

Internet des Objets Longue Distance

Didier Donsez, Vivien Quéma

`didier.donsez@univ-grenoble-alpes.fr`

`vivien.quema@grenoble-inp.fr`

Internet of Things

Gartner : 20 milliards d'objets en 2020

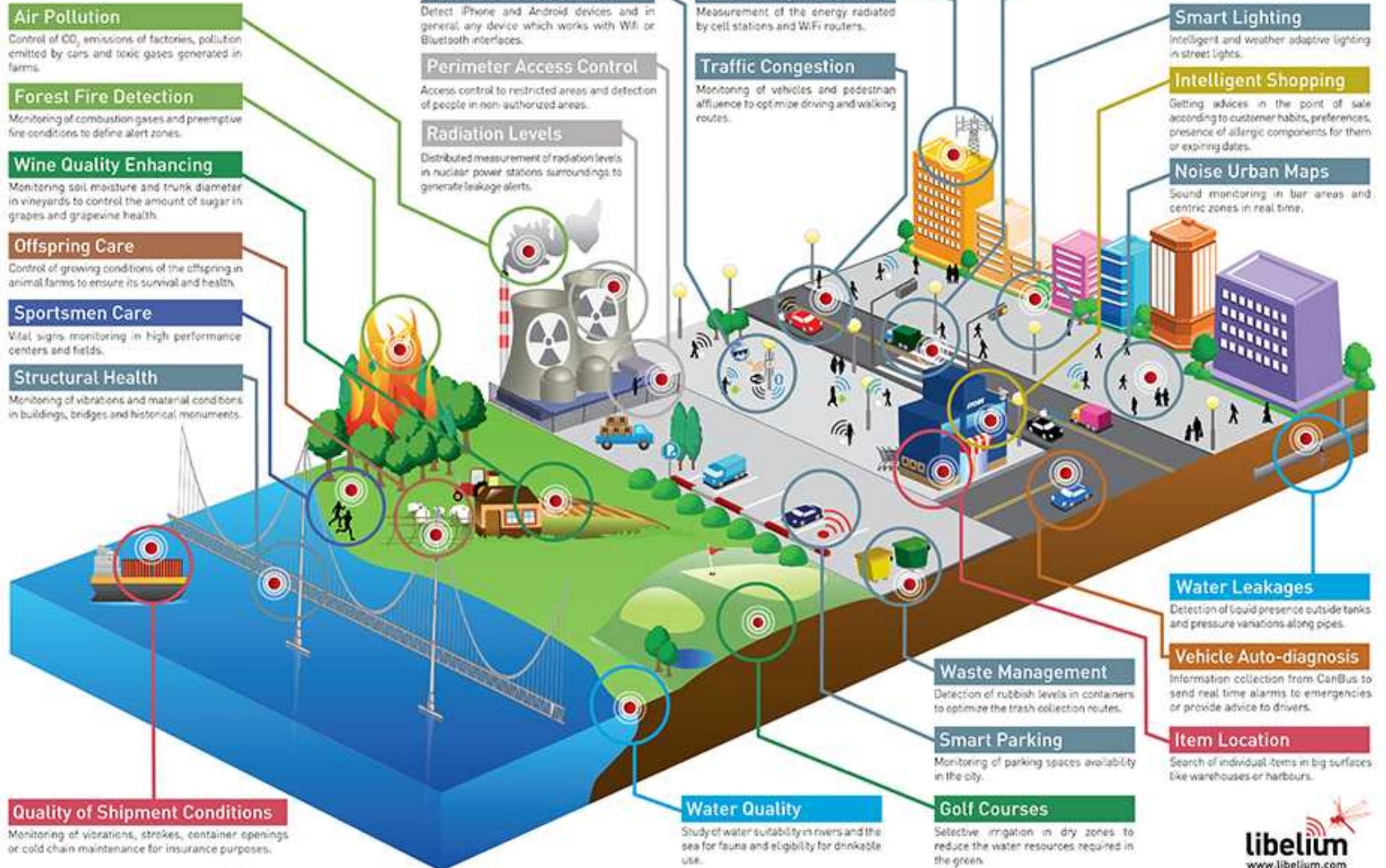
IoT small range : Smart Home, Smart Office

