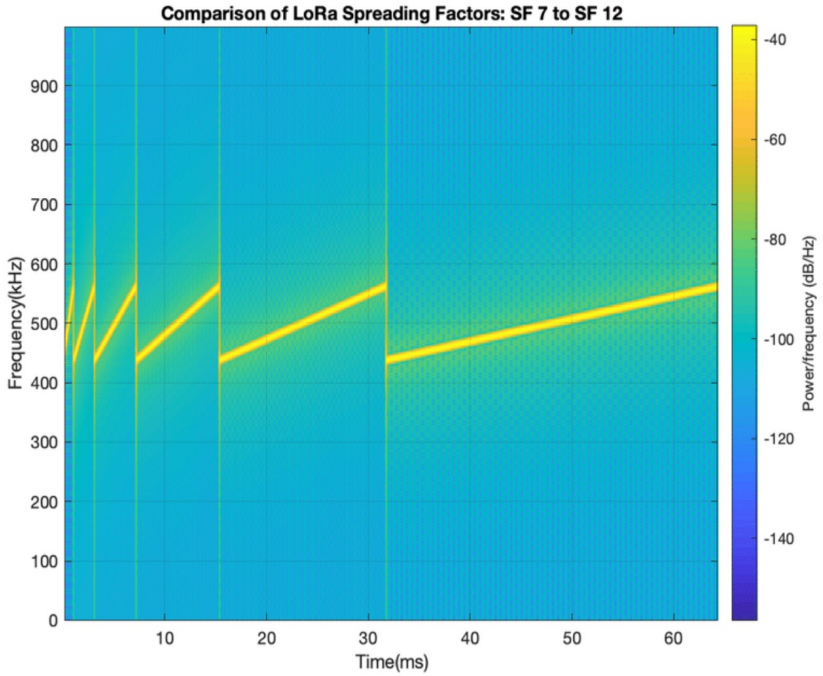
A chirp is a signal in which the frecuencies increases (up-chirp) or decreases (down-chirp) with time





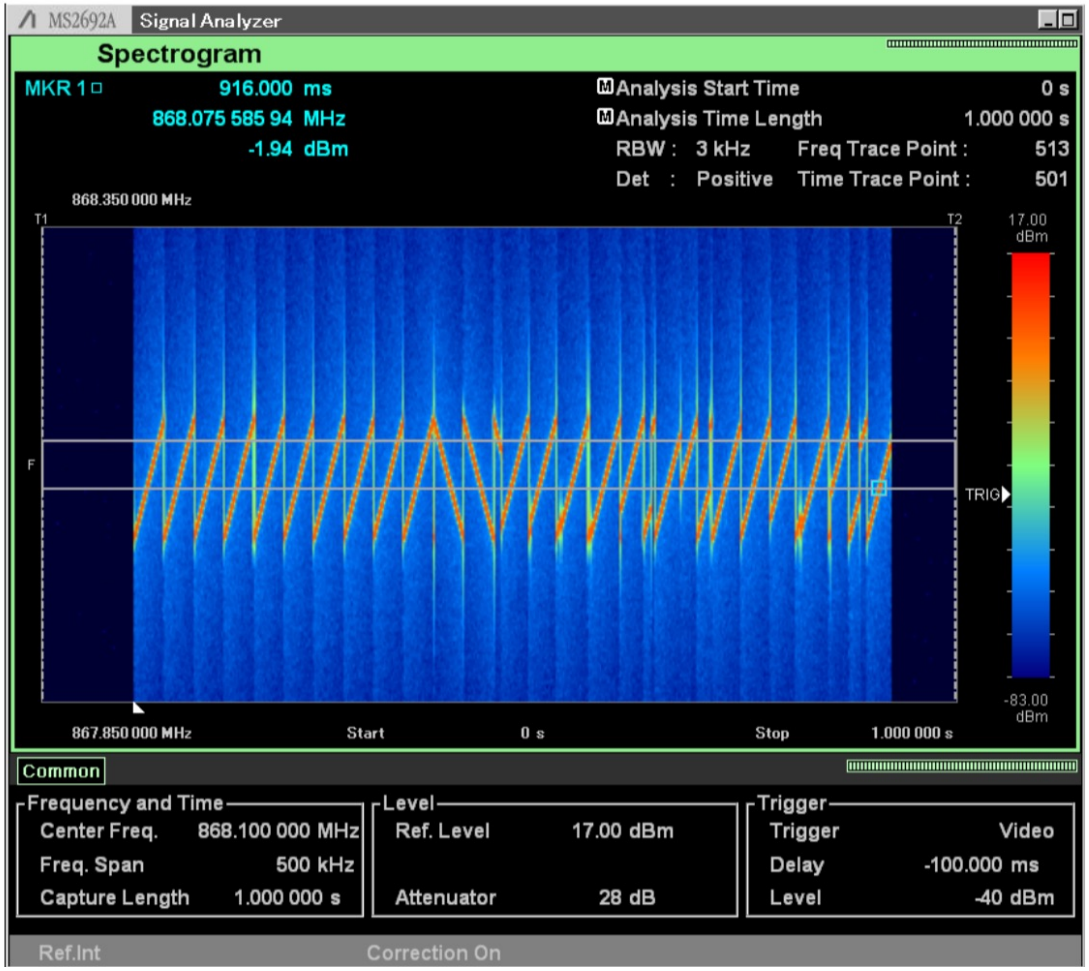
There are 2 critical factors

- **Bandwidth** (BW): 3 possible values 125, 250, and 500 kHz.
- **Spreading factor** (SF): 6 values from SF7 to SF12



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.

Spectrogram of a LoRa packet



Gaelens, Johnny & Van Torre, Patrick & Verhaevert, Jo & Rogier, Hendrik. (2017). LoRa Mobile-To-Base-Station Channel Characterization in the Antarctic. Sensors (Switzerland). 17. 10.3390/s17081903.

Influence of Spreading Factors

- **Data rate**
  - A lower spreading factor provides a higher bit rate for a fixed bandwidth and coding rate.

Case 1: For SF7, 125 kHz > bit rate = **6,836 bps**
Case 2: For SF12, 125 kHz > bit rate = **366 bps**

$$Bit\ Rate = SF.\frac{Bandwidth}{2^{SF}}$$

- **Time-On-Air**
  - Compared to a lower spreading factor, sending a fixed amount of data (payload) with a higher Spreading Factor and a fixed bandwidth needs longer time-on-air.
- **Receiver Sensitivity**
  - Higher spreading factors provide higher receiver sensitivity.
- **Battery Life**
  - The battery life of an end device is highly dependent on the spreading factor used. Higher spreading factors result in longer active times for the radio transceivers and shorter battery life.

Coding Rate

- The Coding Rate is a ratio that increases the number of bits transmitted in order to carry out error detection and correction. In the case of a CR = 4 / 8, there is 8 bits truly transmitted each time we want to transmit 4 bits.

CodingRate (RegModemConfig1)	Cyclic Coding Rate	Overhead Ratio
1	4/5	1.25
2	4/6	1.5
3	4/7	1.75
4	4/8	2

- For example
  - For SF7, 125 kHz and CR4/5 → bit rate = 6.836 kbps / 1.25 = 5469 bps
  - For SF12, 125 kHz and CR4/5 → bit rate = 366 bps/1.25=293bps
- **The documentation of a LoRa transceiver gives the data rates according to the Spreading Factor, the Bandwidth and the Coding Rate.**

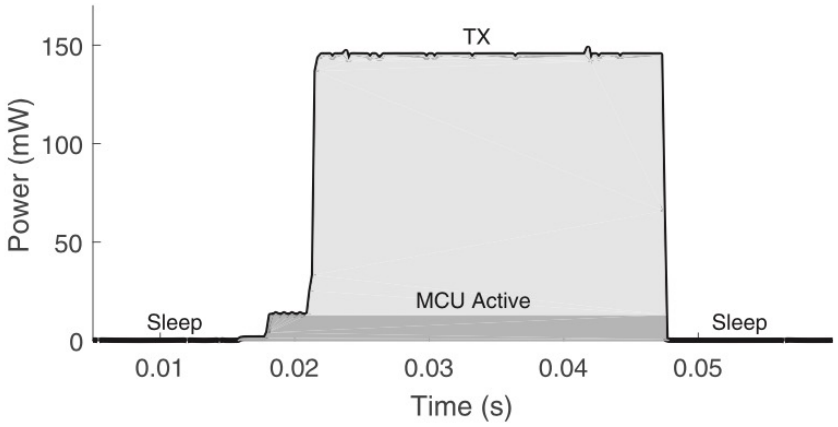
- An online LoRa simulator is also available at https://loratools.nl/#/airtime

EU863-870 Data Rates

Data Rate	Configuration (SF + BW)	Bit rate (bit/s)
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000

Data Rate	Spreading Factor	Bandwidth	Max Frame payload (Number N)
DR 0	SF12	125 kHz	51 bytes
DR 1	SF11	125 kHz	51 bytes
DR 2	SF10	125 kHz	51 bytes
DR 3	SF9	125 kHz	115 bytes
DR 4	SF8	125 kHz	242 bytes
DR 5	SF7	125 kHz	242 bytes
DR 6	SF7	250 kHz	242 bytes

About energy



Energy consumption captured by power monitor for a LoRa transmission with parameter SF7, CR4/5, 125kHz BW, 2dBm TX Pow, and 9 Bytes payload.

Table 2. LoRa Packets Energy Budget Breakdown with PL = 6 Bytes, CR = 4/8, BW = 125kHz, 15min per Packet for SF7 and SF12, and Battery Capacity of 3.7V 2Ah

