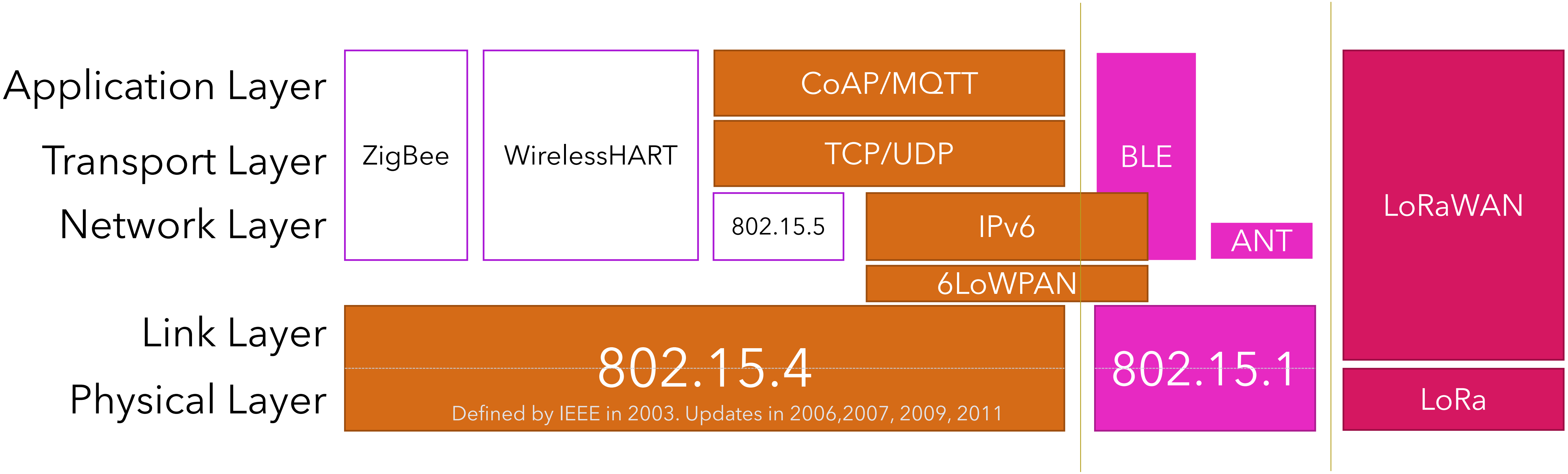
LoRa and LoRaWAN

in IoT

LoRa Stack


Application Layer
Transport Layer
Network Layer
Link Layer
Physical Layer
ZigBee
WirelessHART
CoAP/MQTT
TCP/UDP
802.15.5
IPv6
6LoWPAN
802.15.4
Defined by IEEE in 2003. Updates in 2006,2007, 2009, 2011
BLE
ANT
802.15.1
LoRaWAN
LoRa

LoRa v1.0

Long Range

History of LoRa

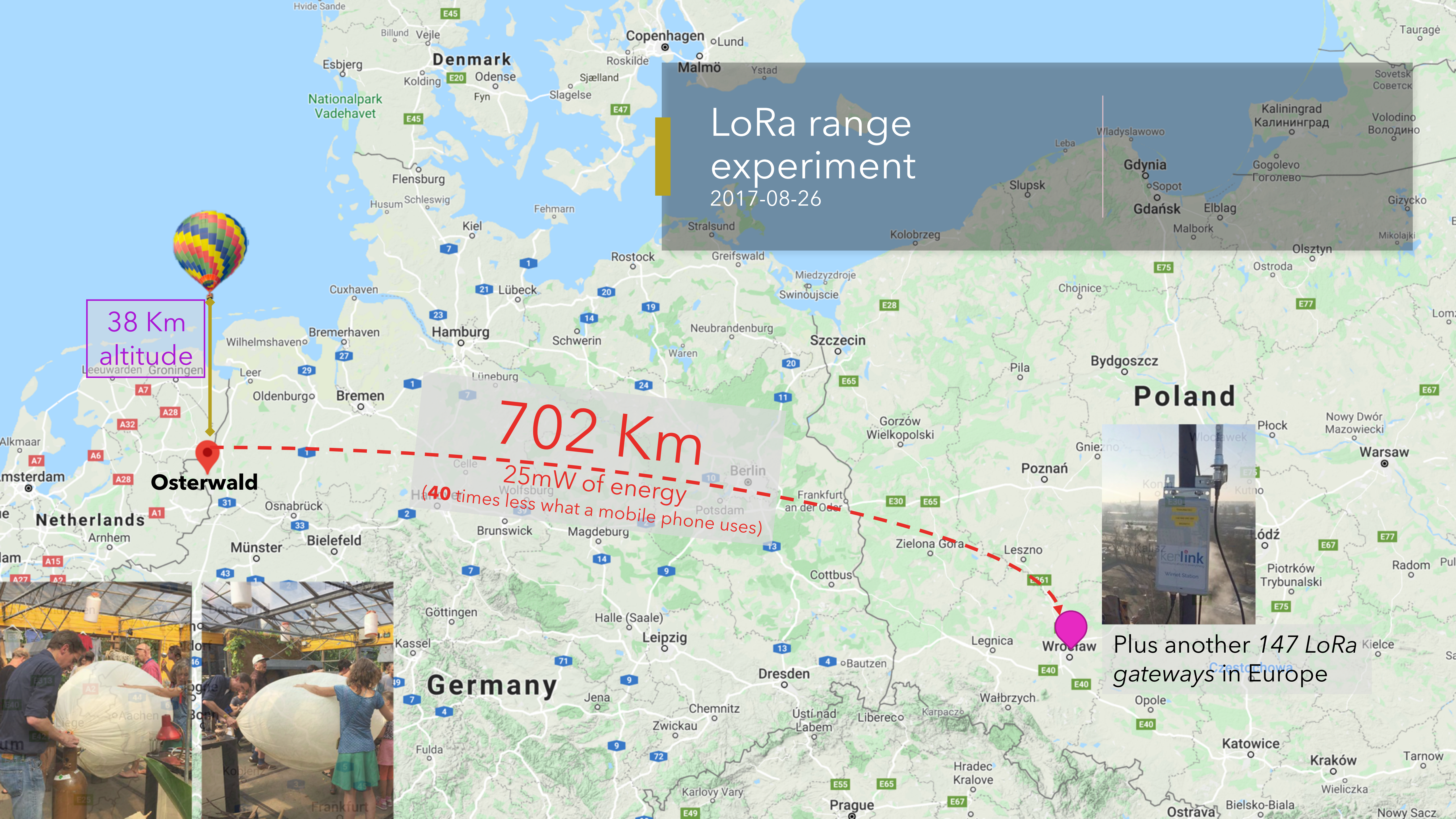
- May 2008 - Cycleo of Grenoble, France, files first patent of LoRa. It uses a technology called ***Chirp Modulation*** (U.S. Patent US7791415)
- March 2012 - Acquired by Semtech (5M USD)
- May 2013 – Semtech files second patent on LoRa (EU Patent EP2763321A1)
- March 2015 - LoRa Alliance is funded with three members: Actility, Semtech and IBM Research
- March 2018 - Google announces that it will be joining LoRa Alliance as a sponsor member.
- Nowadays – 500 members, including:
  - Amazon, Alibaba, Cisco, Orange, Arduino, ST microelectronics, Intel, NEC, NTT, Renesas, Schneider Electric, Bosch, etc.
- January 2015, v1.0
- October 2017, v1.1 – Adds class B

Why LoRa?

Long Range	Many kilometers, on line-of-sight links.
Low power	Can run on battery for years.
Bi-directional	Can send and receive data.
Network security	Uses AES-128-bit end-to-end encryption.
Asset tracking without GPS	Uses Time of Flight (TOF) algorithm.
Low cost	LoRa modules are pocket-friendly.
Network scalability	Easy to scale as it supports millions of messages per station.
Easy commissioning	Easy to deploy in the existing system.