IoT medium range : Smart Building

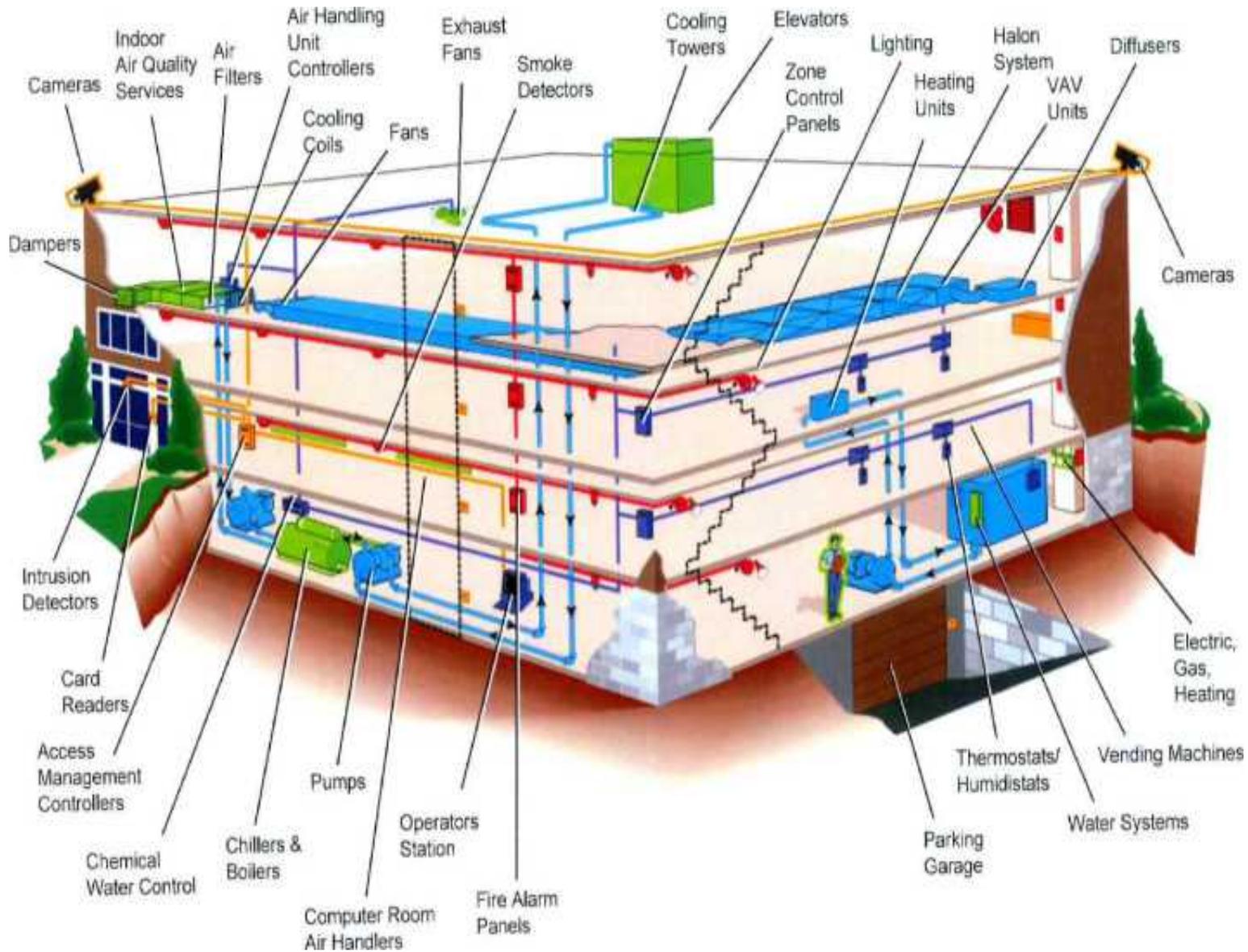
IoT long range : Smart City, Smart Grid, Smart Agriculture, ...



Libelium Smart World



Building Automation



Smart Metering

- Utilities
 - Gas, Water, Electricity, Steam
- Market
 - Status : 88,2M SM installed in 2017
 - Forecast : 588M installations between 2018 and 2022
- Applications
 - Suivi en « temps réel »
 - Détection de fuite
 - Economie
 - Ajustement production-consommation (Smart grid)
 - Fraude
- Remark : *Deep Indoor communications*