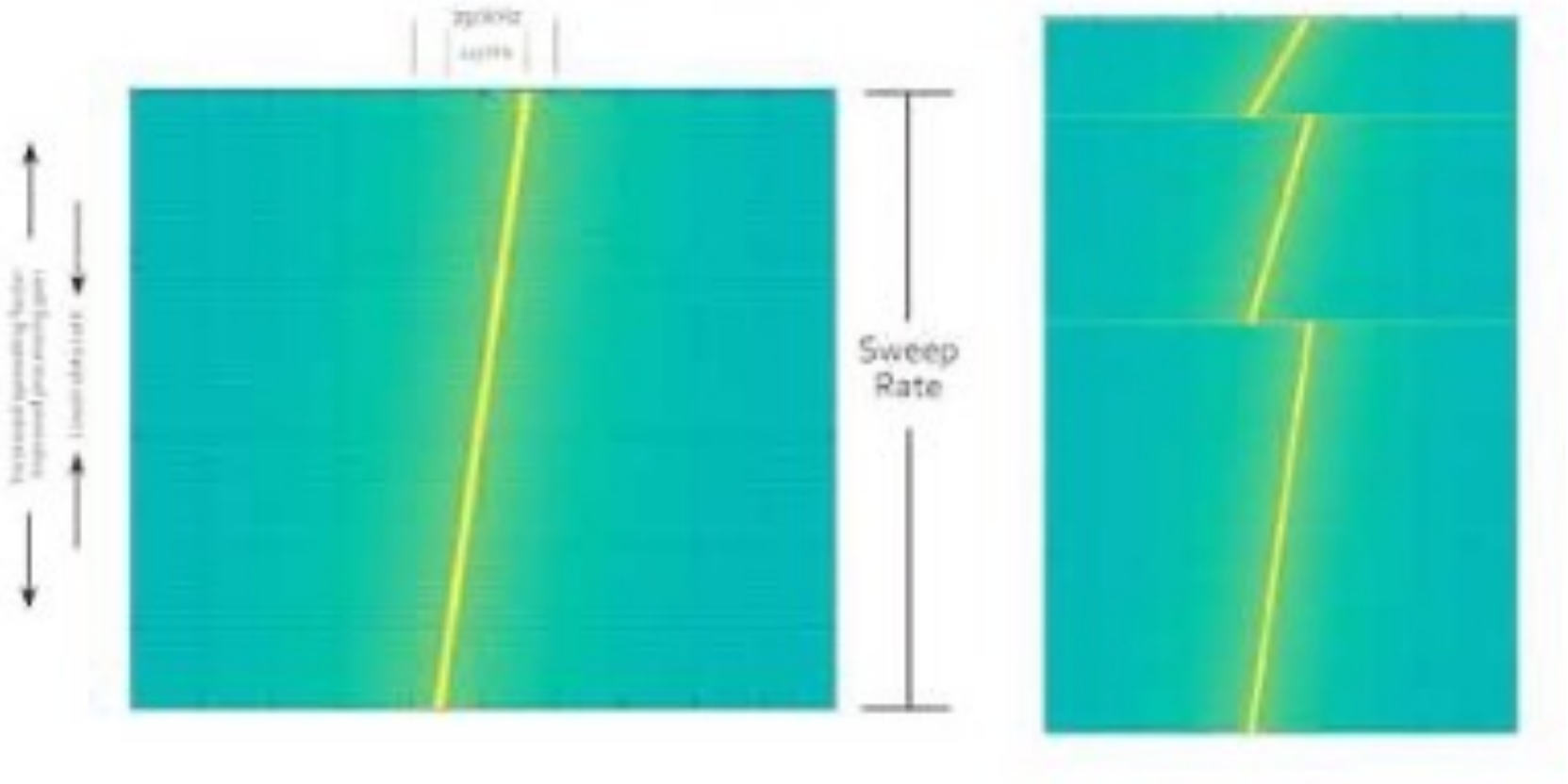
States		Time (ms)	Energy (mJ)	Budget (%)
SF7 2dBm	MCU Active	40.50	0.50	0.30
	MCU Sleep	899,959.50	71.28	43.14
	Radio TX	38.85	4.36	2.64
	Radio Sleep	899,961.15	89.10	53.92
	Total		165.24	4.60 years
SF12 20dBm	MCU Active	933.00	12.25	2.22
	MCU Sleep	899,067.00	71.21	12.87
	Radio TX	926.70	380.73	68.82
	Radio Sleep	899,071.30	89.01	16.09
	Total		553.20	1.37 years

Table 3. Energy Consumption for Different Type of MCU During a LoRa Packet Transmission

MCU	E_{MCU_On}	E_{MCU_Off}
Arduino Pro Mini	12.49mW	81.08μW
Arduino Uno	23.48mW	174.65μW
Raspberry Pi	1.41W	

Jansen C. Liando, Amalinda Gamage, Agustinus W. Tengourtius, and Mo Li. 2019. Known and Unknown Facts of LoRa: Experiences from a Large-scale Measurement Study. ACM Trans. Sen. Netw. 15, 2, Article 16 (May 2019), 35 pages. https://doi.org/10.1145/3293534

LoRa CHIRP by Richar Wenner

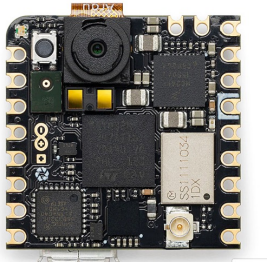


https://www.youtube.com/watch?v=dxYY097QNs0

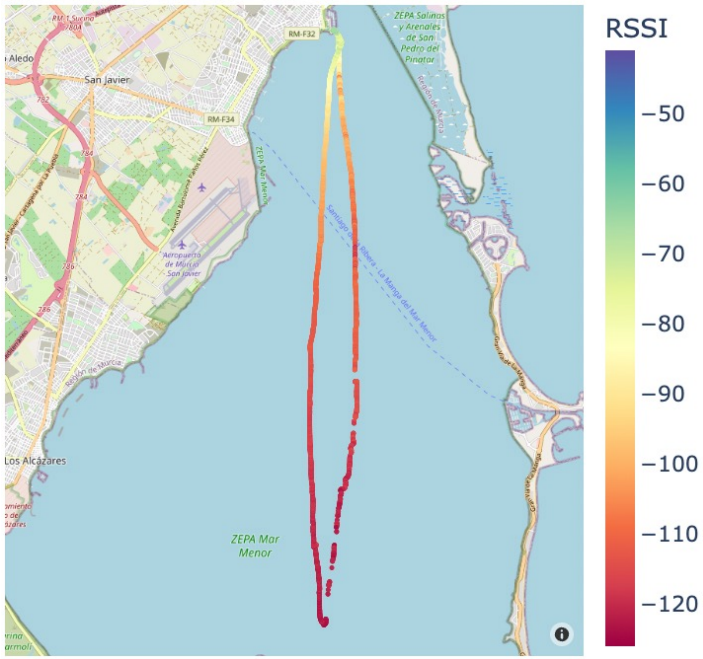
Can I use LoRa alone? Yes! For example…

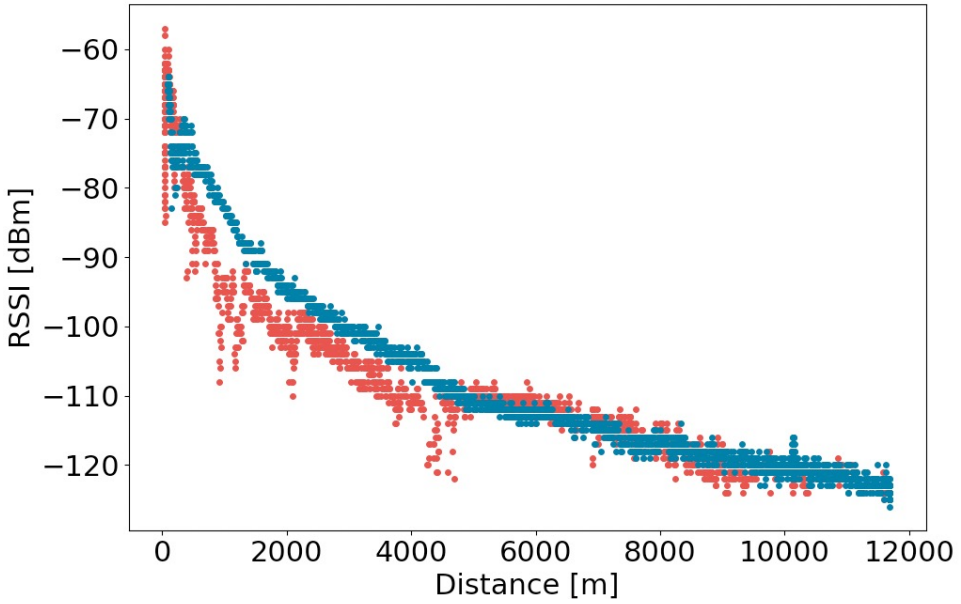
AlLoRa: modular, mesh, multi-device LoRa Content Transfer Protocol

https://github.com/SMARTLAGOON/AlLoRa



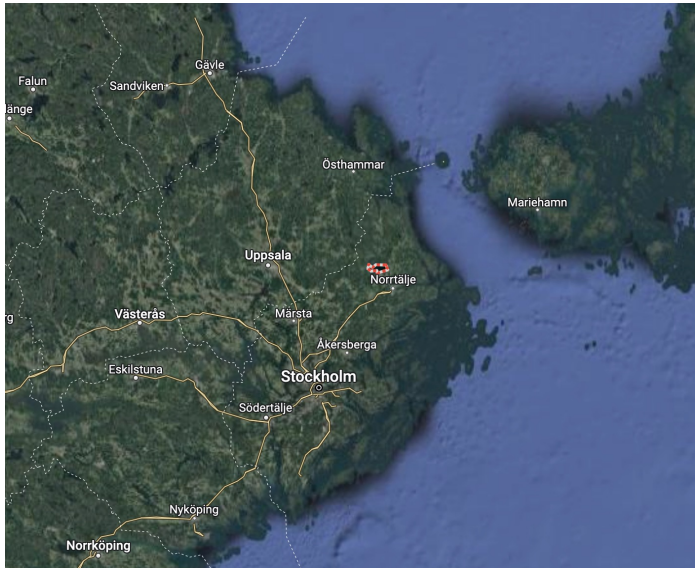
Evaluated scenario: Mar Menor, Murcia, Spain

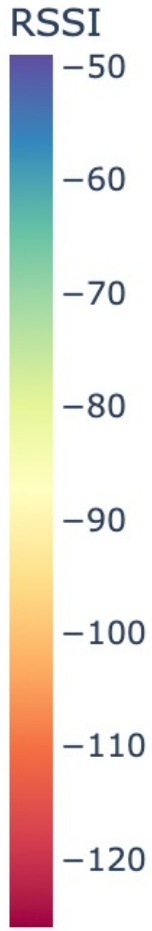




goodput = ~ 2.400 bps

Evaluated scenario: Erken Lake in Sweden

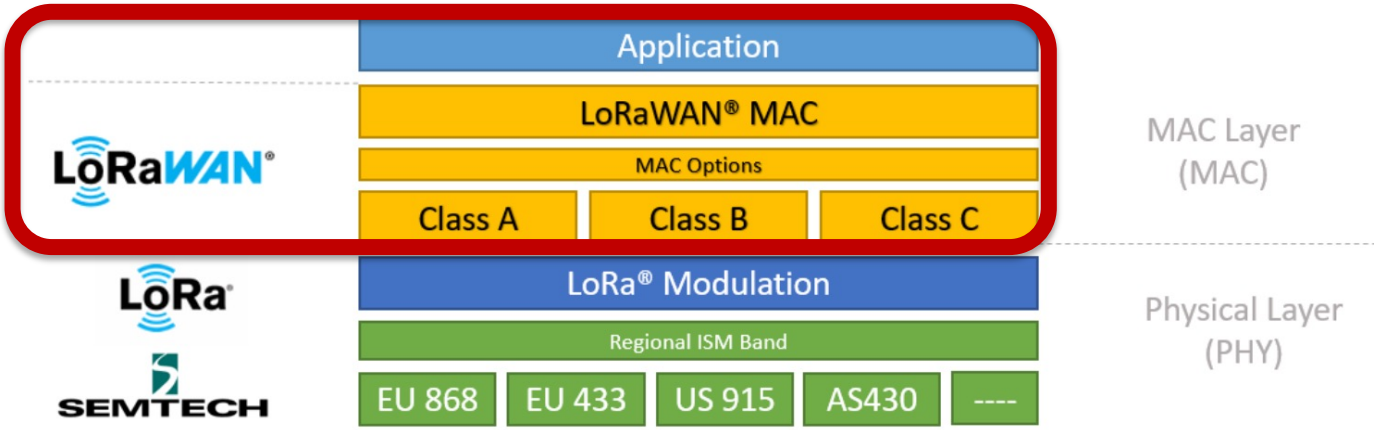




Let's continue with LoRaWAN

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.