LoRa range experiment

2017-08-26



A world of radio signals Modulation

BLE and LR-WPAN

- Frequency Shift Keying

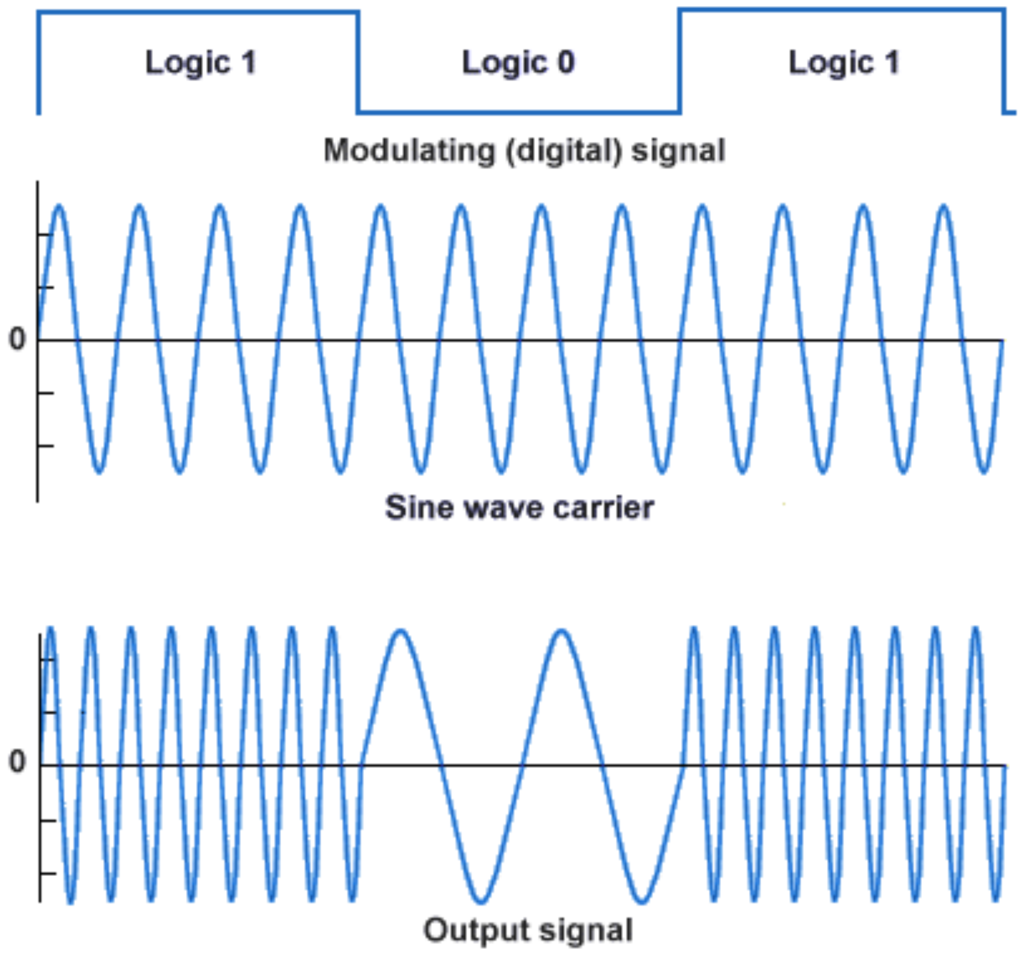
WiFi

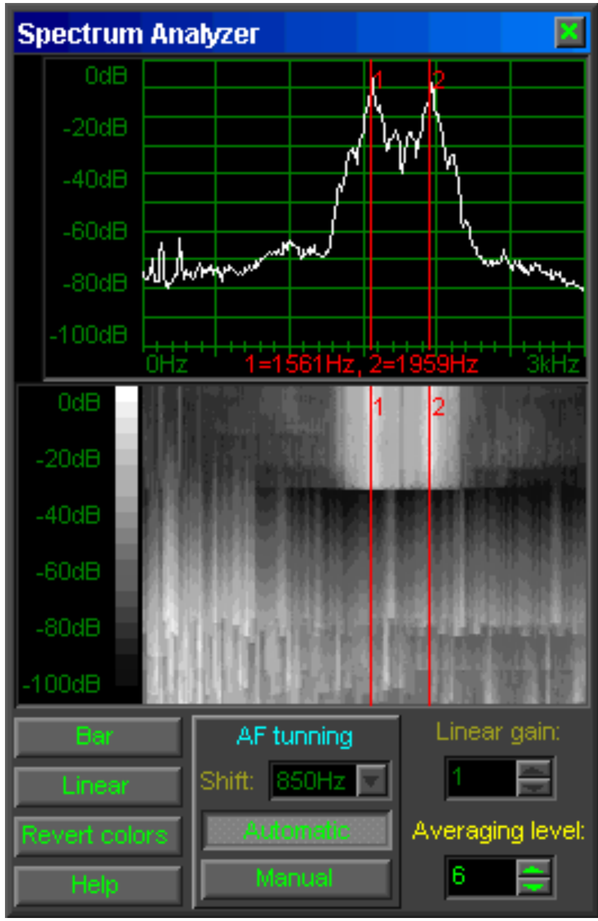
- Direct Sequence Spread Spectrum

LoRa

- Chirp Spread Spectrum

Frequence-Shift Keying (FSK) 802.15.4

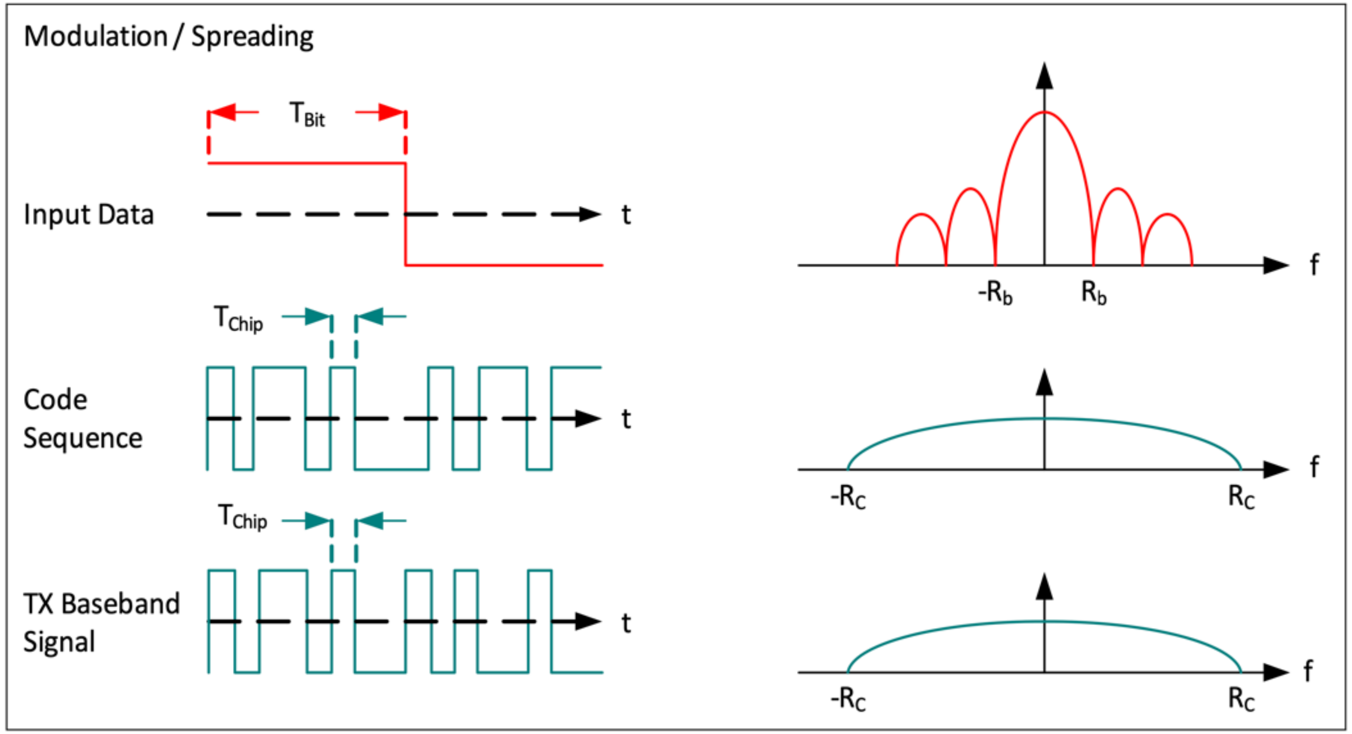




A logic state is mapped to an output frequency signal

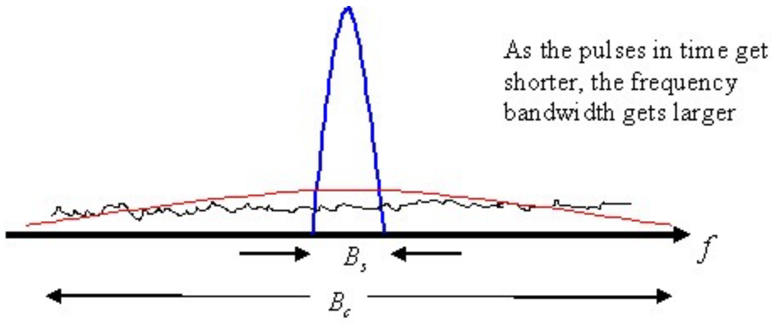
Direct Sequence Spread Spectrum (DSSS)

WiFi and 802.15.4 (2.4GHz)



Narrowband signals are easily jammed by any other signal in the same band.

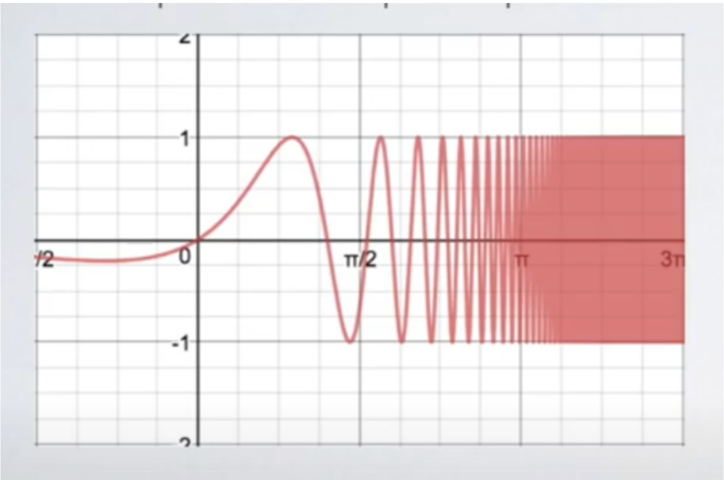
DSSS uses more bandwidth than the original message while maintaining the same signal power. A spread spectrum signal does not have a clearly distinguishable peak in the spectrum. This makes the signal more difficult to distinguish from noise.