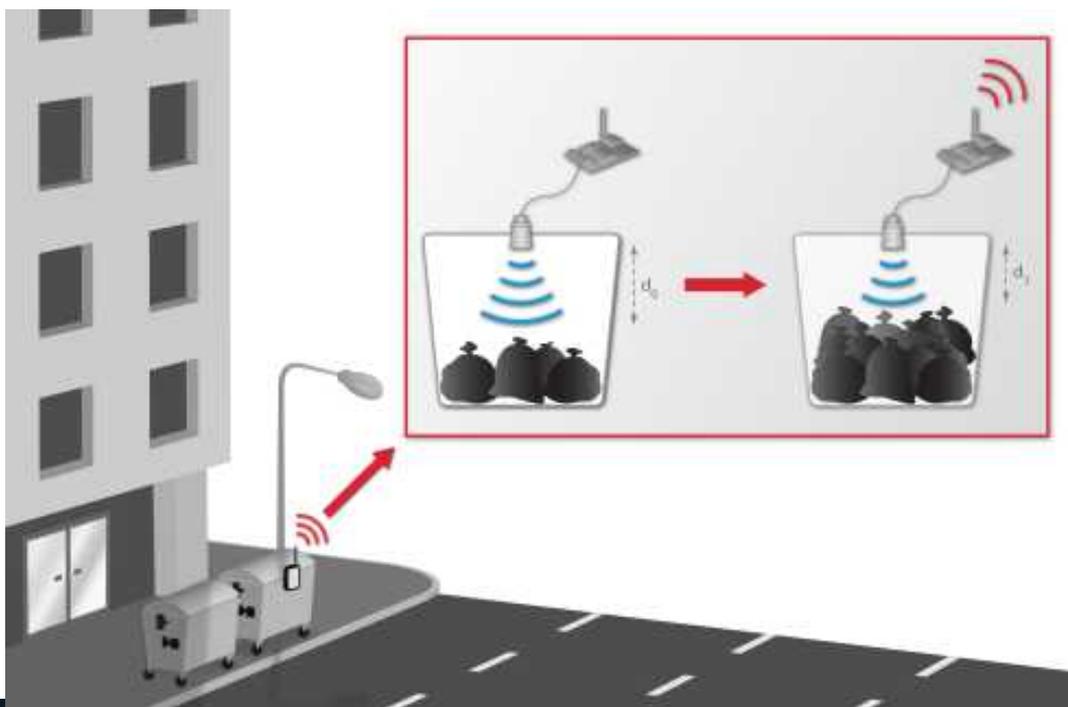
Smart Grid

- Consommation d'énergie
 - Anticiper en temps réel la demande globale pour gérer la production glob
 - Auto-consommation au niveau d'un quartier, d'une résidence
- Production d'énergie
 - Panneaux solaires, Eoliennes, ...
 - Individuel, Toit d'immeuble, Collectivité, Ferme, ...



Gestion des déchets

- Collecte optimisée
- Paiement au volume

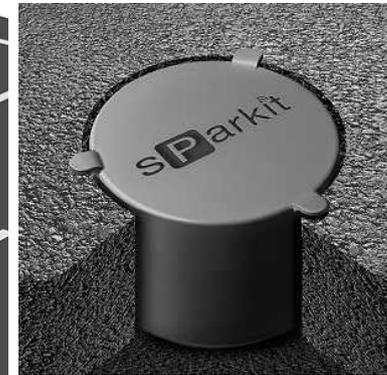


Smart Parking

- Applications

- Aide au guidage des automobilistes vers les places libres
 - Aide à la recherche des places handicapé libres
 - Détection des infractions (places handicapés, livraisons, ...)
 - Paiement à la minute
-
- A smart parking solution can reduce a 43% the time spent looking for parking, a 30% the miles traveled with a vehicle searching for a parking, the 8% of the traffic volume and the 40% of green house gas emissions.

Smart Parking



Colas



Suivi de flotte

- Véhicules, conteneurs ...
 - Optimisation
 - Conduite dangereuse
 - Fraude
 - Vol
 - Urgence
 - Couplage avec les feux de trafic



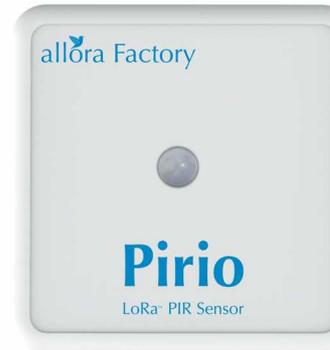
Smart Urban Lighting

- Eclairage urbain
 - 40 % de la facture d'électricité des villes
 - 1900 milliard de kg de CO2 (4 fois les émission de la France)
- Contrôle individuel des lampadaires urbains
 - 1 sur 2,
 - gradation (LED),
 - présence,
 - « précède moi »
 - « je suis en panne » (maintenance)
 - ...



Sécurité

- Bâtiments
 - Bureau, Hall, Communs
 - Isolé : Cave, Hangar, Parking souterrain
- Applications
 - Présence/Intrusion
 - Incendie
 - Radiation
 - Panic Button (travailleur isolé)
- Risques naturelles
 - Nilomètre
 - Nivelomètre
 - Mouvement de terrain
- Risques industriels
 - Radiation
 - Pollution des eaux



Air Quality

- Facts
 - Air pollution generate 8.2 million deaths per year in the world
 - Estimated cost : 68 to 97 G€/year (for France)
- Measurements
 - Fixed/mobile air quality stations
 - Flying stations



Pigeons wearing wireless pollution-monitoring devices will report back via Twitter

- Picture credits Plume Labs

<https://www.linkedin.com/pulse/when-pigeons-tweet-birds-iot-harald-naumann>

Air Quality

- Particules (PM), VOC, CO2, NO2, ...



- Forecast : Particle sensors market will reach \$1.2B in 2023, with 300Munits (all applications included)

Risk management

- Risks
 - Floods, Snowslide, Landslide ...
- Measurements
 - River level, Motion detection ...



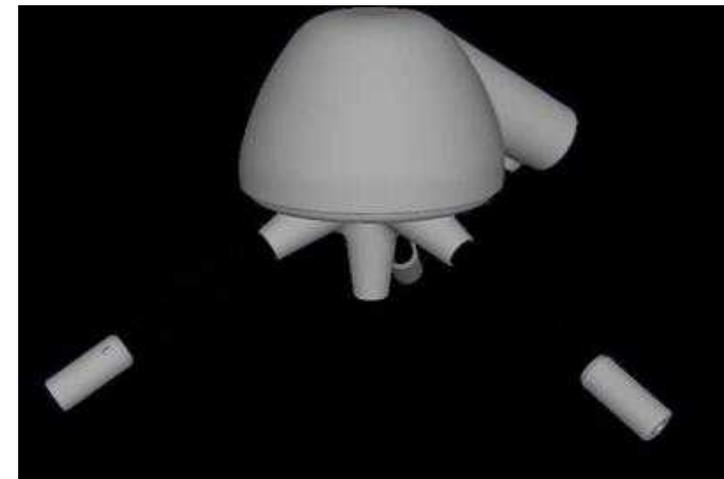
<https://air.imag.fr/index.php/IRock>



<https://twitter.com/decentlab/status/731042251665747968>

Nuisances sonores

- Faits
 - Un coût sur la santé du bruit des transports s'élevant à 11,5 milliards d'euros par an en France, dont 89% induit par le trafic routier (*)
- Applications
 - Traffic routier
 - Lutte anti-fétard