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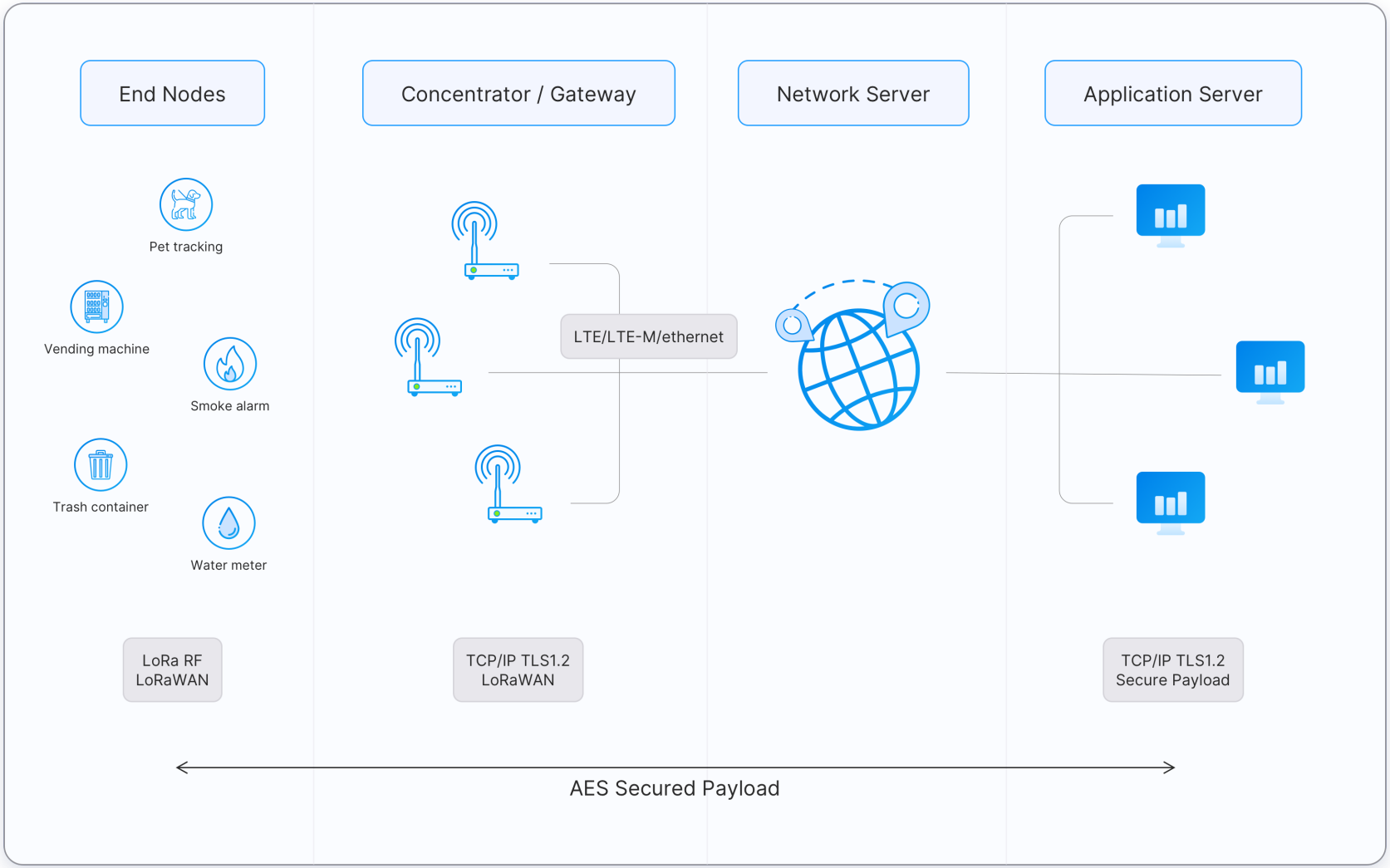
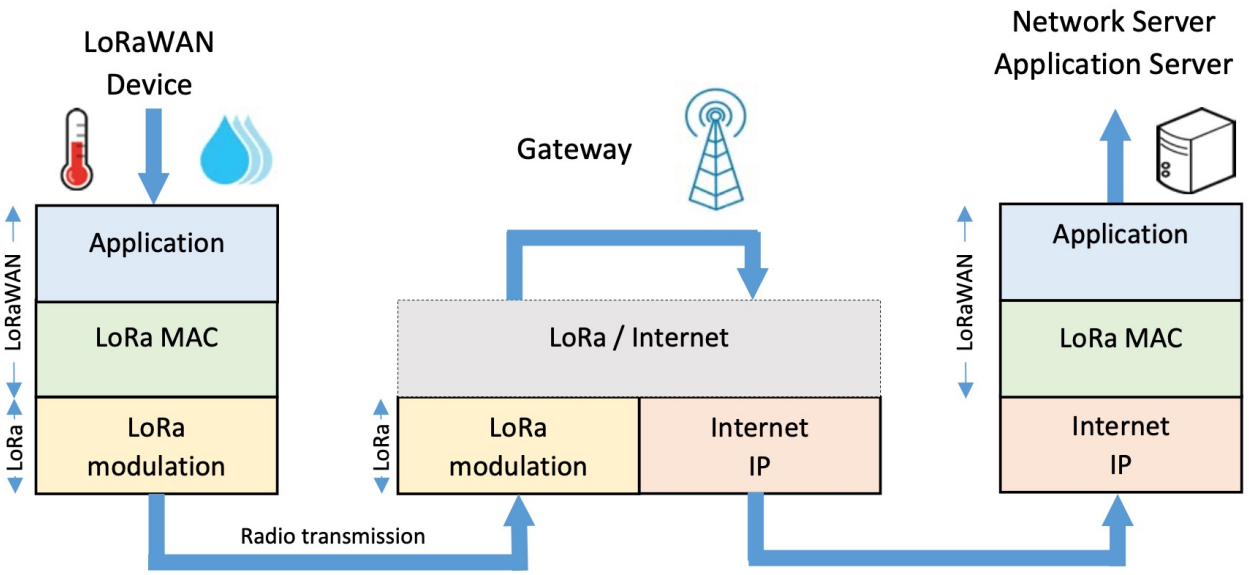
LoRaWAN network architecture



LoRaWAN gateways

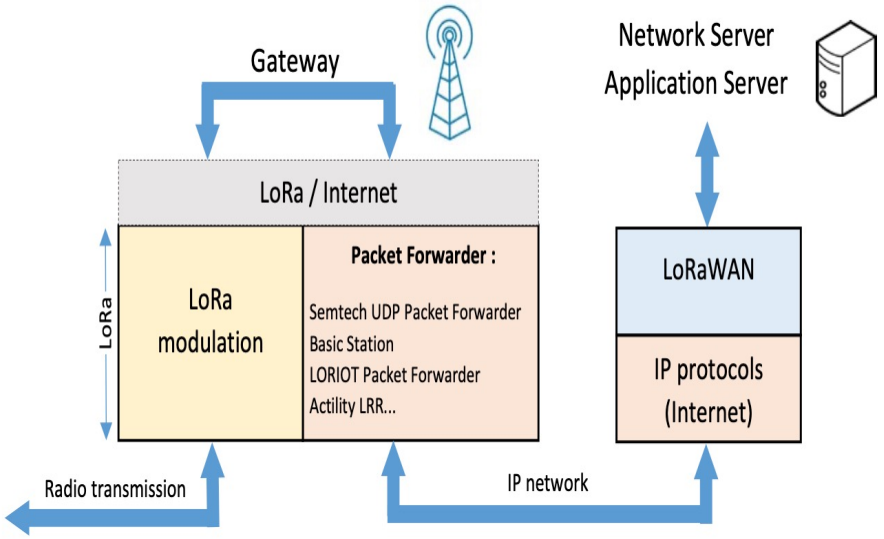
- They listen on all channels and on all Spreading Factors simultaneously. When a LoRa frame is received, it transmits its content over the internet to the Network Server previously configured in the gateway.
- On one side, the gateway receives a LoRa modulation on its antenna. On the other side, it is connected to the internet via any possible backhaul: WiFi, 3G, 4G, 5G, Ethernet, LTE-M…
- Each LoRaWAN gateway has a unique identifier (64 bits EUI). This ID is useful for registering and activating a Network Server gateway.



© https://www.univ-smb.fr/lorawan/en/

Detail of a LoRaWAN gateway

- **SEMTECH UDP Packet Forwarder**: This was the first widely used Packet Forwarder. It is now deprecated because it has no functionalities other than transmitting uplink and downlink data. It is also a non-secure protocol. This Packet Forwarder is supported by The Things Stack, but according to the documentation, it will be removed in the future. It is still supported by ChirpStack.
- **LoRa BasicsTM Station Packet Forwarder**: LoRa BasicTM Station is the new Packet Forwarder provided by Semtech. It offers many additional features: TLS, gateway software update, time synchronization, gateway management, etc...
- ...



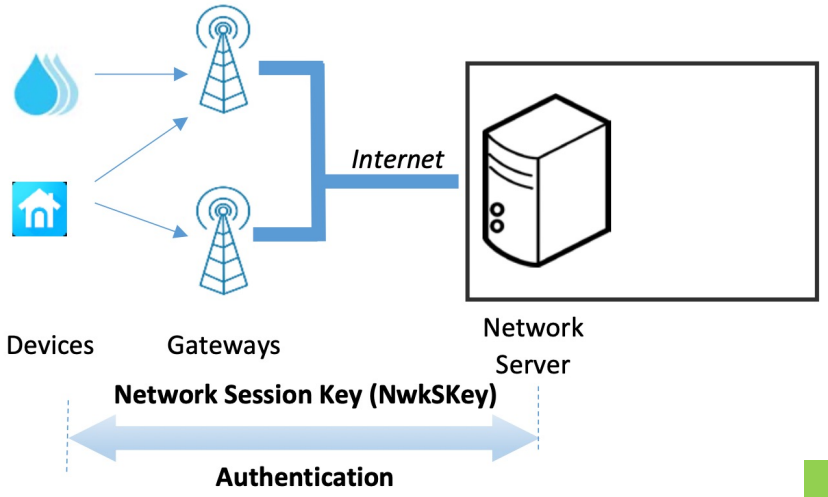
https://lora-developers.semtech.com/build/software/lora-basics/lora-basics-for-gateways/

https://github.com/lorabasics/basicstation

© https://www.univ-smb.fr/lorawan/en/

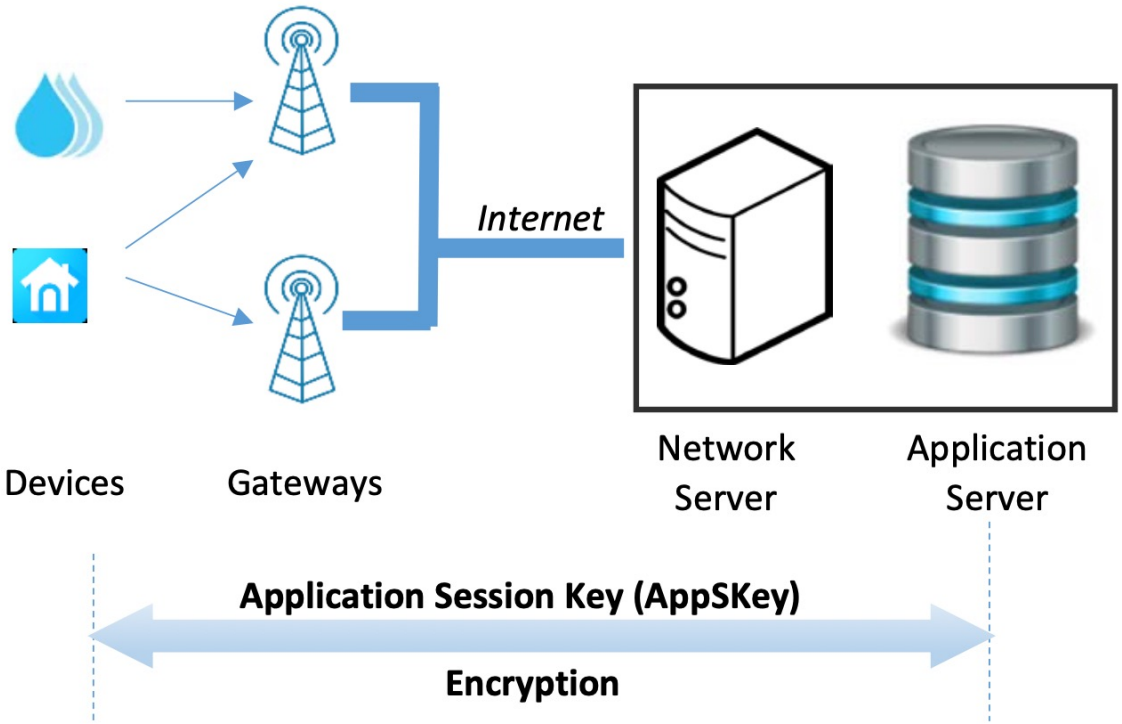
The Network Server

- The Network Server receives the messages transmitted by the gateways and removes **duplicate packets** (several gateways may receive the same message and transmit them to the same Network Server). Then, the Network Server authenticates the message thanks to a 128-bit AES key called **NwkSKey** (Network Session Key). We are talking about authentication, not encryption.
  - If the authentication process fails, the Network Server drops the LoRaWAN message.
  - If the authentication process succeeds, the Network Server transfers the message to the Application Server.