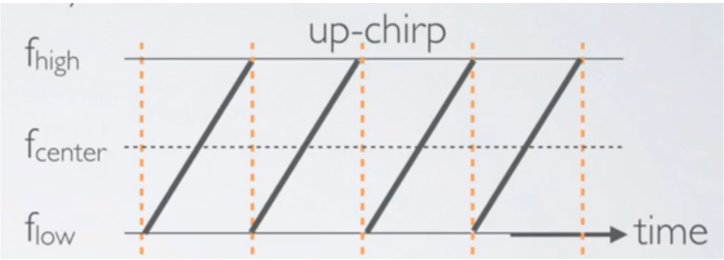


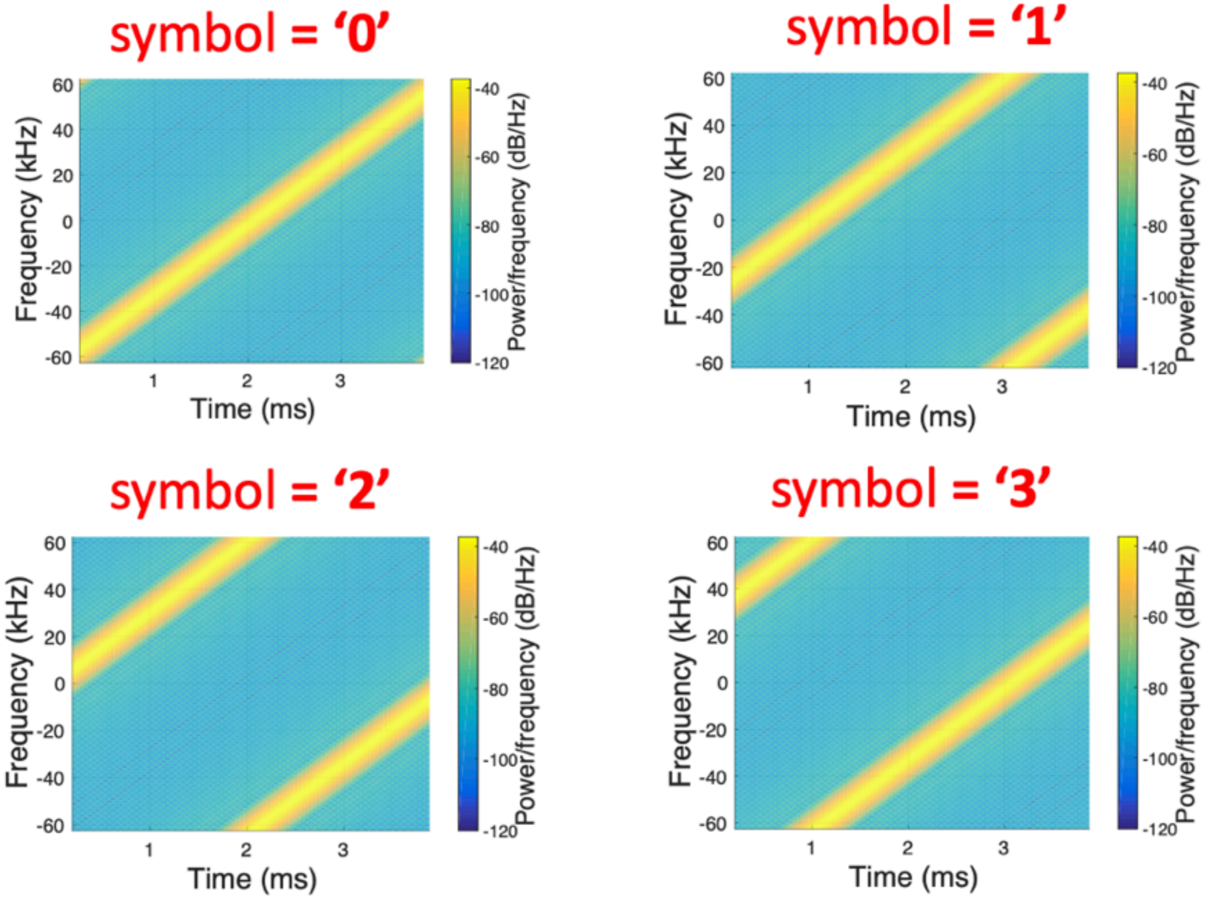
One of the downsides of a DSSS system is the fact that it requires a highly-accurate (and expensive) reference clock.

Chirp-Spread Spectrum (**C**ompressed **H**igh **I**ntensity **R**adar **P**ulse)
LoRa Modulation (propietary)

Chirp (or *sweep signal*): a tone in which the *frequency increases* (up-chirp) or *decreases* (down-chirp) with time.

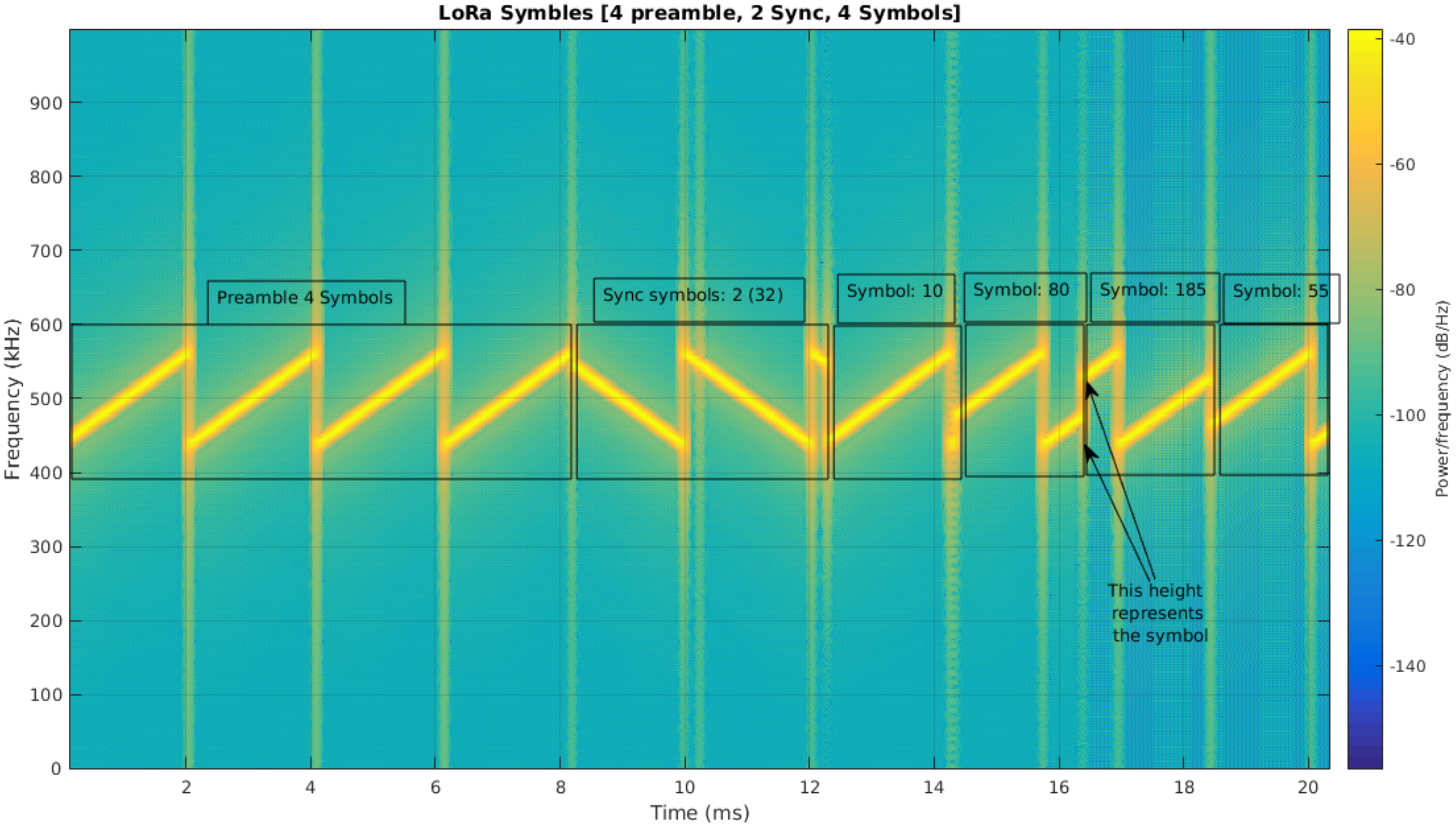






Examples of chirp modulation (not necessarily LoRa)