Capteur sonore Bruitparif

* <http://www.bruit.fr/cout-social-du-bruit-en-france-57-milliards-deuros.html>

Distributeurs automatiques

- Niveaux de remplissage des compartiments
- Pics d'activité
- Remontées des anomalies



Personnes fragiles

- Services à domicile (santé, repas, ménage)
 - Badgeuse (Suivi)
- Activités
 - Mouvement
 - Consommation fluide



Lysbox du CG Loiret

Agriculture de Précision

- Greenhouses, Open fields, Beehives, ...
- Water distribution, Temperature, Ice, Air humidity, Soil moisture, Light, Acidity, ...



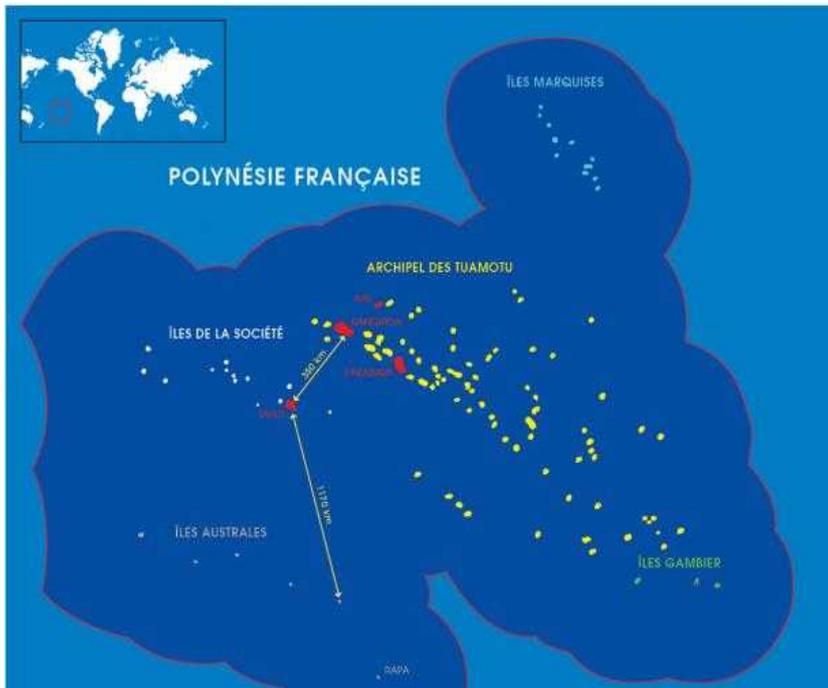
<http://sencrop.com/fr/produits/anemometre-connecte/>