Application Server

- The Application Server receives encrypted messages from a Network Server. Encryption is made thanks to a 128-bit AES key called **AppSKey** (Application Session Key).



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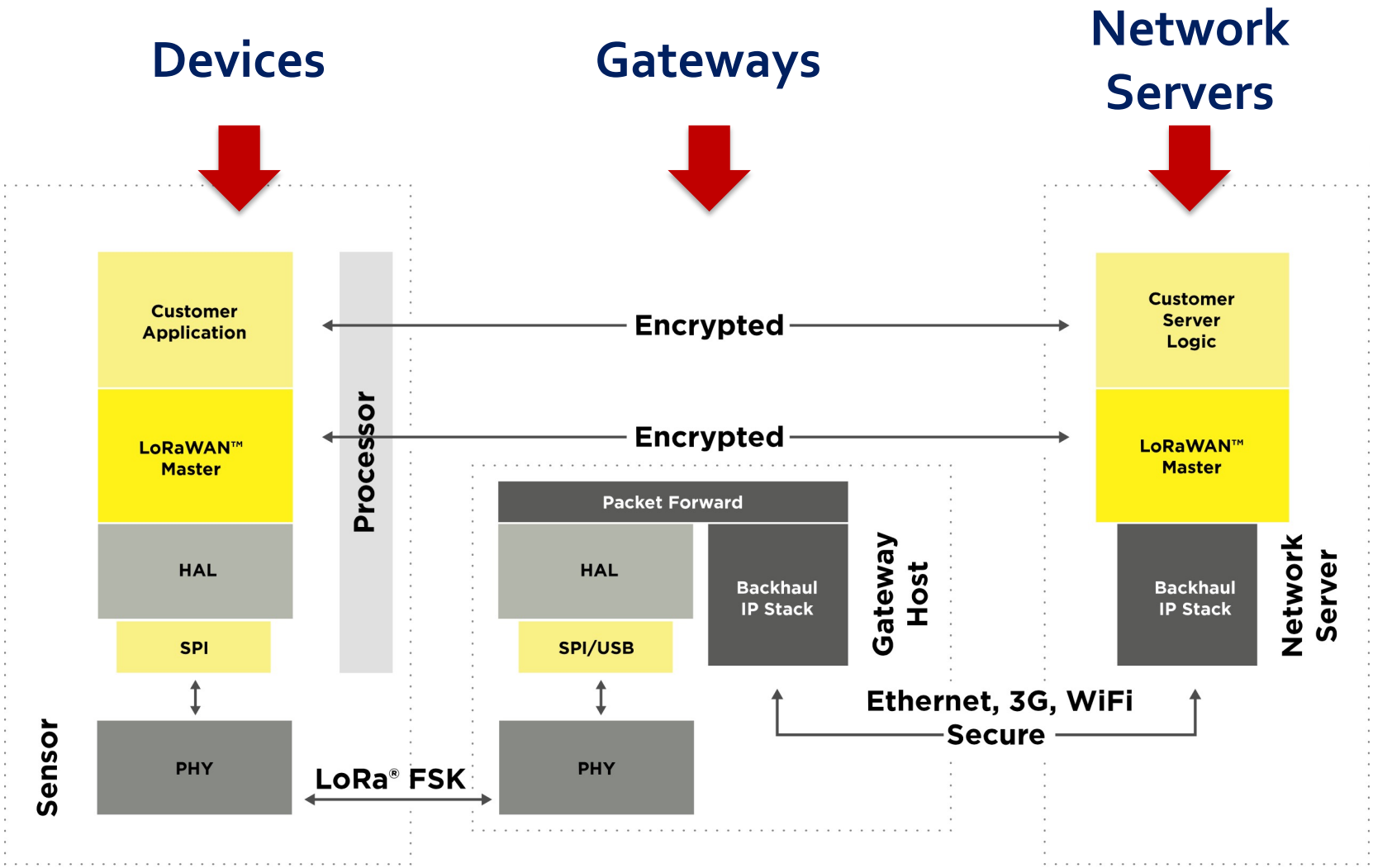
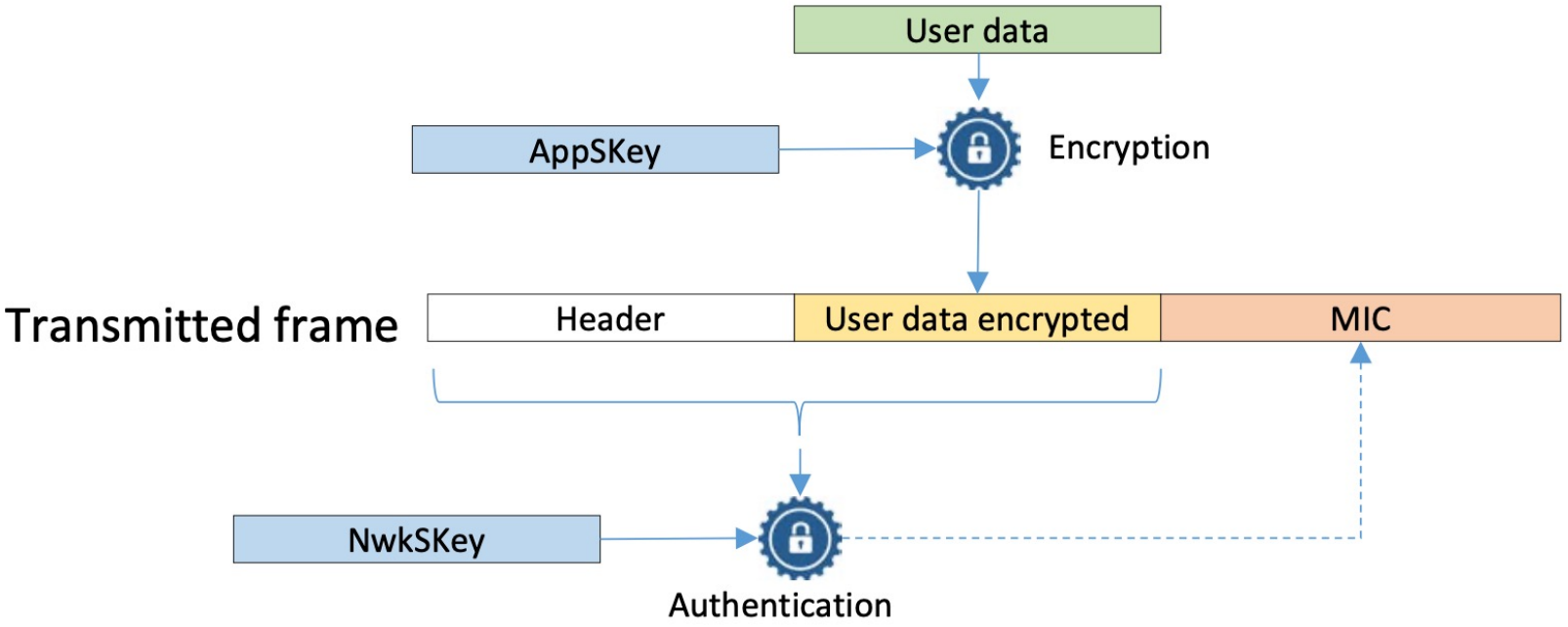
LoRaWAN data flow



HAL: Hardware Abstraction Layer

Combining authentication and encryption



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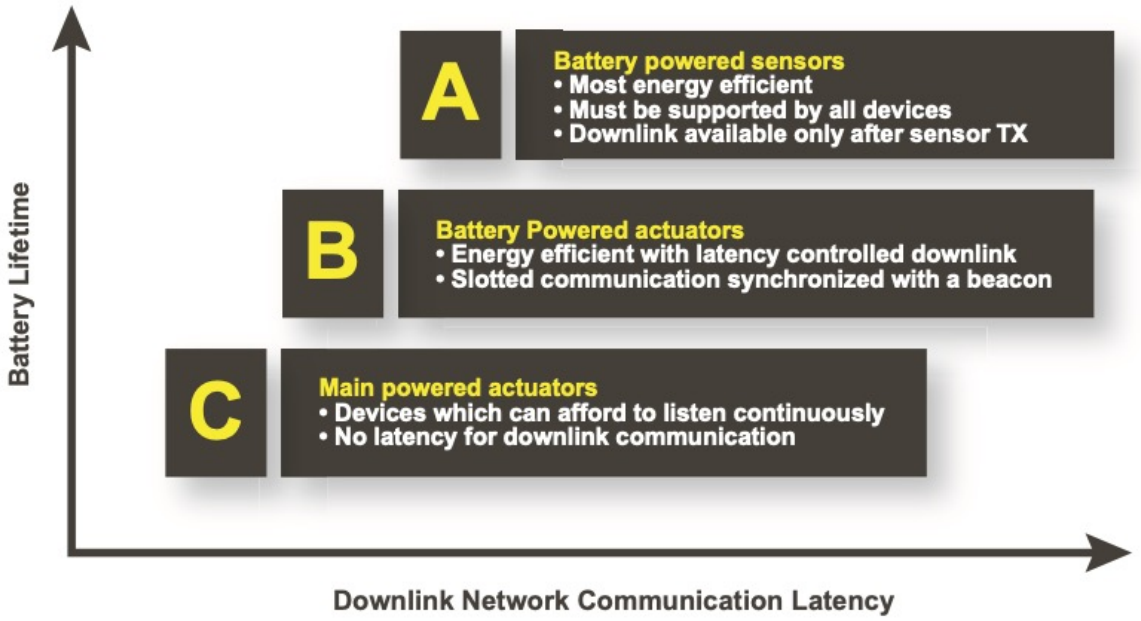
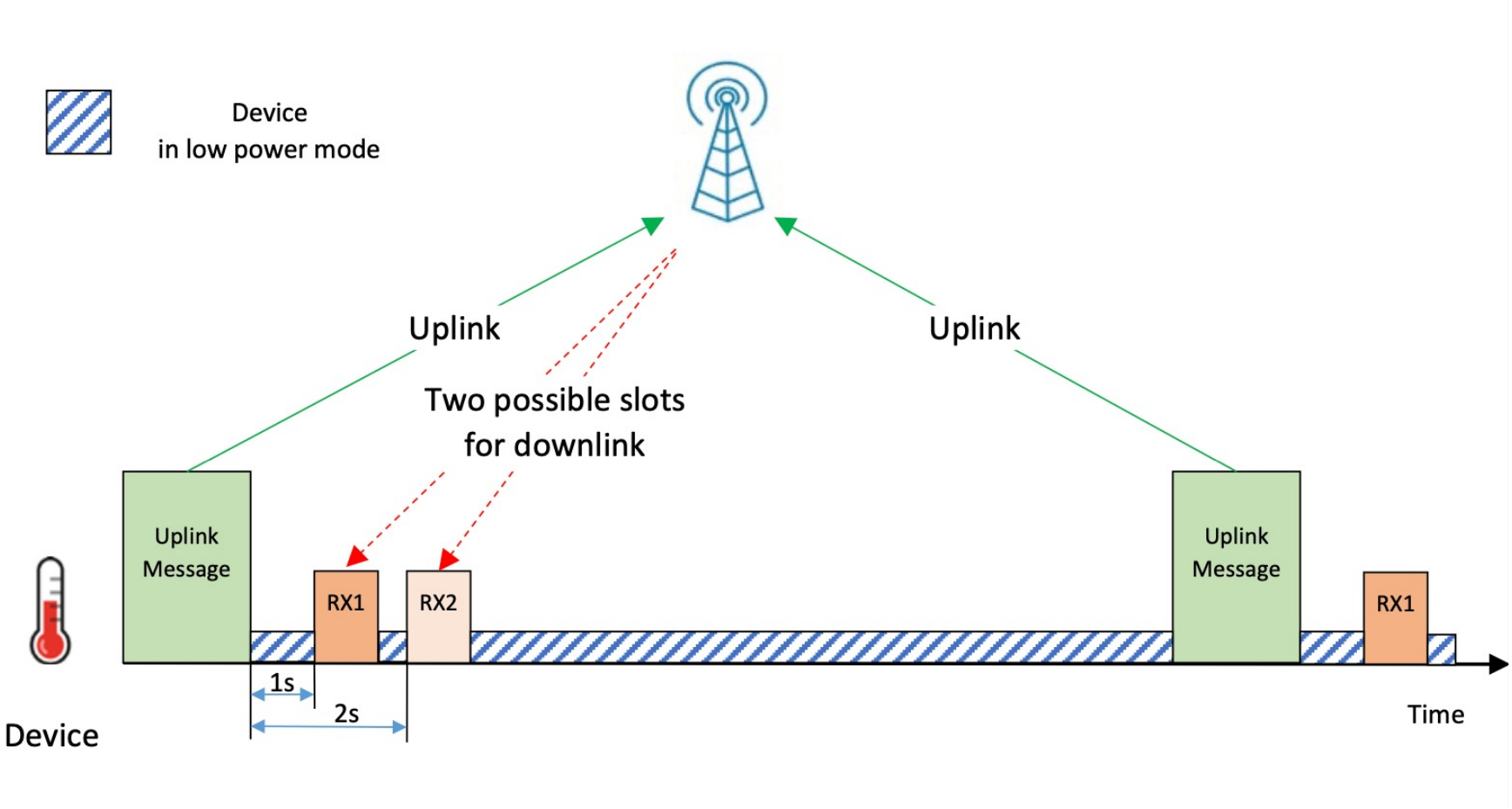
Three types of devices