LoRa Modulation



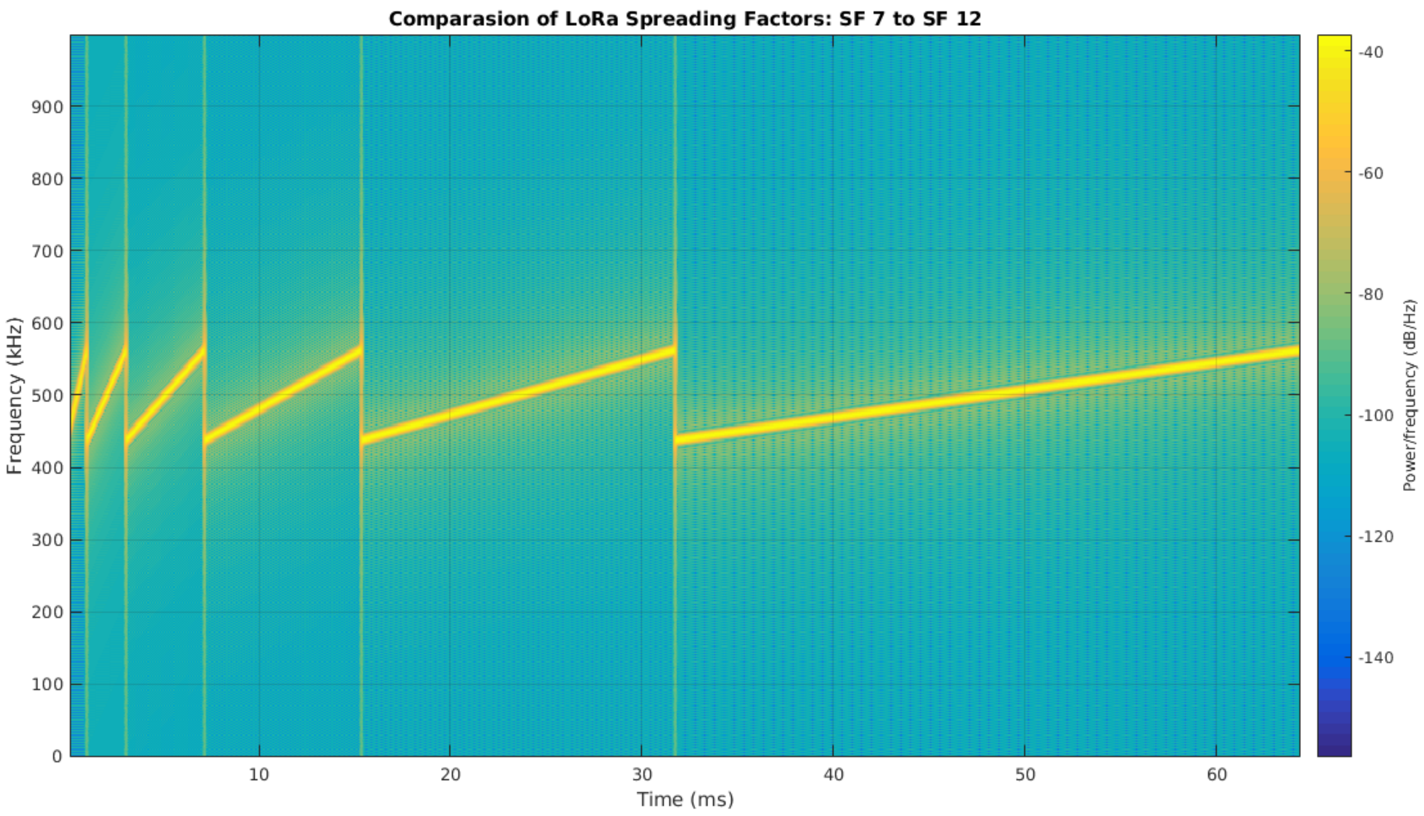
Non-official information.
Taken from: https://www.sghoslya.com/p/lora-is-chirp-spread-spectrum.html

Spread Factor

- SF8 takes exact twice the time of SF7 and SF9 takes exact twice time of SF8.
- Symbol Rate (Rs), Bandwidth (BW) and Spreading Factor (SF) relation:

$$Rs = \frac{BW}{2^{SF}}$$

- The higher the SF, the larger over-the-air time (power).



Spread Factor, Bandwidth, Data Rate and Max Payload Size (EU)

Data Rate	Configuration	bits/s	Max payload (bytes)
DR0	SF12/125kHz	250	59
DR1	SF11/125kHz	440	59
DR2	SF10/125kHz	980	59
DR3	SF9/125kHz	1 760	123
DR4	SF8/125kHz	3 125	230
DR5	SF7/125kHz	5 470	230
DR6	SF7/250kHz	11 000	230
DR7	FSK: 50kpbs	50 000	230

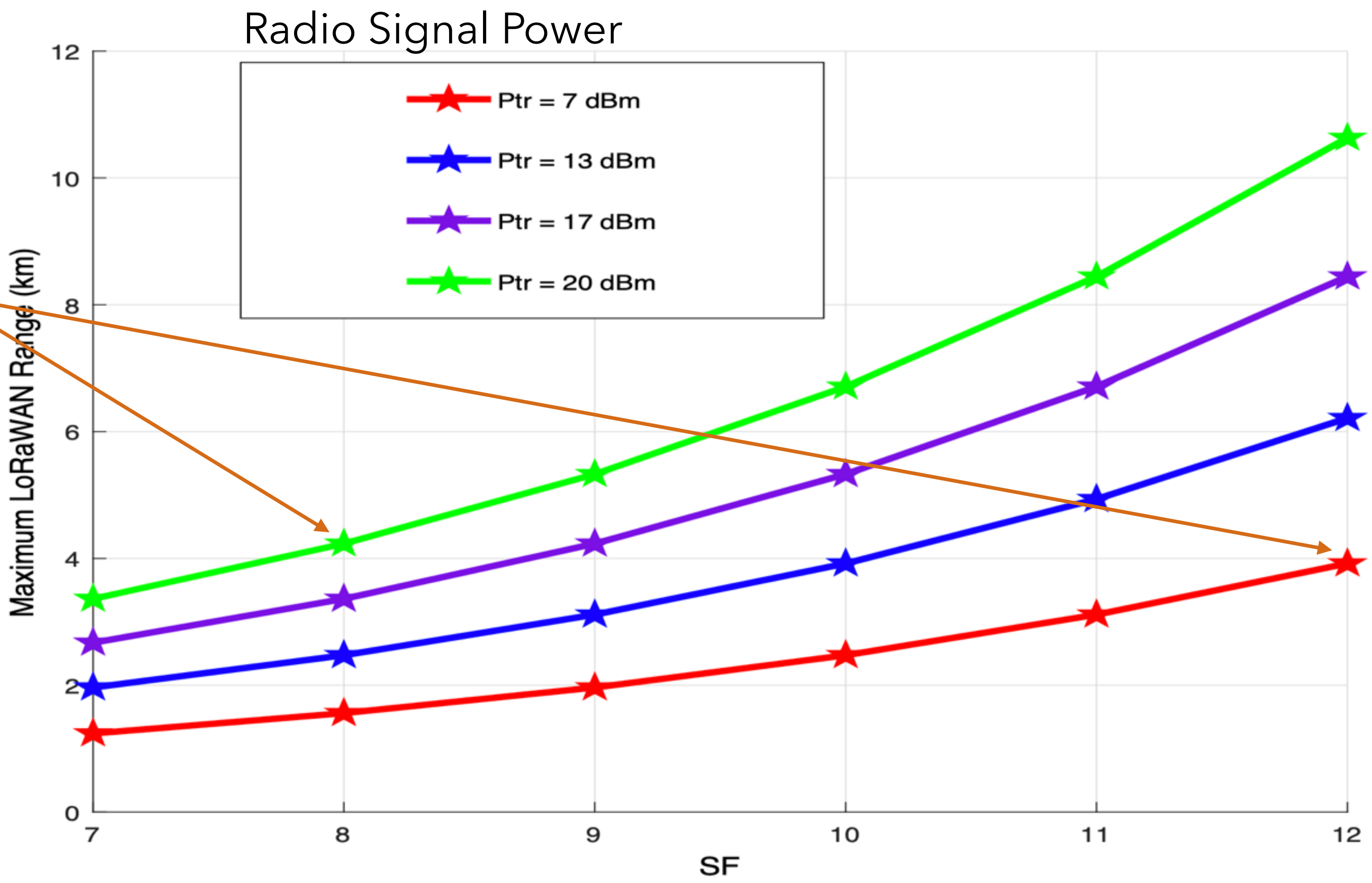
Spread Factor and Range

A range of 4 Km can be achieved either by

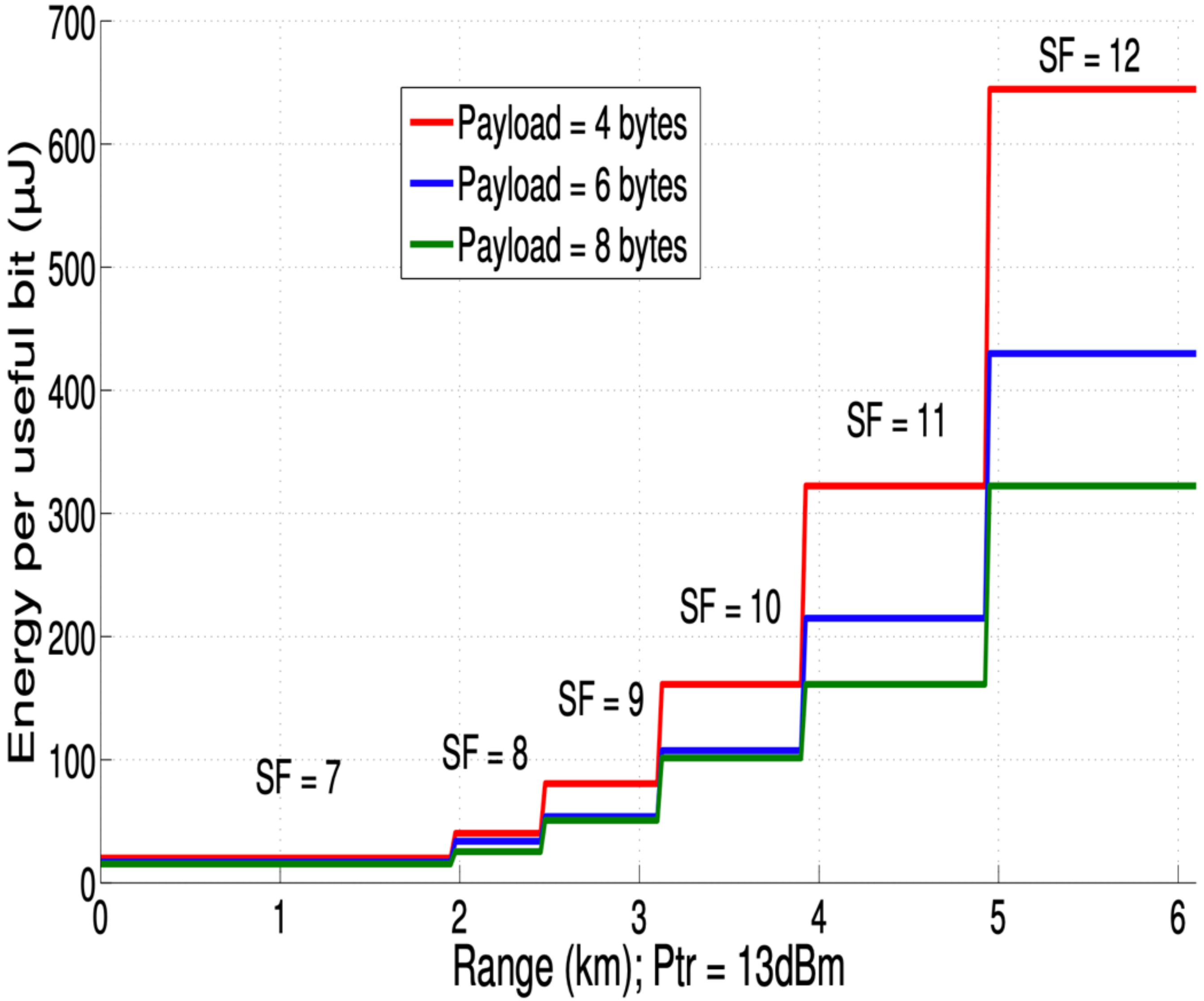
- using SF = 8 (high data rate) with a radio signal power amplification of 20dBm (high power), or by
- using SF = 12 (low data rate) with a radio signal power amplification of 7dBm (low power)