The Internet of Isolated Things

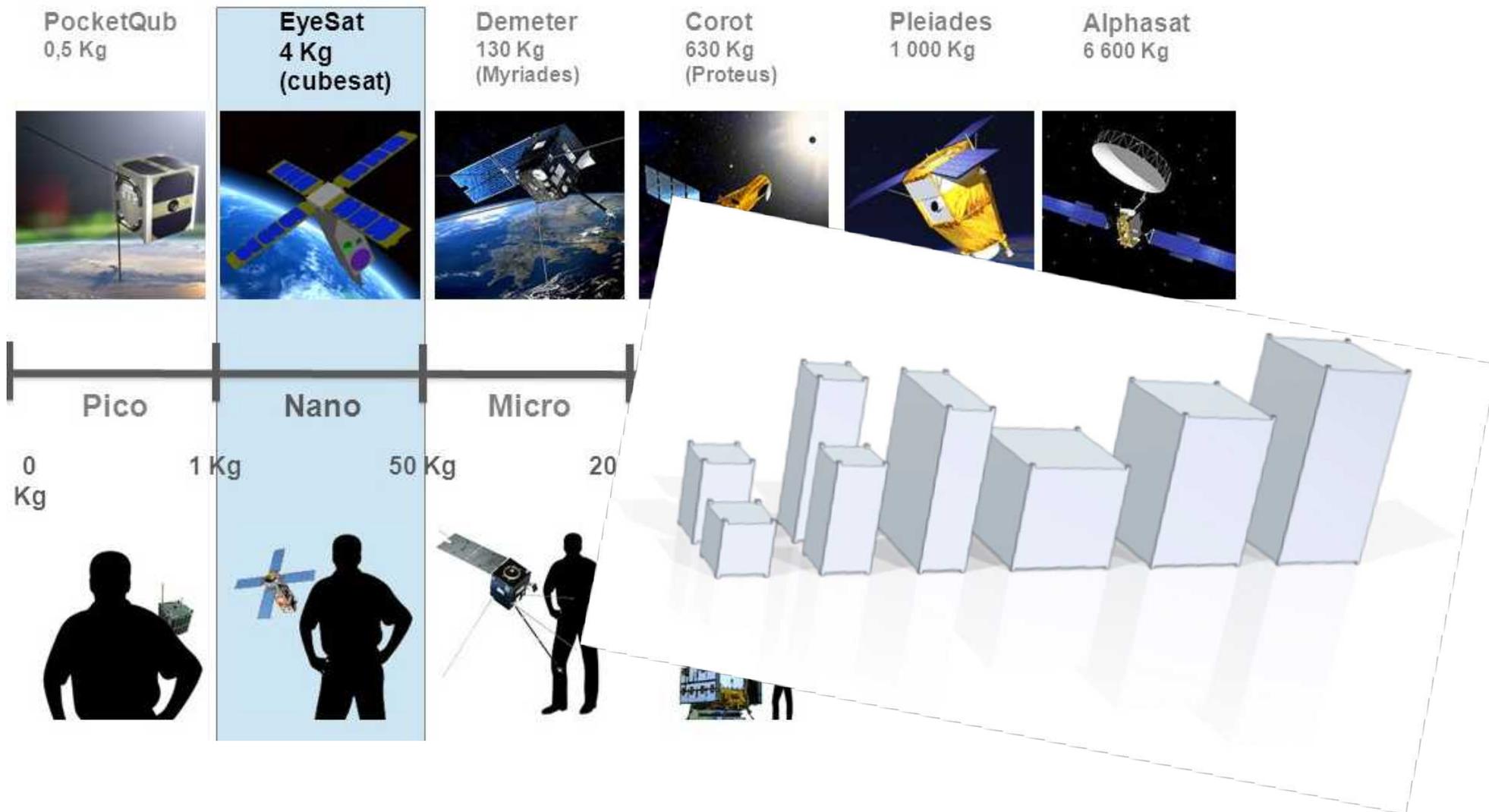
IoT networks cover only a few part of the Earth (*Orbi*)

Deserts, oceans, pole regions, unpopulated areas are “not” connected to the global web