- 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

Class A (All): Minimal power Application



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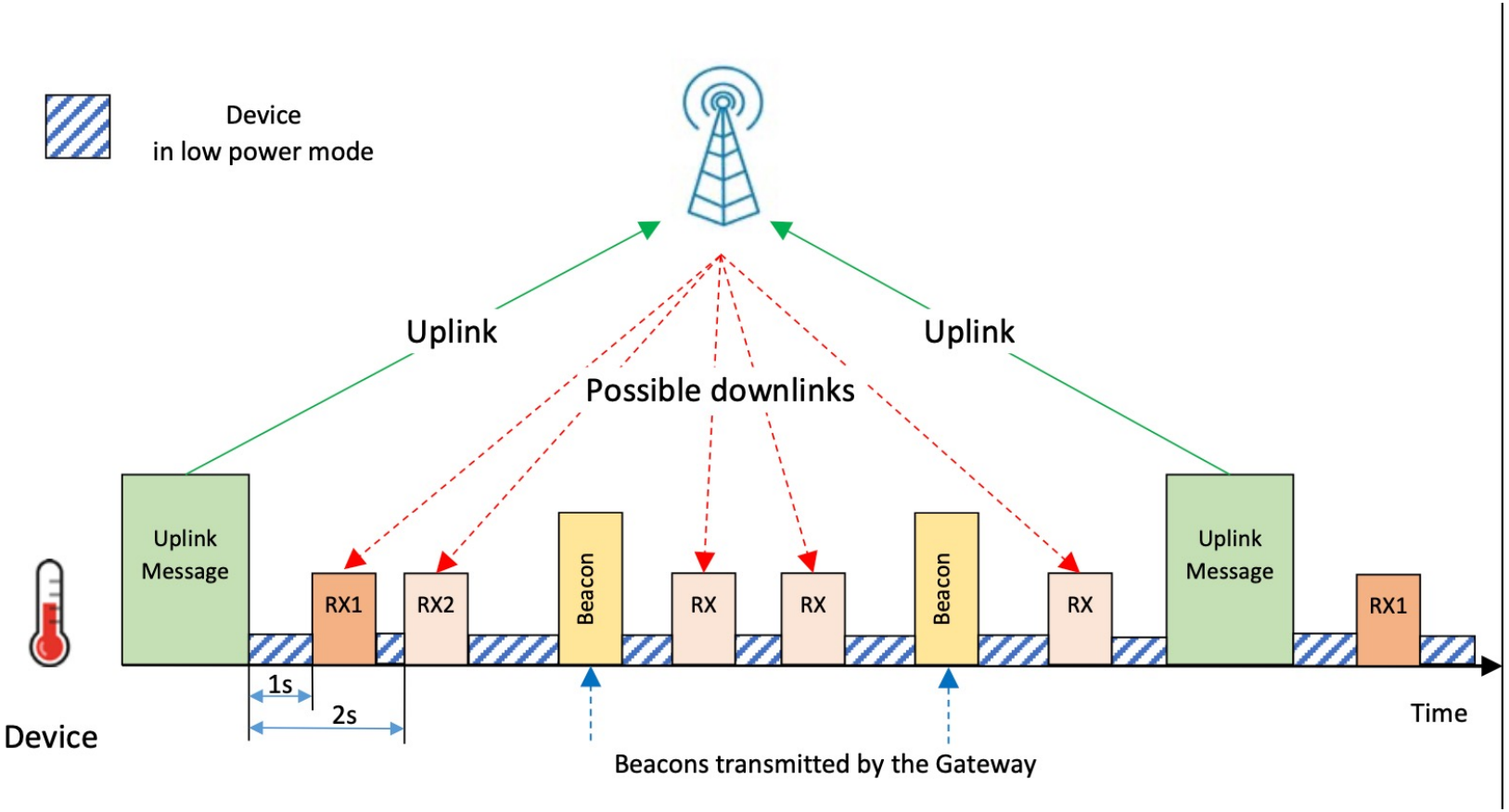
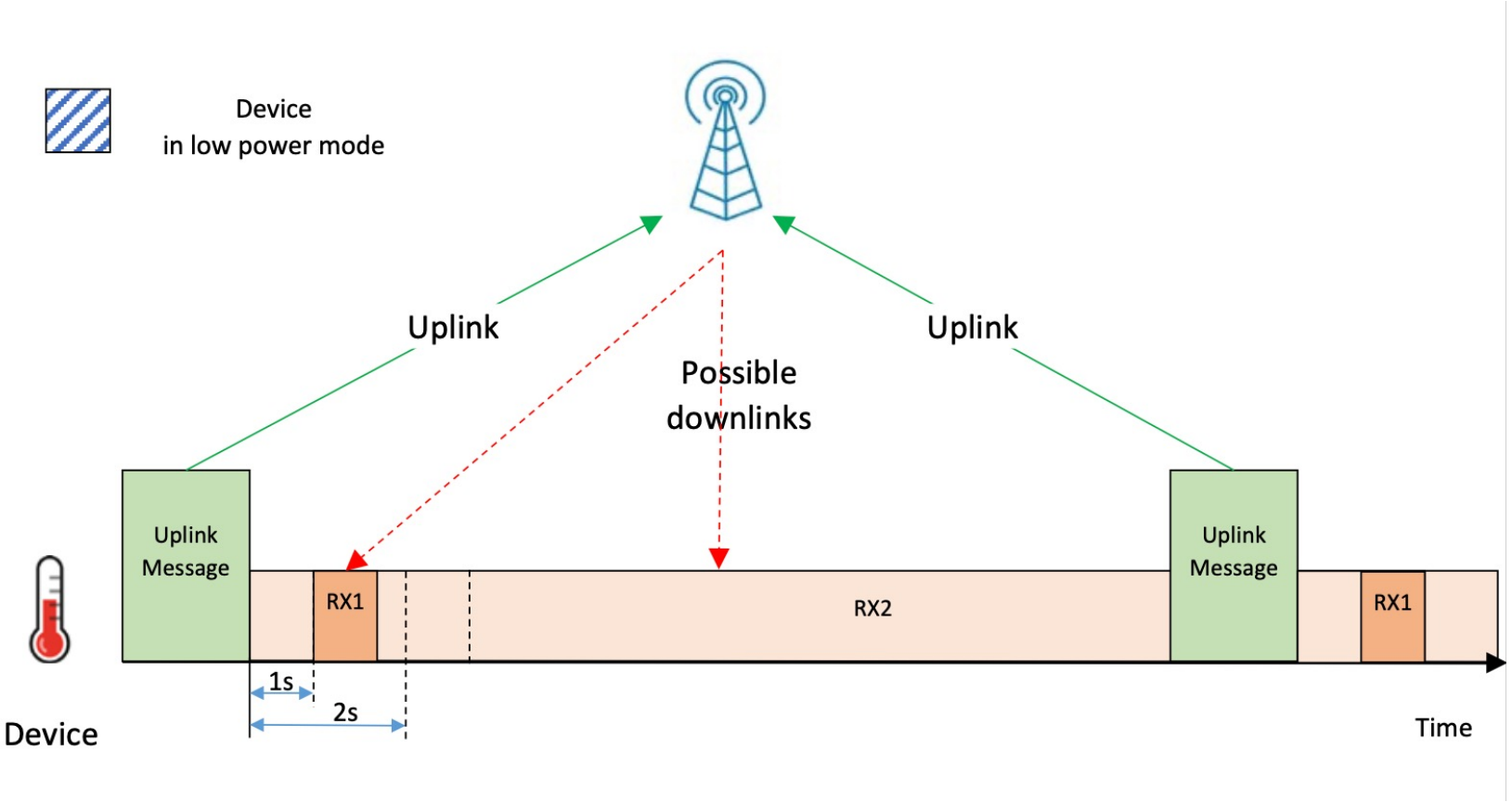
Class B (Beacon): Scheduled receive slot



Class C (Continuous): Continuously listening



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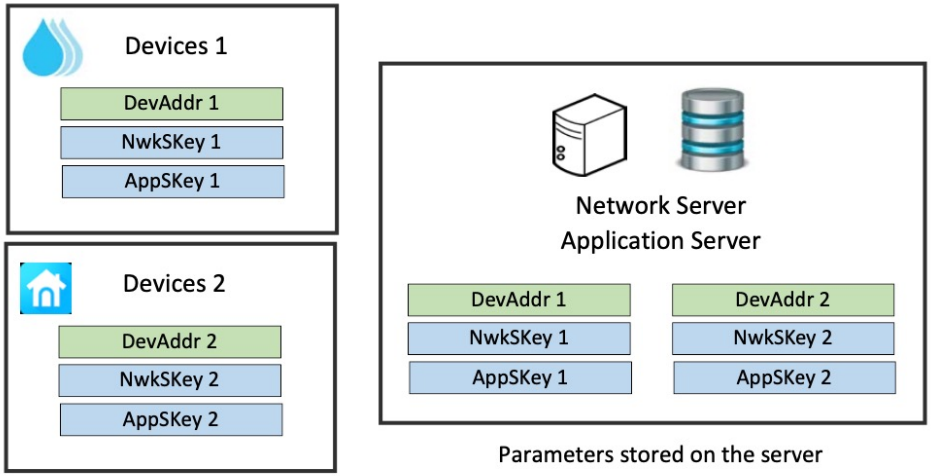
Activation of LoRaWAN end-devices: ABP and OTAA

- Applications in LoRaWAN have a 64 bit unique identifier (AppEUI).
- 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**.
- In LoRaWAN, the three essential elements for communication are the DevAddr for the identification of the end-device, as well as two keys: the NwkSKey for authentication and the AppSKey for encryption.
- Two methods are possible to provide this information to both the end-device and the LoRaWAN server:
  - Activation By Personalization: ABP.
  - Over The Air Activation: OTAA.