Which one is more energy efficient?

$$energy = time \times power,$$
$$time \sim {}^{1}/_{data\_rate}$$



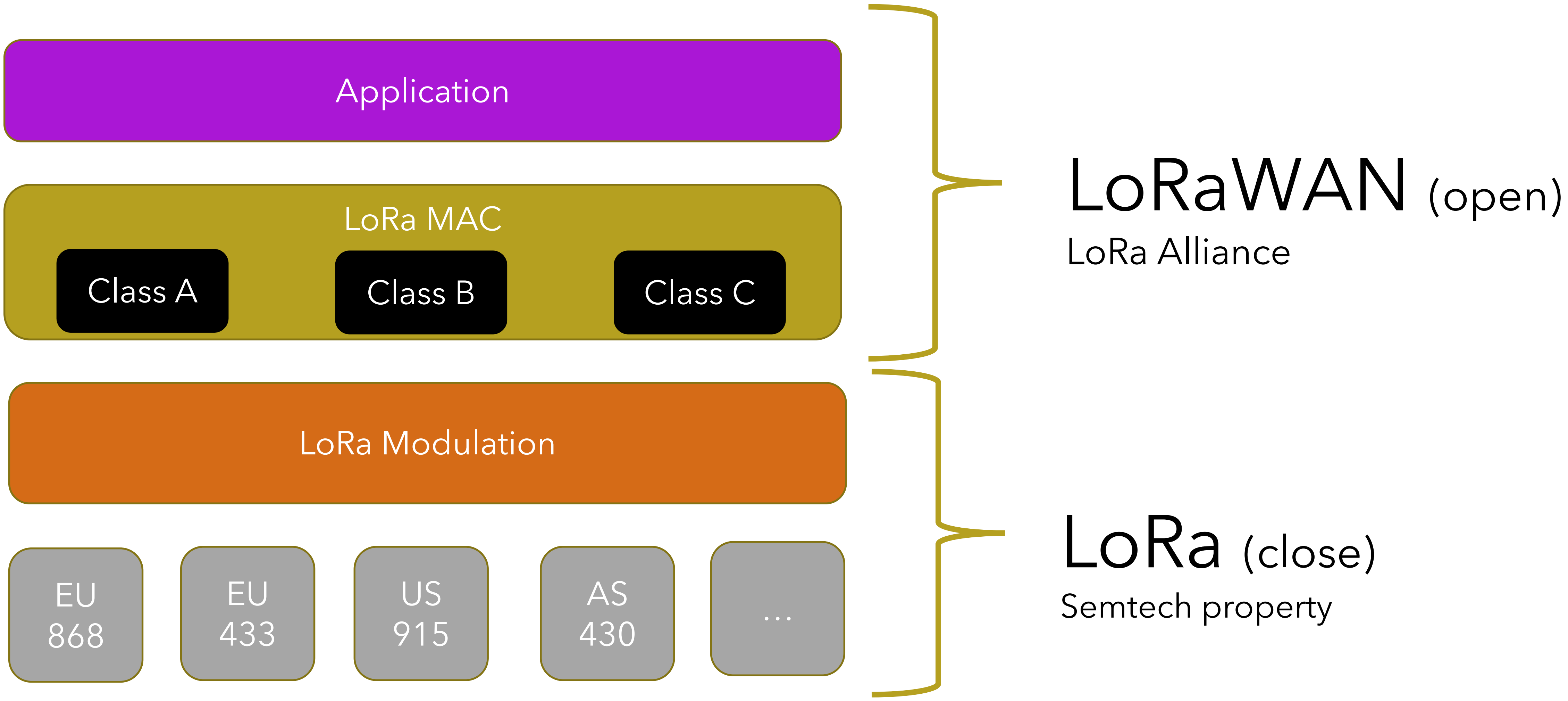
SF, Range and Energy Consumption



LoRa Gateways

- Single-Channel gateways
  - Based on chipset SX1272/SX1276
  - Cheap, only for hobbists, poor range, support of only a single channel and a single (fixed) SF, low capacity. Not compatible with all LoRa devices. Most of them cannot support downlinks (!)
- Pico-Gateways: 4 or 8 channels
  - Based on chipset SX1308/SX1257
  - Suitable as gateways for small areas (home) and with a lower number of connections
- Macro-Gateways: 16, 64 or more channels
  - Based on chipset SX1301/SX1257
  - Used by ISP (such as Orange) for covering a wide area

LoRaWAN


Application
LoRa MAC
Class A
Class B
Class C
LoRa Modulation
EU 868
EU 433
US 915
AS 430
...
LoRaWAN (open)
LoRa Alliance
LoRa (close)
Semtech property

LoRa Classes

Class A

- Lowest-power
- Highest-latency

Class B

- Bounded power
- Deterministic latency

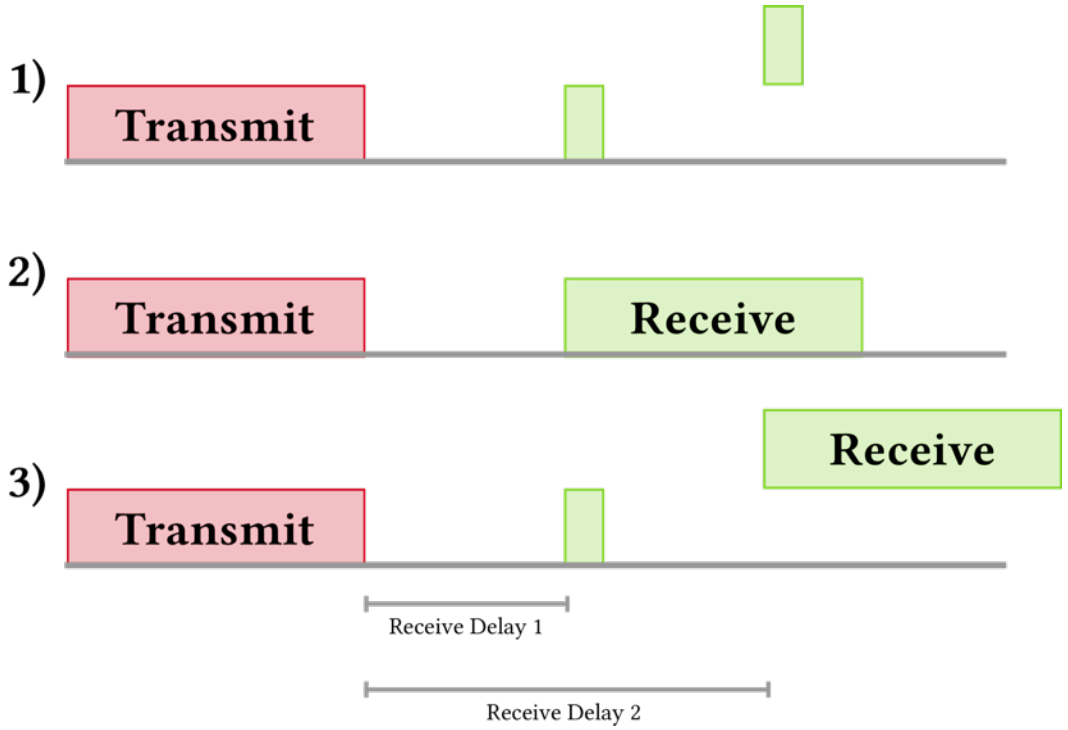
Class C

- Highest-power
- Lowest-latency

Class A(ll end-devices)

Lowest power, bi-directional end-devices

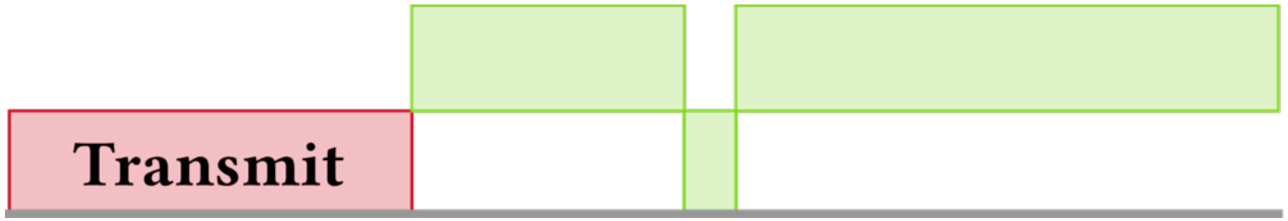
- **Class A** devices support bi-directional communication between a device and a gateway.
- Uplink messages (from the device to the server) can be sent at any time (randomly).
- The device then opens two receive windows at specified times (1s and 2s) after an uplink transmission.
- The server can respond either in the first receive window, or in the second receive window, but should not use both windows.
- If the server does not respond in either of these receive windows (situation 1 in the figure), the next opportunity will be after the next uplink transmission from the device.