New Space & Cubsats

- Agile and “affordable” LEO satellites

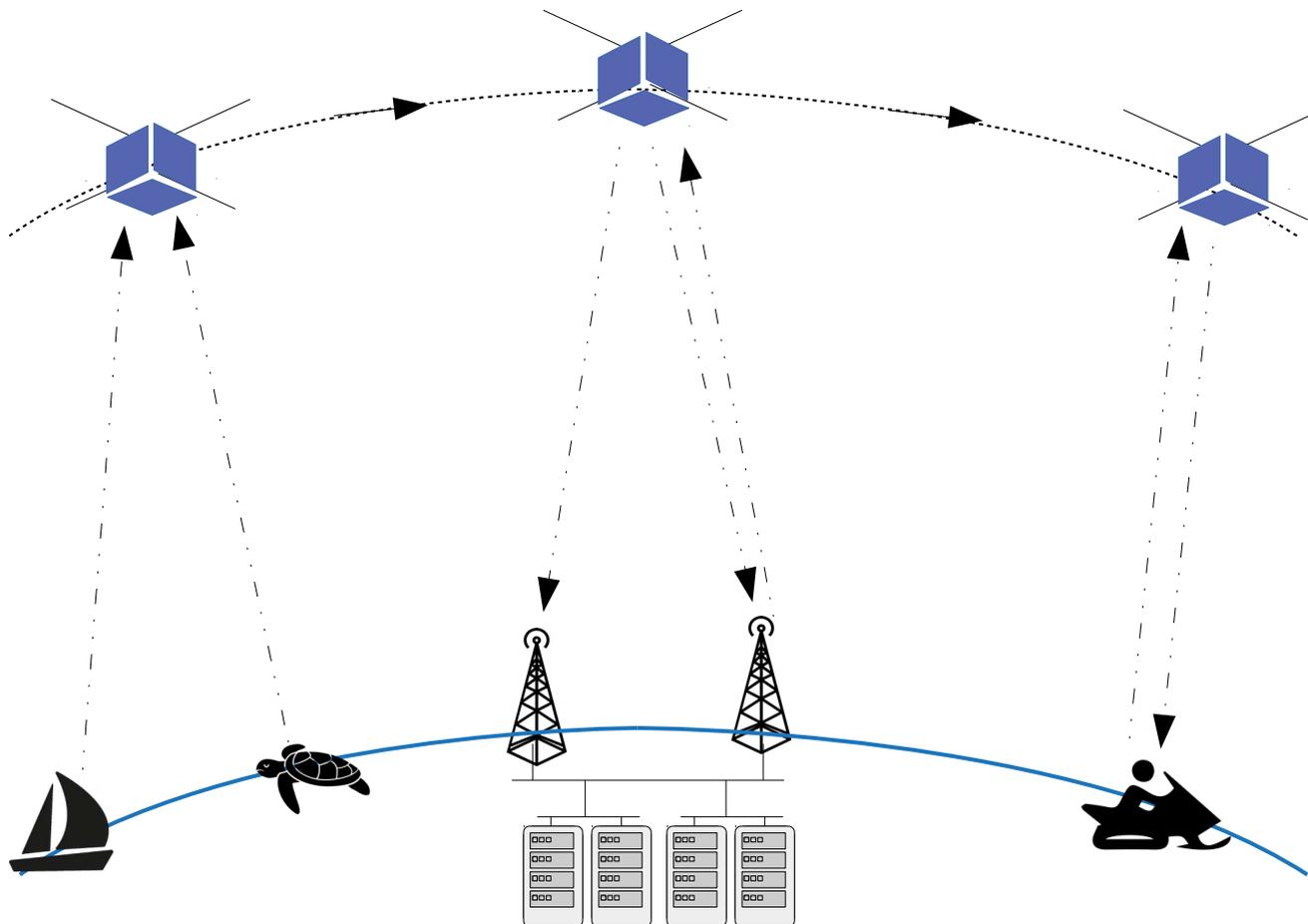


Sat-IoT



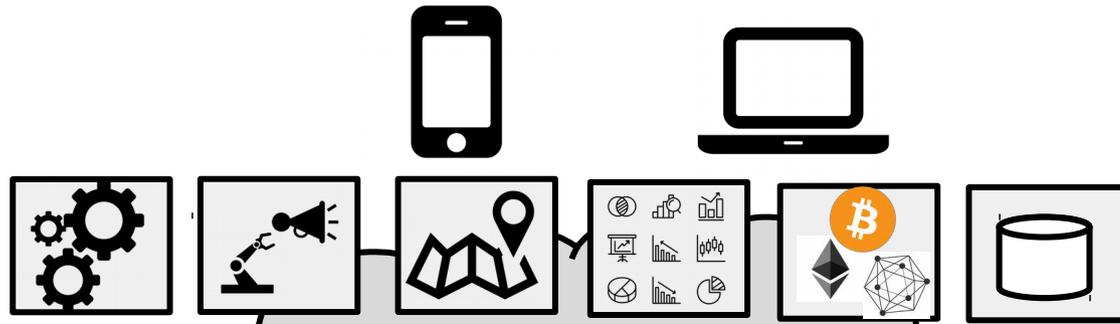
Projet
ThingSat

Constellation de nano-satellites servant de « mules »
des messages reçus du sol

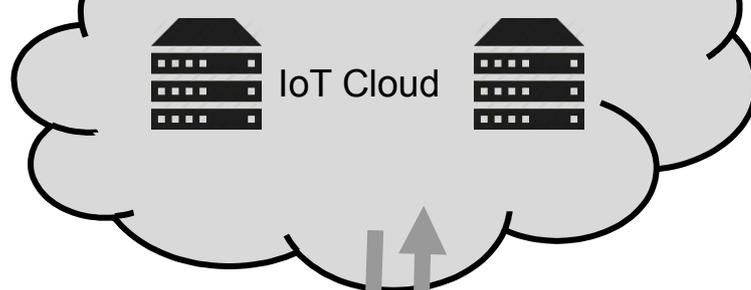


Architecture d'un système IoT

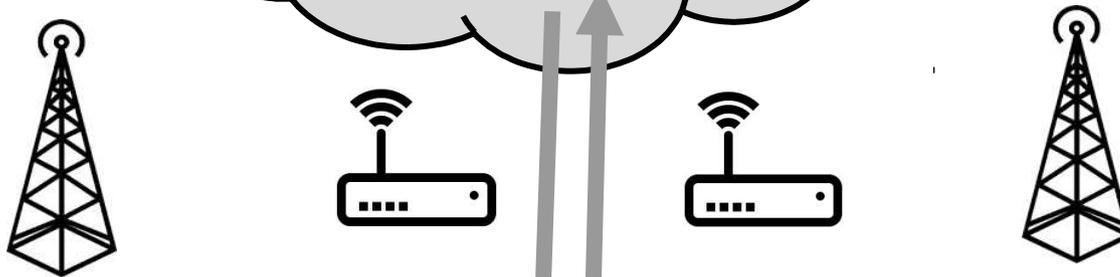
IoT Applications



Cloud infrastructure
(public, private)



Fog/Edge Computing

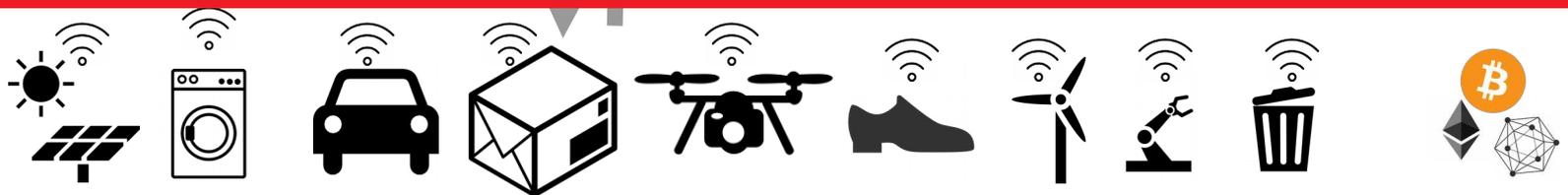


Communications

- wired/wireless
- IP / No IP
- licensed/free bands



Connected Things
(sensors & actuators)