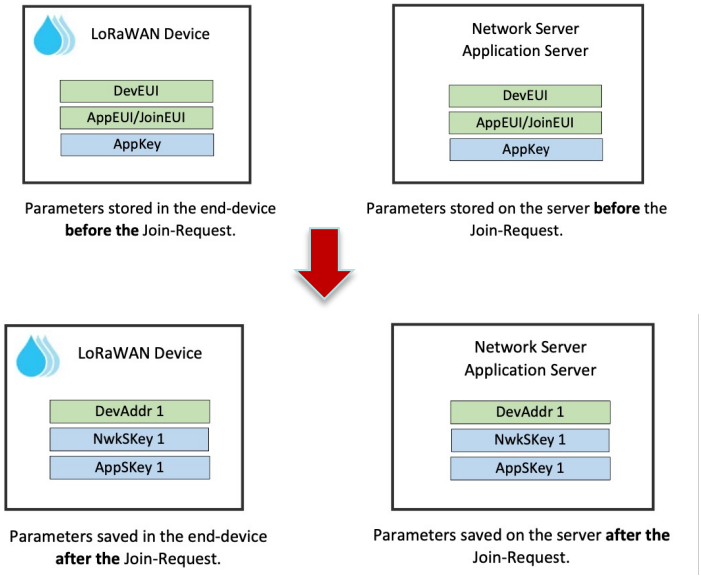
ABP: Activation By Personalization

- This is the simplest method. It is therefore perhaps the one we tend to use when testing a prototype and setting up a LoRaWAN communication.
  - Static **DevAddr**, **NwkSKey** and **AppSKey** are stored in the end-device.
- In ABP, all the information needed for communication is already known by the end-device, the Network Server and the Application Server.
- As soon as the end-device has started, it can send and receive LoRaWAN messages.



OTAA: Over The Air Activation

- With this activation mode, the **DevAddr**, **AppSKey** and **NwkSKey** will be generated during a Join procedure when the LoRaWAN end-device connects to the Network Server. To achieve this Join procedure, the LoRaWAN end-device must be configured with:
  - DevEUI; AppEUI/JoinEUI; AppKey
- The Network Server must know the same DevEUI, AppEUI/JoinEUI, and AppKey and the main purpose of the Join-Request is to retrieve the final configuration with DevAddr, NwkSKey and AppSKey on both sides.
- All the items named "EUI" (Extended Unique Identifier) are always unique with an 8 bytes size.



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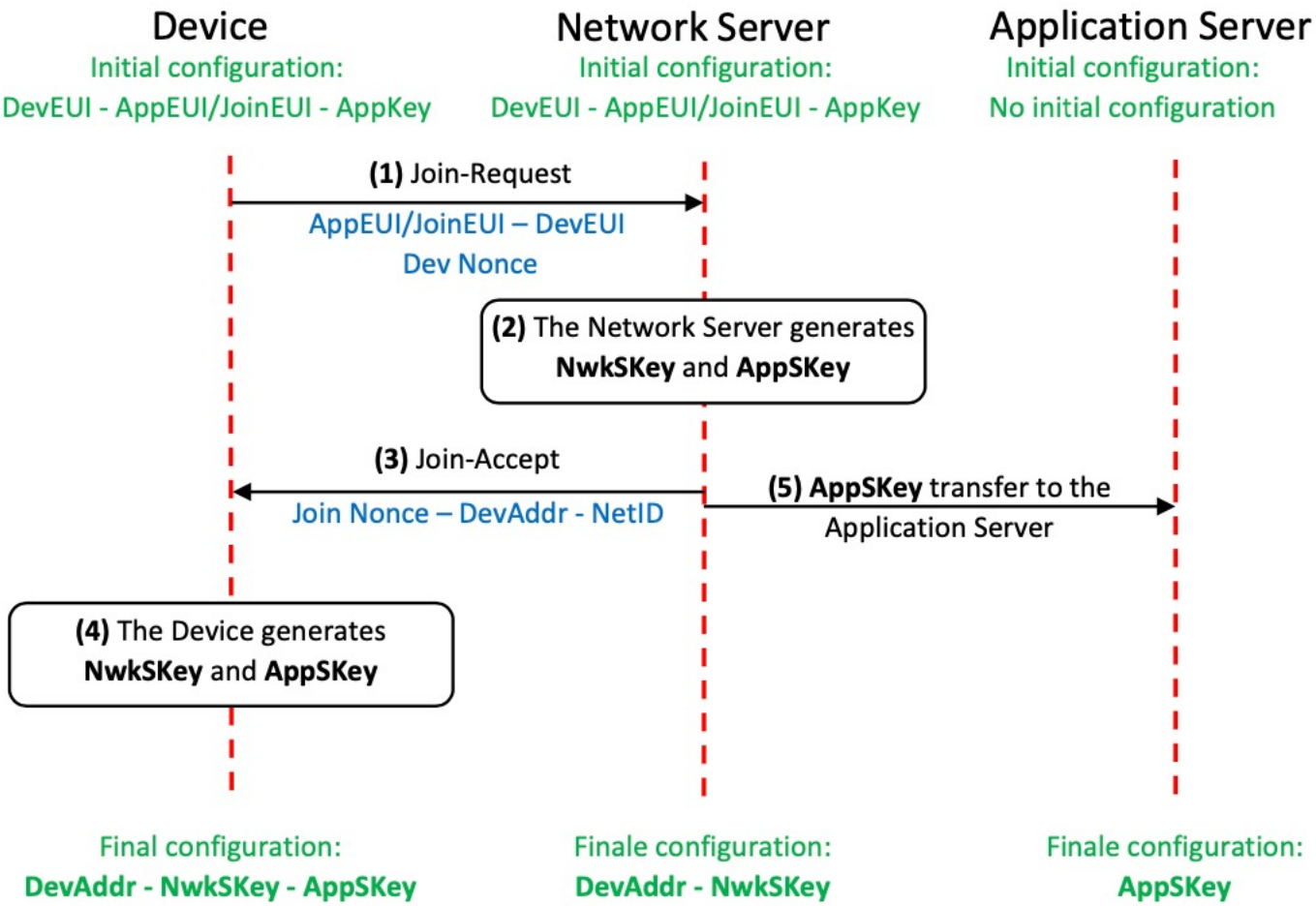
Initial configuration

- Meaning of the initial configuration stored in the end-device and on the server before the Join-Request:
  - **DevEUI**: Unique Identifier for the LoRaWAN end-device. This is Equivalent to a MAC address on Ethernet. Some LoRaWAN end-devices already have a fixed DevEUI stored during factory firmware programming and cannot be changed.
  - **AppKey**: AES 128 key used to authenticate the Join-Request, to encrypt the Join-Accept and to generate the session keys. This key must be kept secret and never be shared with anyone.
  - **AppEUI/JoinEUI**: This parameter has different meaning depending on the LoRaWAN version. In LoRaWAN 1.0.3 and before, it was an application identifier (AppEUI).
    From LoRaWAN 1.0.4, this parameter has been renamed in JoinEUI as it defines a Join Server identifier.

Join-Request and Join-Accept procedure in detail



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.
- According to European regulations, radiofrequency end devices should transmit **at most 1% of the time** in the 868 MHz band. If an end device transmits during 1, it must stay quiet for 99, regardless of the time unit used.
  - Example: when using SF7, the Time on Air is 46.3 ms. The LoRa device should, therefore, not transmit for 99 x 46.3ms = 4.58 seconds.

- 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.

https://www.chirpstack.io/

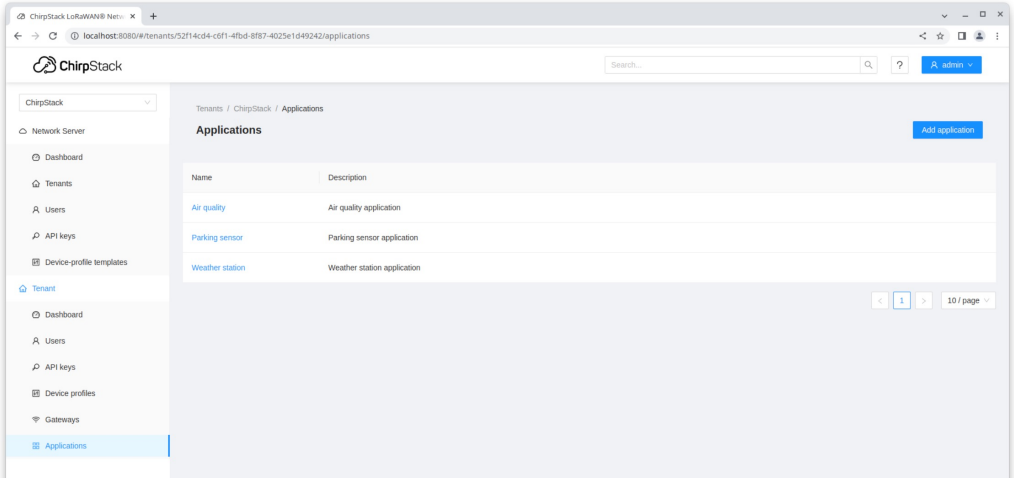
ChirpStack

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

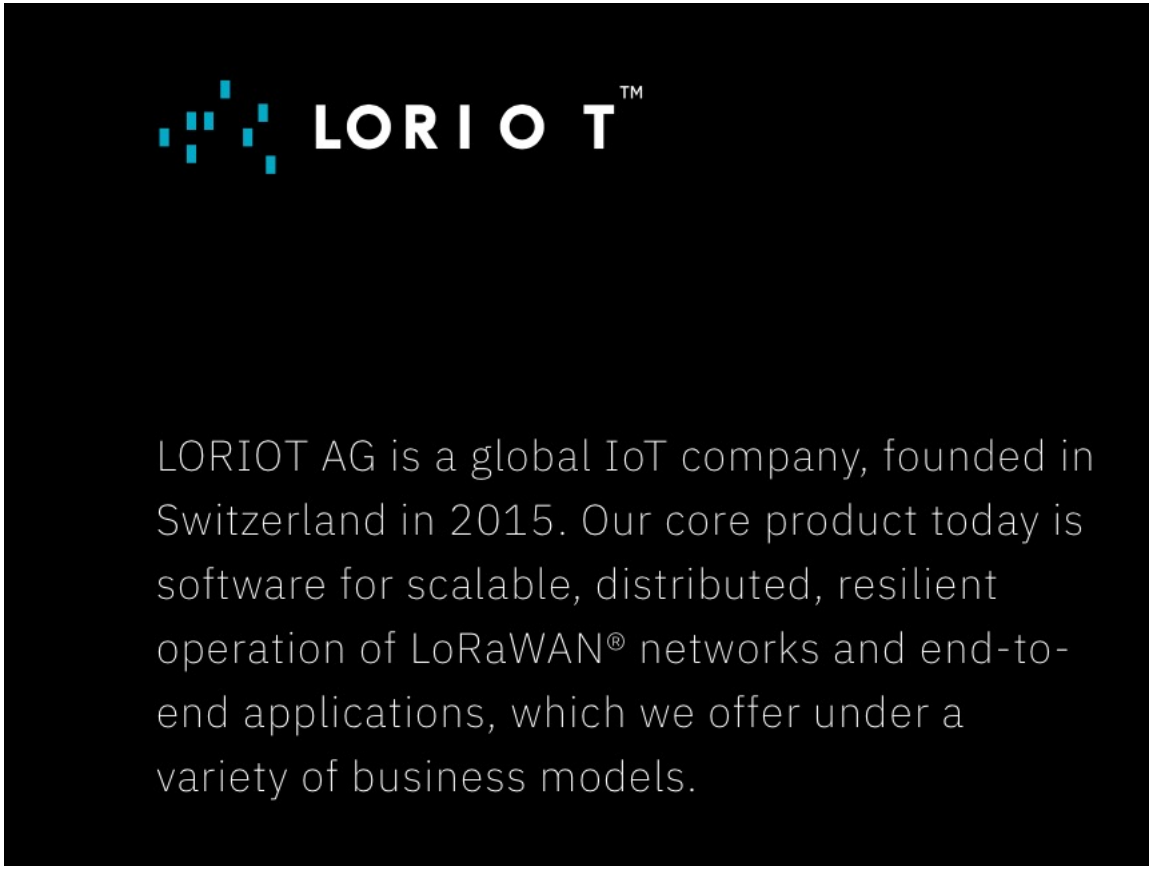
ChirpStack, open-source LoRaWAN® Network Server