Class C(ontinously listening)

Lowest latency, bi-directional end-devices

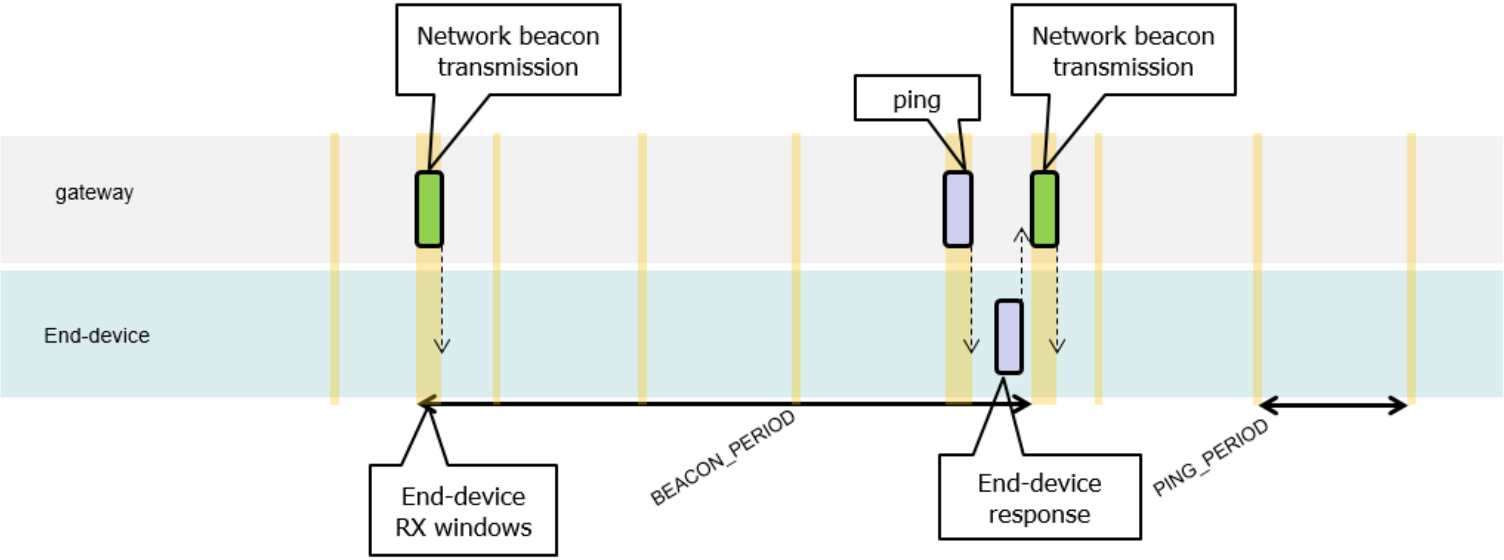
- **Class C** devices extend Class A by keeping the receive windows open unless they are transmitting.
- This allows for low-latency communication but is many times more energy consuming than Class A devices.



Class B(eaconing)

Bi-directional end-devices with deterministic downlink latency

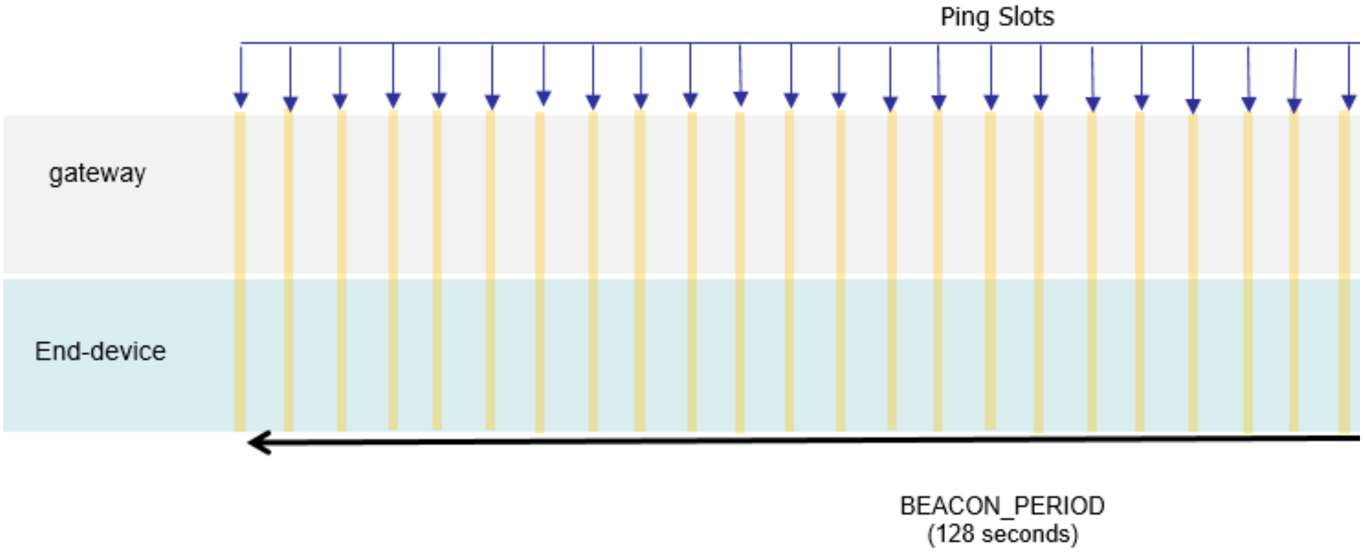
- **Class B** devices extend Class A by adding scheduled receive windows for downlink messages from the server.
- End devices in Class B mode provide for regularly-scheduled receive windows, in addition to those that open whenever a Class A-style uplink is sent to the server.



- All LoRaWAN end devices start in Class A mode; however, devices programmed with a Class B stack during manufacturing may be switched to Class B mode by the application layer.
- Based on the beacon timing reference, end devices can open receive windows (*ping slots*) periodically. Any of these ping slots may be used by the network infrastructure to initiate a downlink communication.

Class B(eaconing) (2)

Bi-directional end-devices with deterministic downlink latency



Beacon TOA	0.16	sec
Beacon periodicity	128	sec
Average beacon demodulation current	**12.5**	**uA**
ping slot min duration	32	mSec
ping slot periodicity	32	sec
Average ping slot Rx current	**10**	**uA**
ping slot duration when receiving downlink	300	mSec
downlink periodicity	3600	sec
Average Class B downlink demodulation current	**0.83**	**uA**
Class B related current	**23.33**	**uA**

- Synchronization beacons are transmitted by network gateways once every 128 seconds.
- The interval between two consecutive beacons is divided evenly into 4096 ping slots.

LoRaWAN MAC

MAC Message Formats

	(physical header)	(physical header CRC)	(physical payload)	(only uplink)
Preamble	PHDR	PHDR_CRC	PHYPayload	CRC*

(MAC header)	(MAC payload)	(message integrity code)
MHDR	**MACPayload** **Join-Request** **Join-Response**	MIC

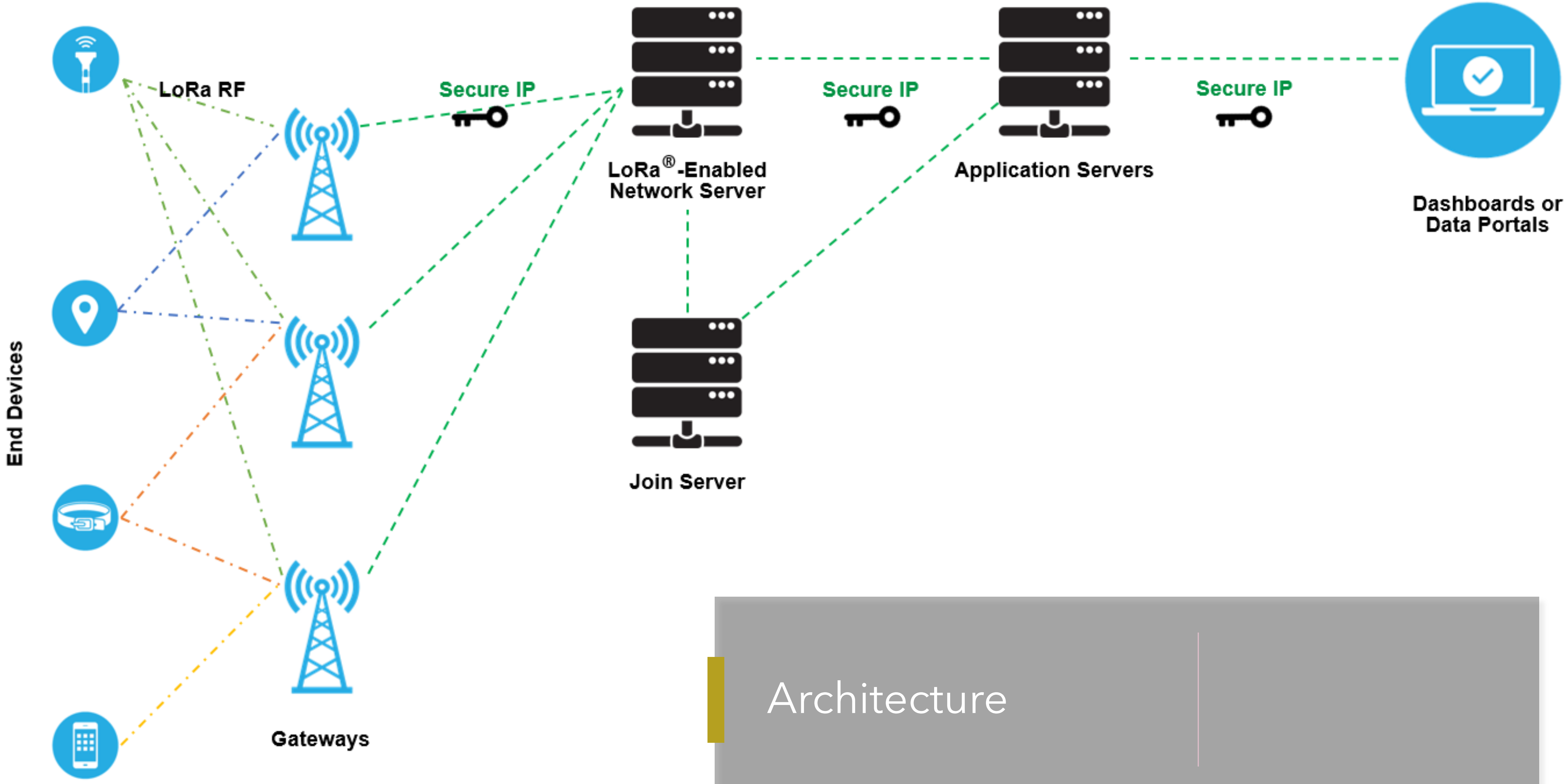
(frame header)	(port)	(frame payload)
FHDR	**FPort**	FRMPayload