LPWAN Communication Technologies

Low-Power and Long Range WAN

The 3C : Cost, Current, Coverage

LoRa/LoRaWAN

Sigfox

NB-IoT and LTE-M (3GPP)

covers most of the (previous) IoT use cases

Low-Power and Long Range WAN

Example: Elsys ELT2 (LoRa endpoint with temperature sensor)

- Battery lifetime from **6** to **18** years (1 temp. msg/hour)



Sample time: Seconds
Sensor: Select Elsys sensor
Battery capacity: Capacity(mAh)
Battery performance: Performance(%)

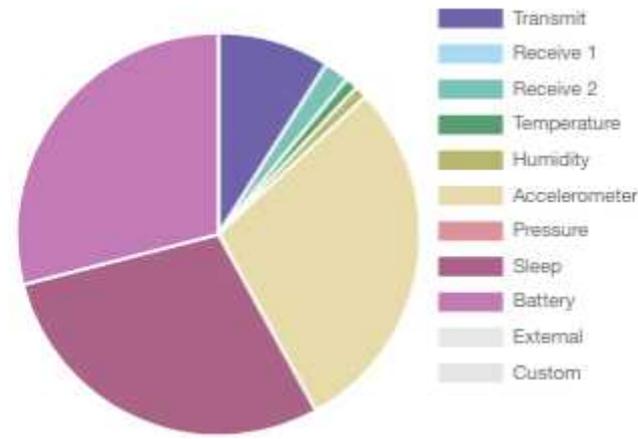
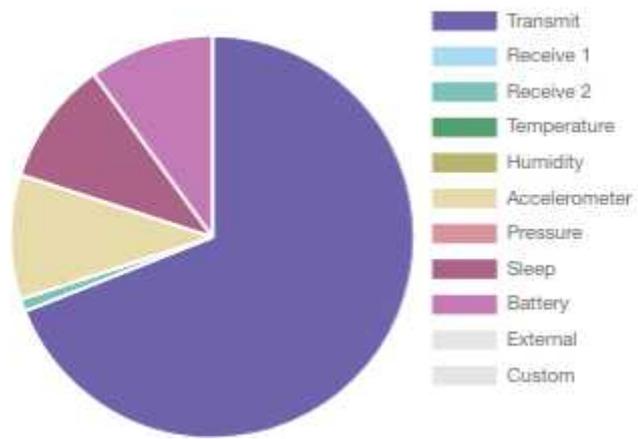
Spreading factor:
 SF7 SF8 SF9 SF10 SF11 SF12

Result:
The battery will last for **6.2** years*. The sensor will draw **40uA** and **351mAh** in one year.

Sample time: Seconds
Sensor: Select Elsys sensor
Battery capacity: Capacity(mAh)
Battery performance: Performance(%)

Spreading factor:
 SF7 SF8 SF9 SF10 SF11 SF12

Result:
The battery will last for **18** years*. The sensor will draw **14uA** and **120mAh** in one year.



Low-Power and Long Range WAN

Example: Elsys ELT2 (LoRa endpoint with temperature sensor)

- Mont-Blanc → Strasbourg 300 kms (Eclipse IoT Days 2018)

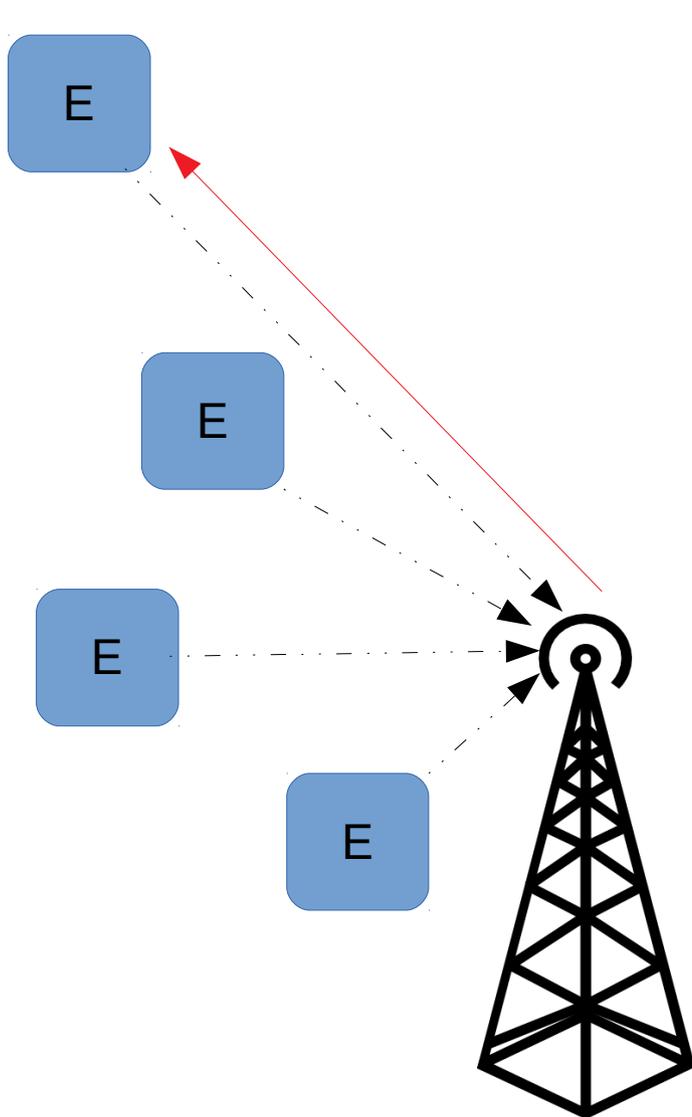
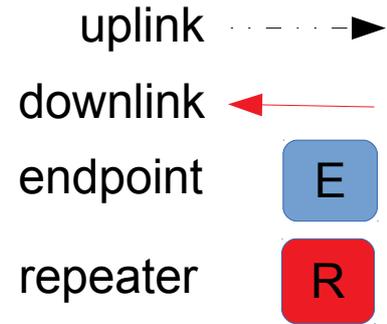