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



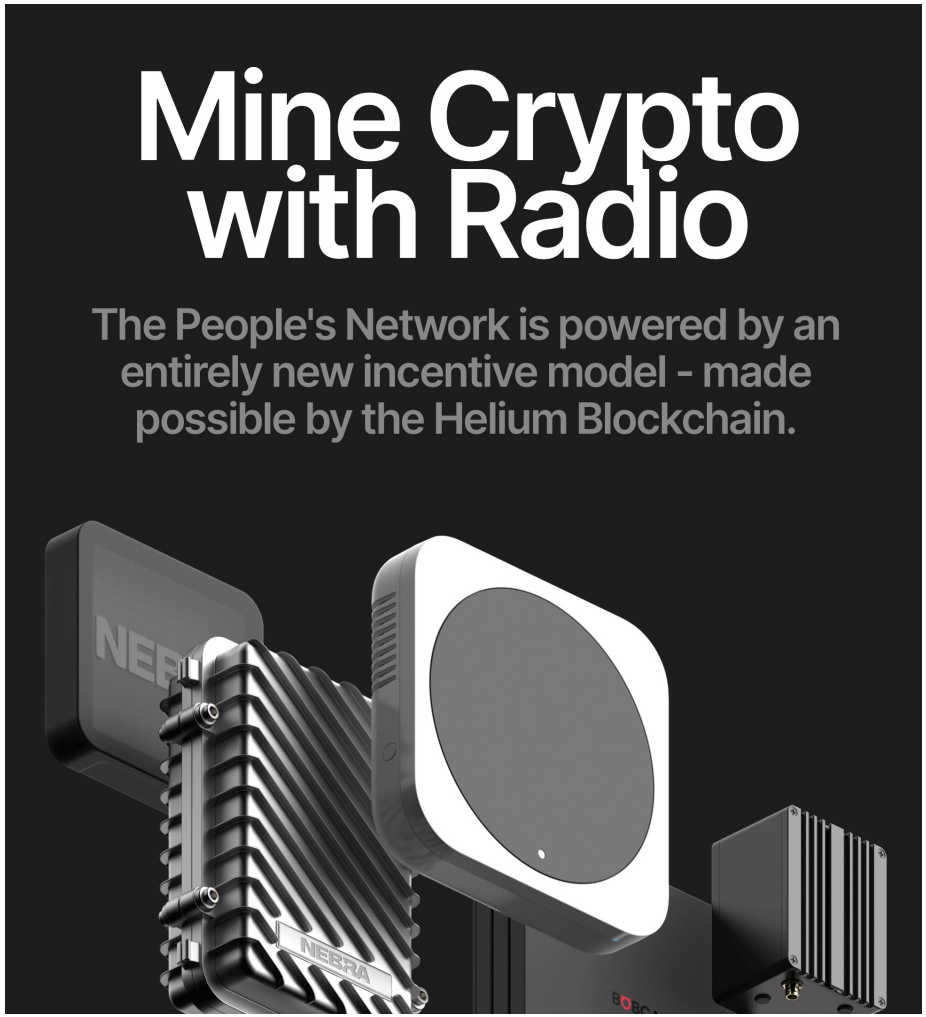
LoRaWAN Network Servers



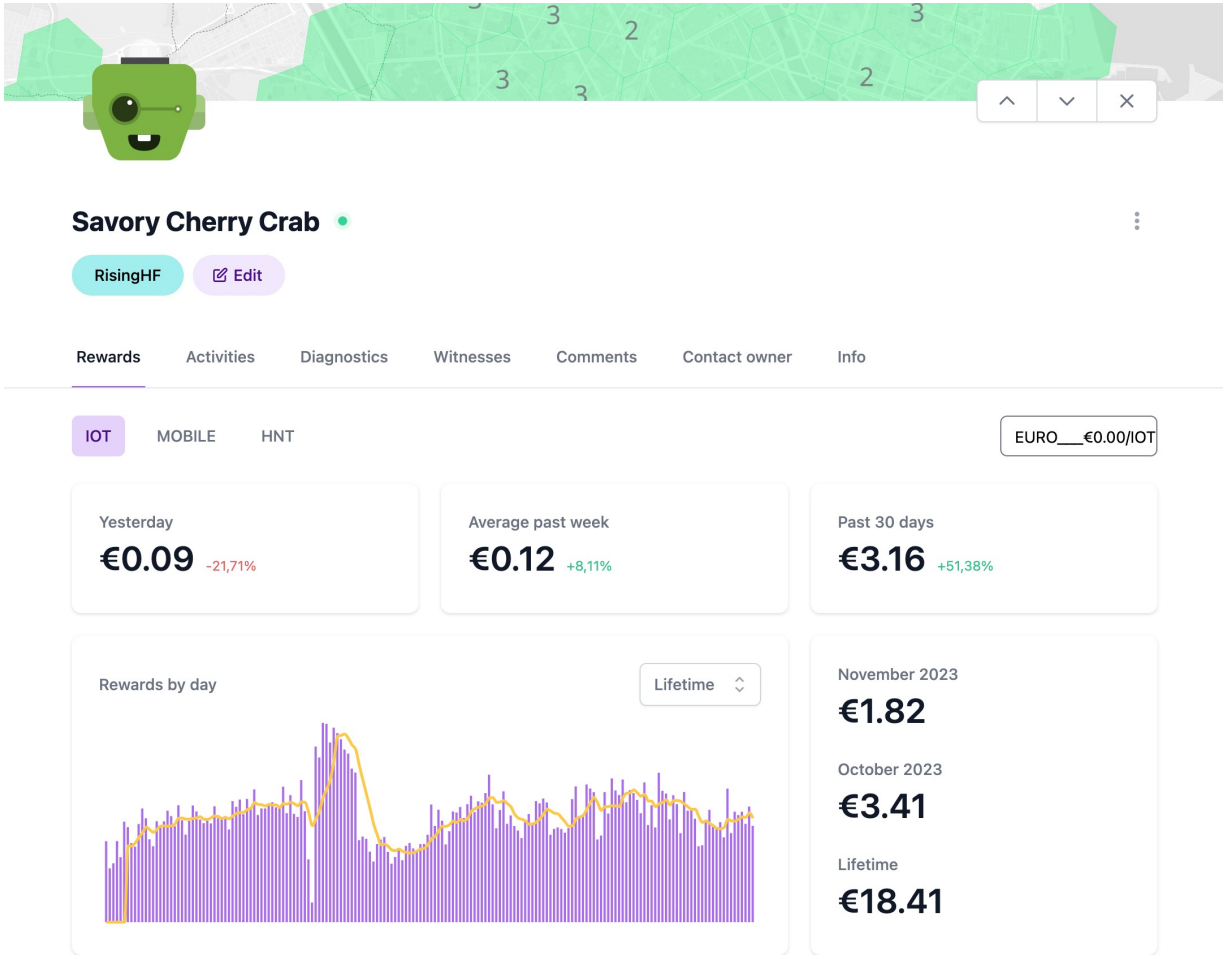
https://www.loriot.io/

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".

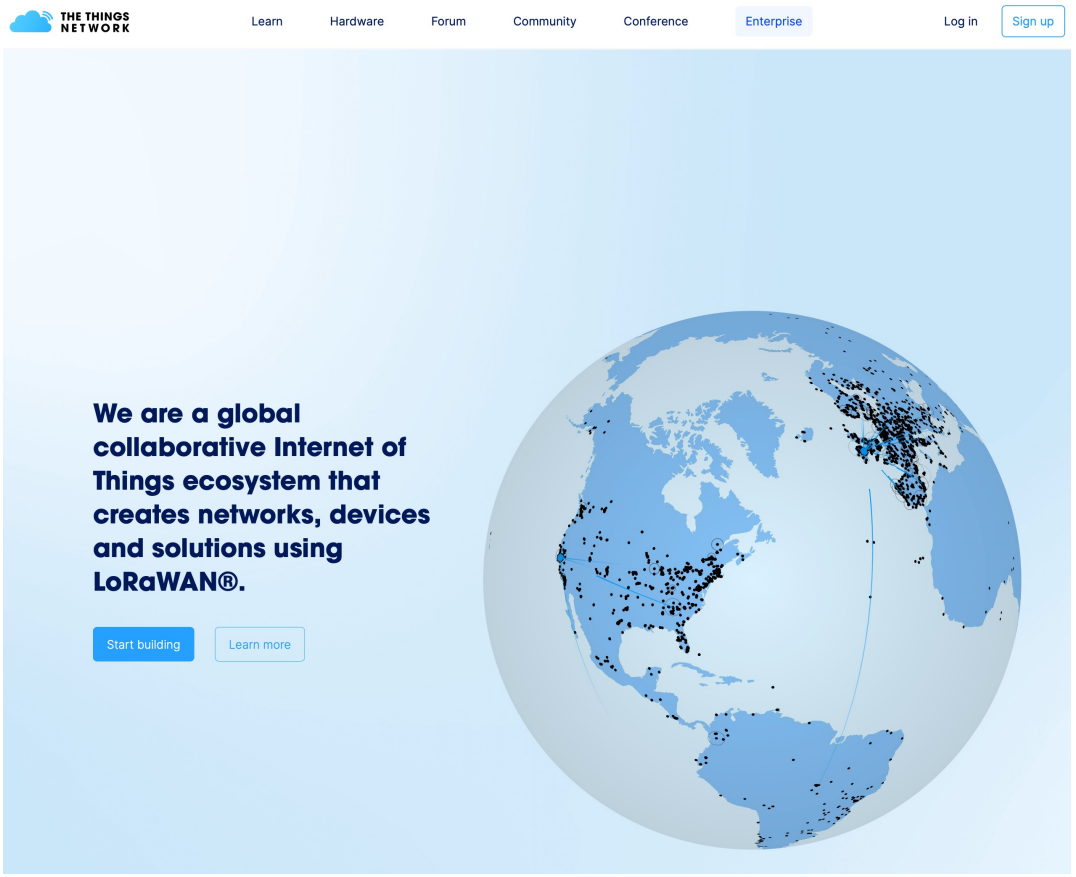


Experimenting...