(short dev address)	(frame control field)	(frame counter)	(frame options)
DevAddr	FCtrl	FCnt	FOpts

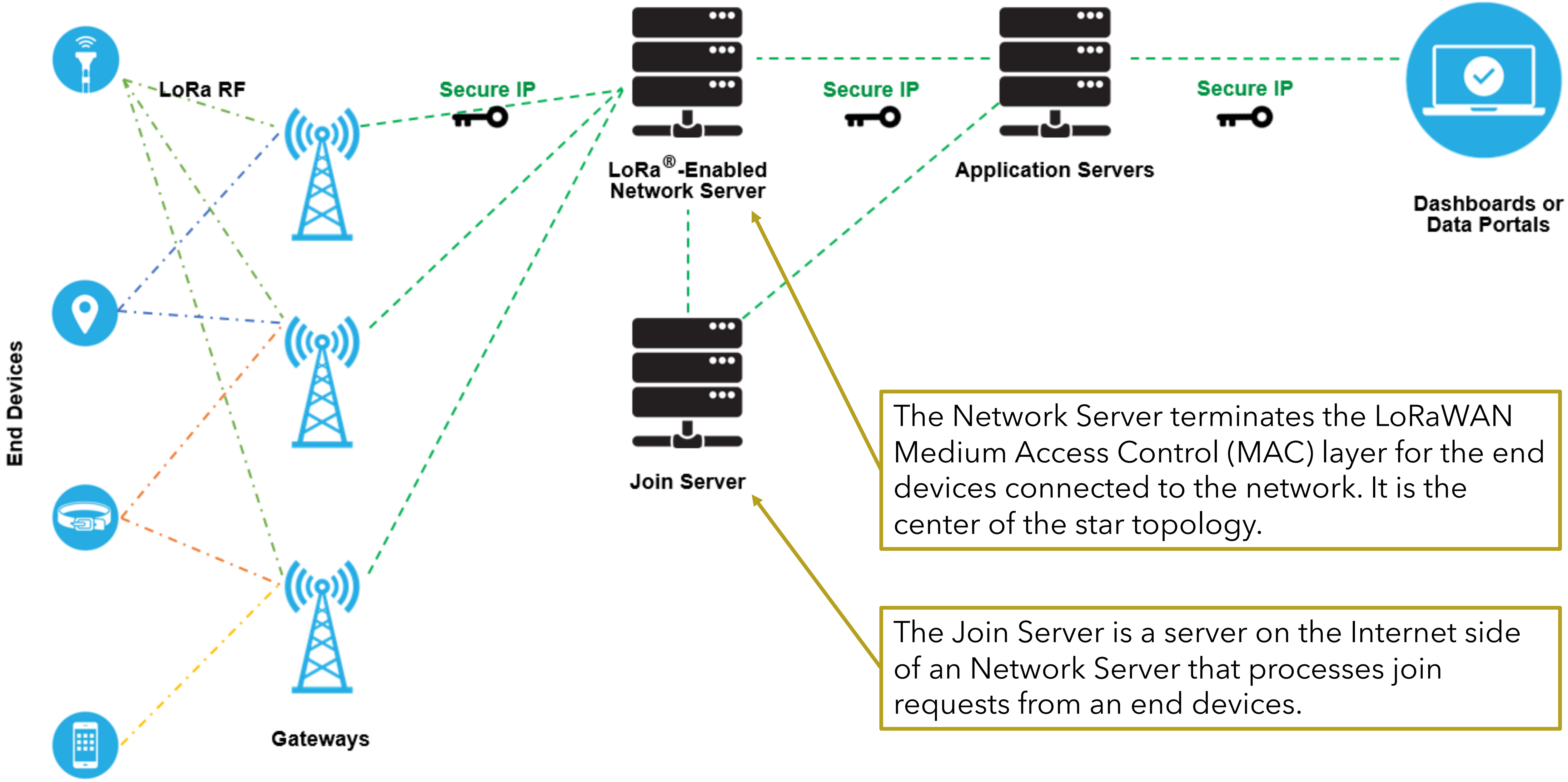
LoRaWAN MAC Singularities

- Field DevAddr (4 Bytes) is the address of the end-device.
  - source when up-link
  - destination when down-link
- Field FPort (1 Byte)
  - If 0, indicates the presence of a MAC command in the Frame Payload
  - If 1…223, may be used by the Application Server for addressing
  - If 224, used for testing purposes of new functionality