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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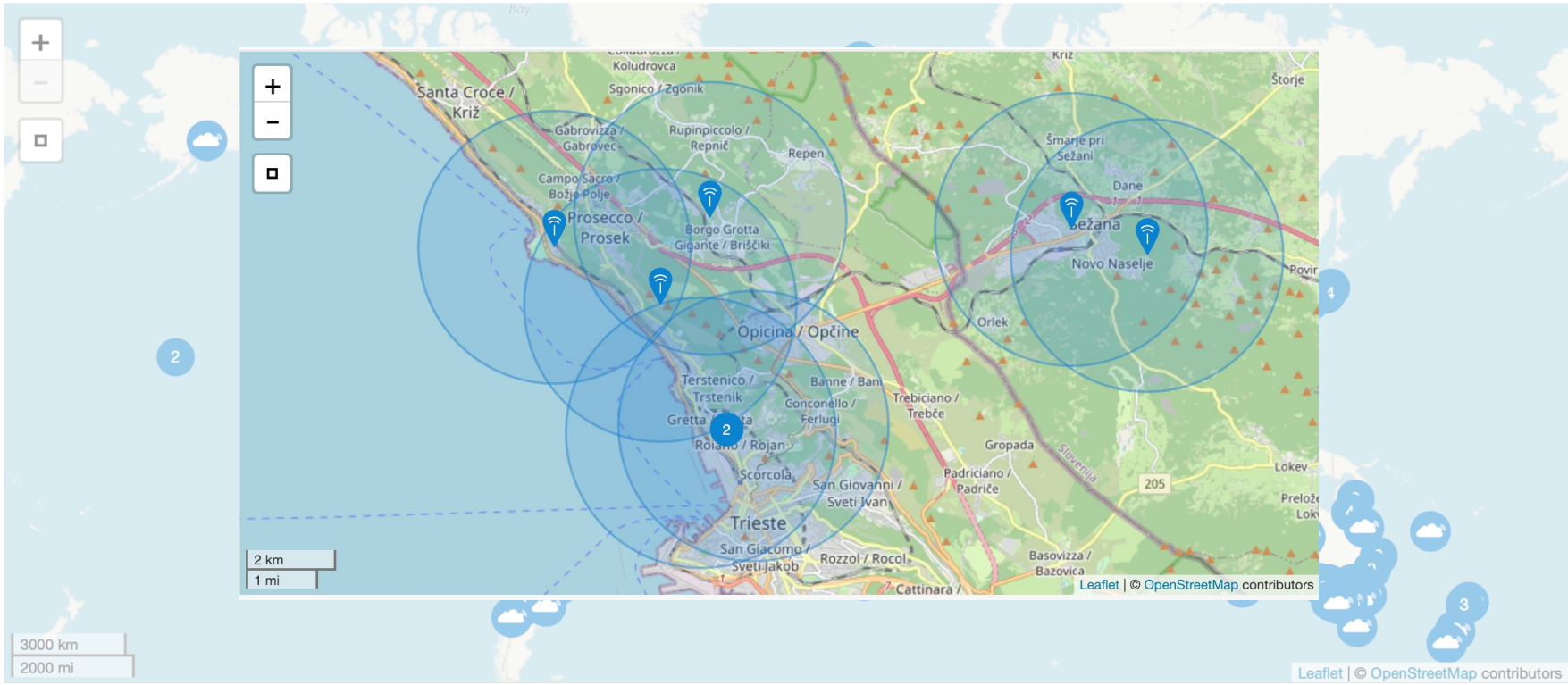
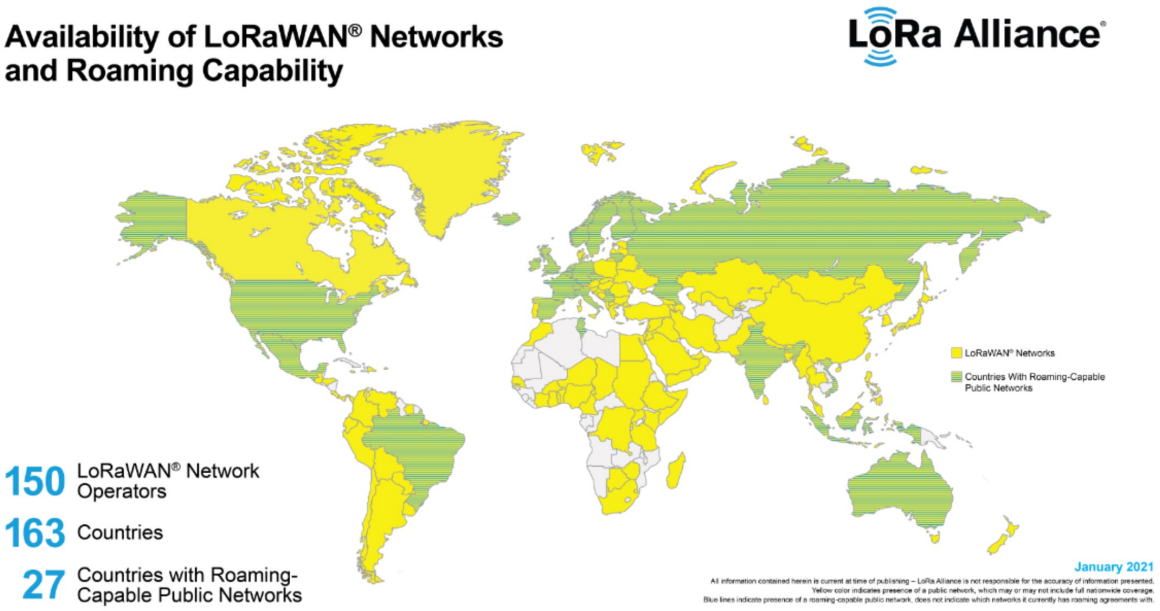
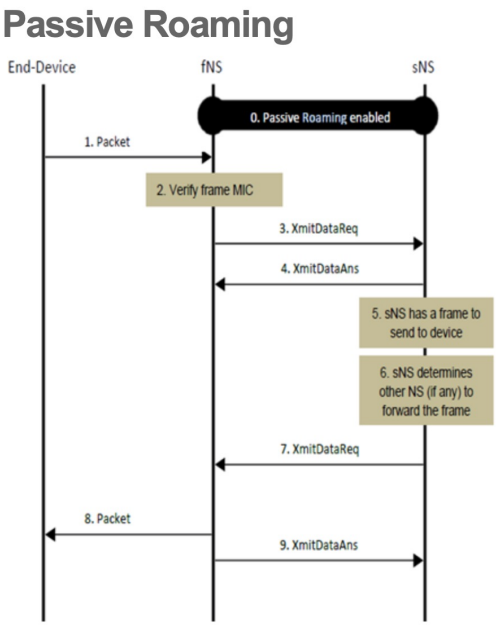


LoRaWAN Roaming





or..

Packet Broker

https://packetbroker.net

A **neutral** and **open** Internet of Things packet broker allowing IoT operators to interoperate according to the open principles of the internet.

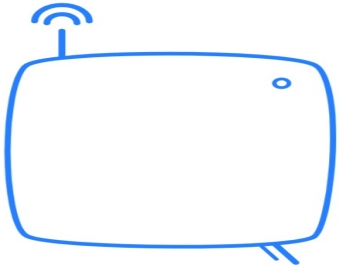
https://eu1.cloud.thethings.network/console/

Welcome back, Pietro Manzoni! 👋

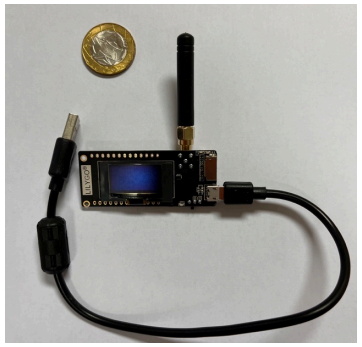
Walk right through to your applications and/or gateways.

Need help? Have a look at our Documentation or Get support.

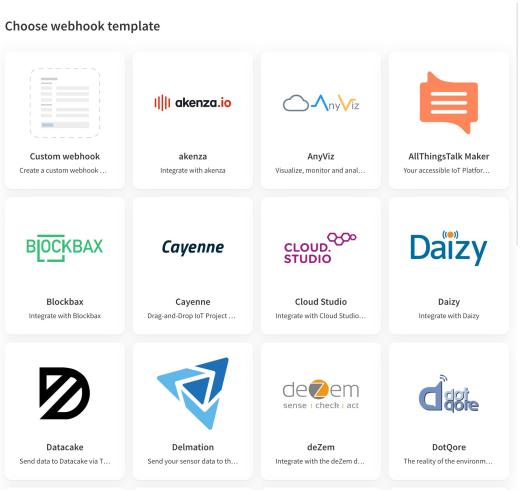
Go to applications

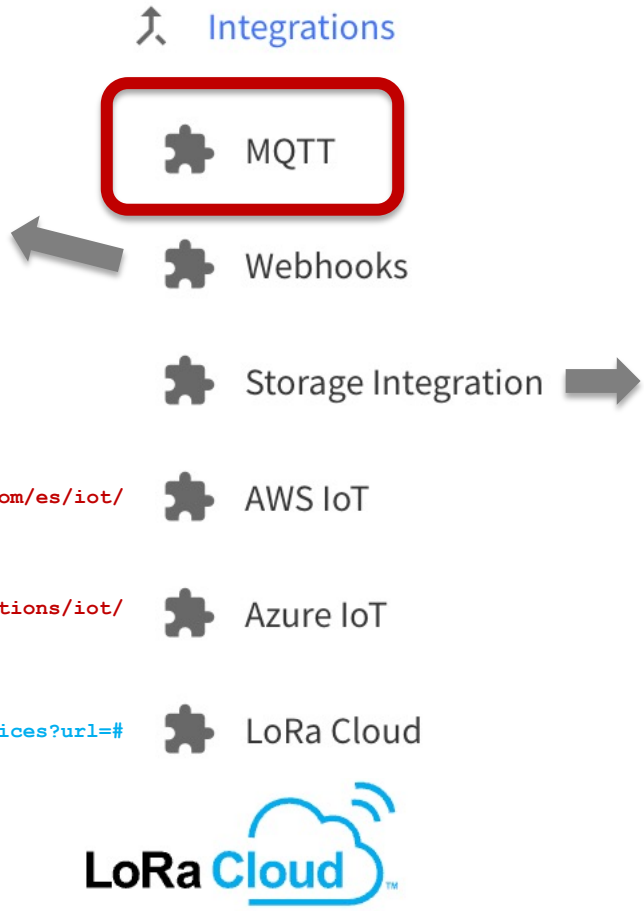


Go to gateways



«Integrations»

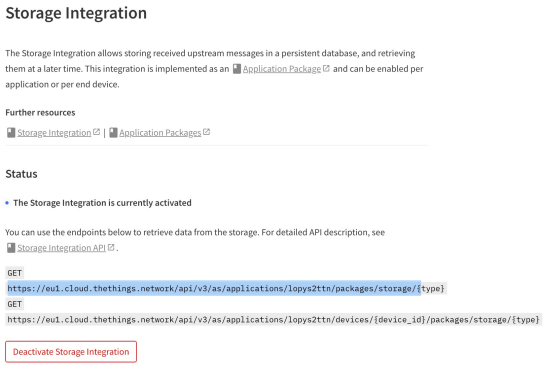




https://aws.amazon.com/es/iot/

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

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



References

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- https://www.thethingsnetwork.org/docs/lorawan/
- https://docs.rakwireless.com/Knowledge-Hub/Learn/
- https://www.univ-smb.fr/lorawan/en/
- State of LoRaWAN and the IoT Ecosystem by Wienke Giezeman
  - https://www.youtube.com/watch?v=f3fxpsSxQzY

Any questions?

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https://bit.ly/aboutLoRa