LoRaWAN Architecture

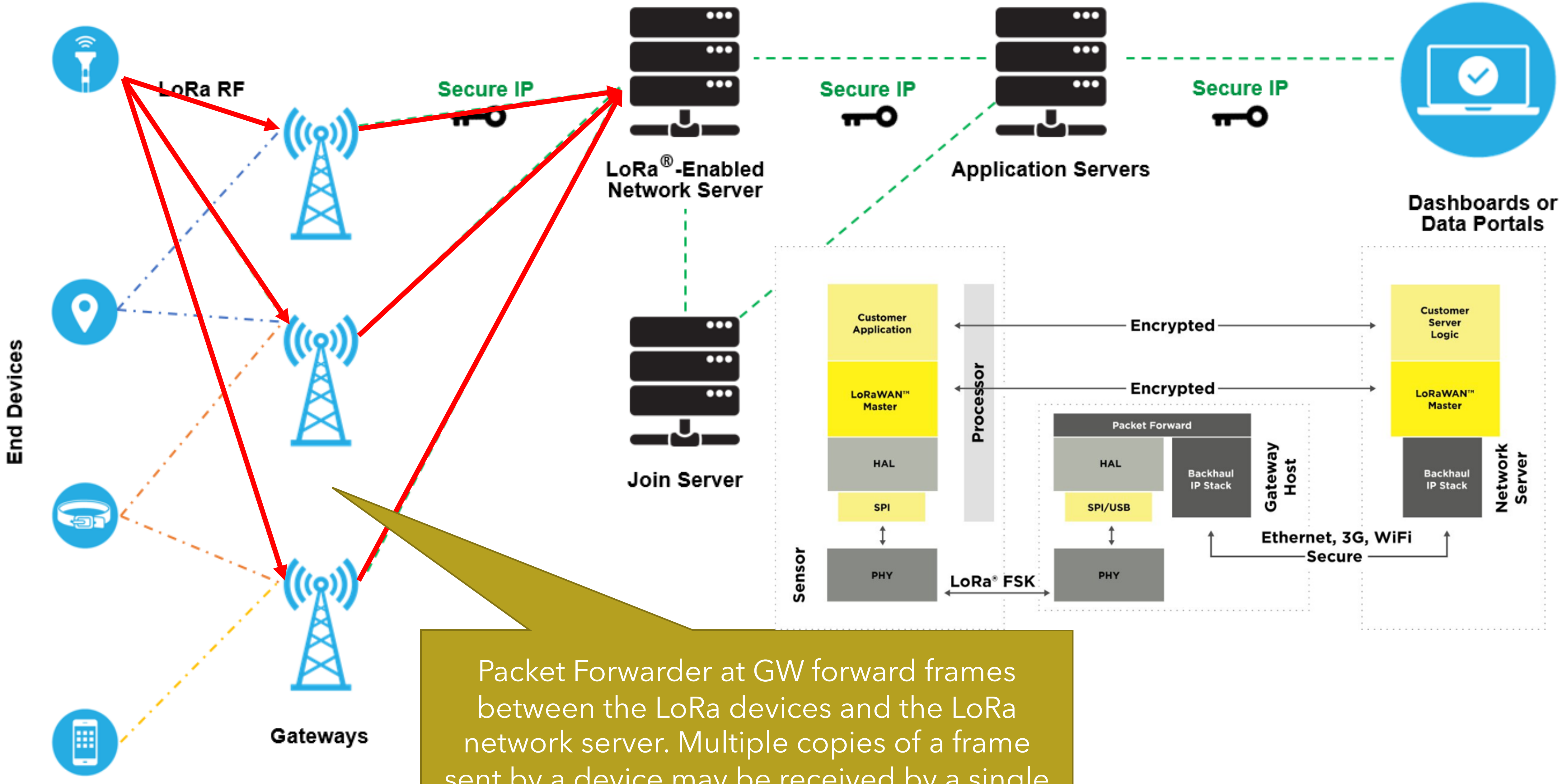


Architecture

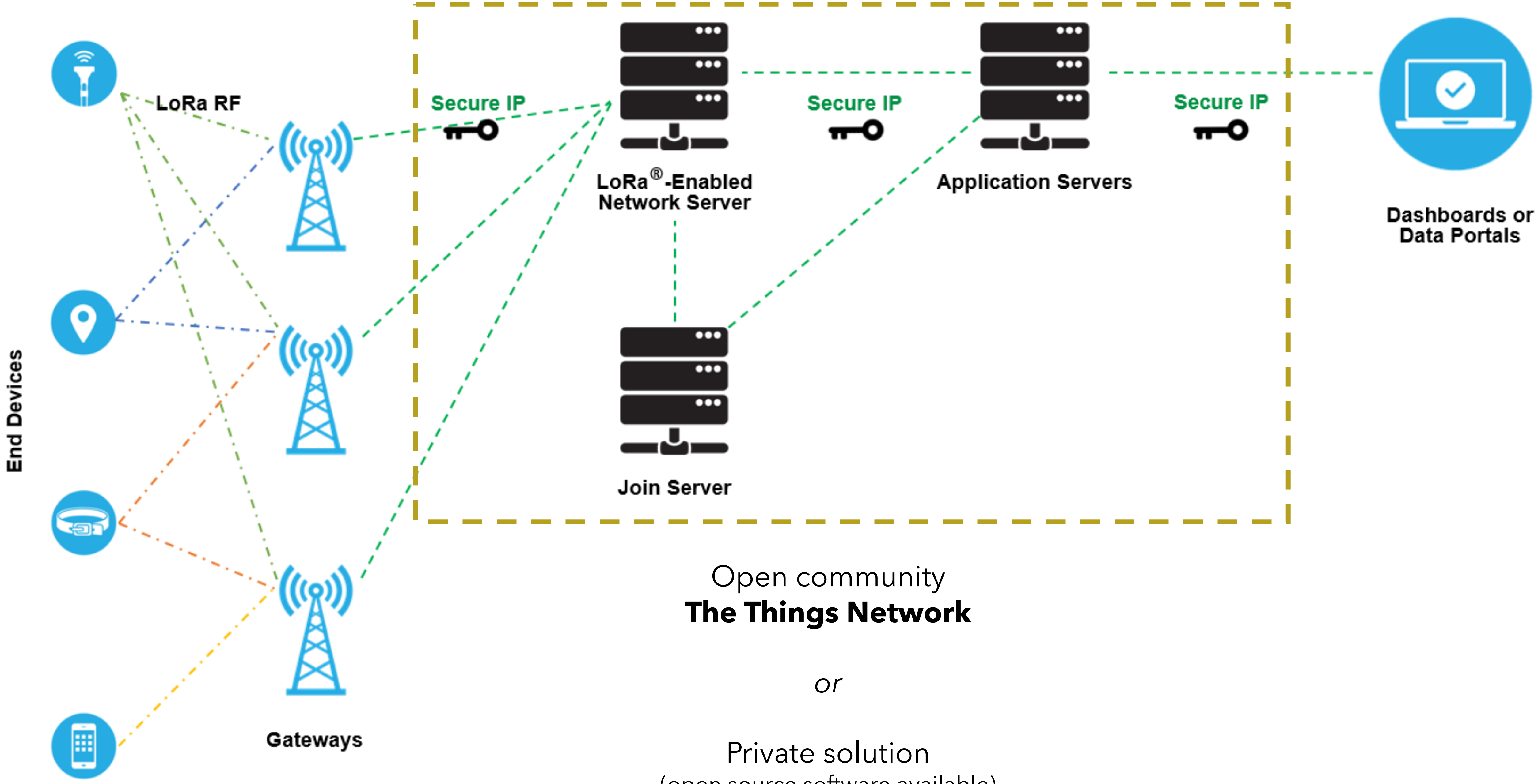


The Network Server terminates the LoRaWAN Medium Access Control (MAC) layer for the end devices connected to the network. It is the center of the star topology.

The Join Server is a server on the Internet side of an Network Server that processes join requests from an end devices.



Packet Forwarder at GW forward frames between the LoRa devices and the LoRa network server. Multiple copies of a frame sent by a device may be received by a single Network Server (each GW forwards its copy)



Open community
The Things Network

or

Private solution
(open source software available)

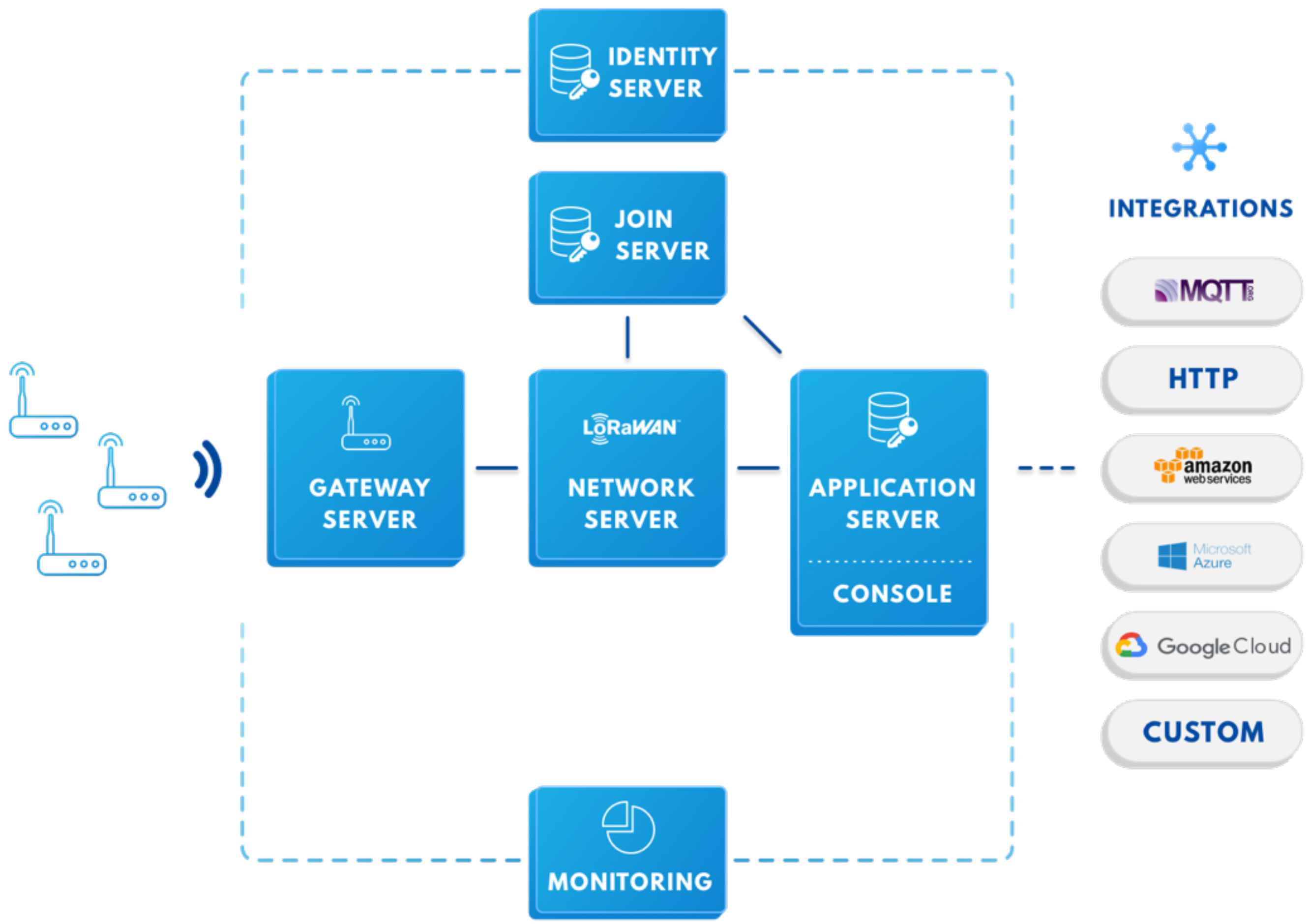
The Things Network

Public LoRa Network & Application Server Infrastructure

www.thethingsnetwork.org

At this moment, there are 11505 gateways up and running in 150 countries

The Things Network



LoRa Deployments Worldwide

- Reindeer tracking in Finland[25]
- Smart fire alarms and fire detection[30][31]
- Smart Parking[32]
- Black rhino poaching protection[33] and endangered sea turtle monitoring[34]
- Natural disaster prediction[35]
- Cotton farming in Australia[36]
- Utility metering in India[37]
- Autonomous irrigation[38] and soil health monitoring[39]
- Smart water monitoring[40] and water monitoring for commercial farms[41]

Competing Radio Technologies

SigFox

- It was deployed in France in September 2017. It's operating in 36 countries. It claims to work for 10 years on a single AA battery.

NarrowBand-IoT

- This is a cellular-based network optimised for low power consumption and long-range communication. Compared to LoRa, NB-IoT has the advantages of an already mature ecosystem for mobile networks with support from telecom equipment vendors.

RPMA

- Owned by the US company Ingenu, RPMA stands for Random Phase Multiple Access and useful for building machine networks.

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- Energy Consumption Model for Sensor Nodes Based on LoRa and LoRaWAN. Taoufik Bouguera, Jean-François Diouris, Jean-Jacques Chaillout, Randa Jaouadi and Guillaume Andrieux. MDPI Sensors 2018, 18, 2104; doi:10.3390/s18072104