IoT Wireless Communication Ranges

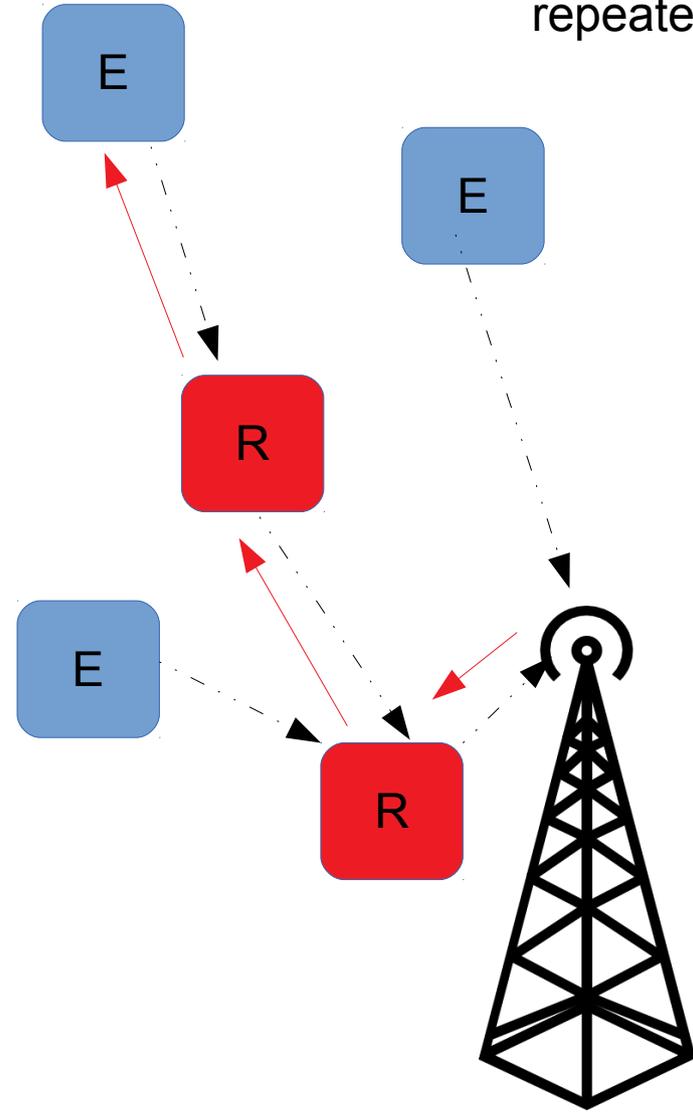
- Proximity
 - RFID (NFC)
- Short
 - RFID (HF, UHF EPC Global) *no battery*
 - Wifi, Bluetooth Low Energy
 - Zigbee, Zwave
 - enOcean *energy scavenging*
 - Rfxcom433, Thread
- Medium
 - WMBus
- Long
 - SMS/2G/3G/4G, HAM
 - Sigfox (UNB), LoRa, Weightless, LTE-M, NB-IoT
- Ultra-long
 - Iridium, Argos, LPGAN (Sat-IoT)

Network Topology

Star versus Mesh

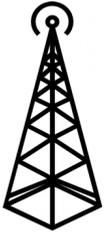


Base station (BTS)



Base station (BTS)

Base Stations (Gateways)



- LoRa (200-2000€, 10 W)

- LTE BTS 234G (>100K€, >10KW)

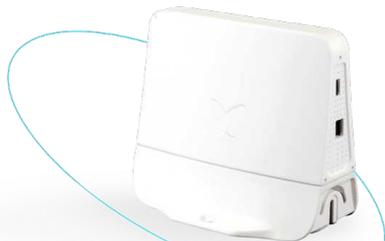


Pico Base Stations

- Home, deep-indoor and building automation
 - Target price 50-100 euros / gateway
- One mile
- « Mono-channel »
 - Pycom, ESP32, Archos Picowan (SX1276)
- « Multi-channel » (LoRa SX1308)
 - Picocell, Murata, ...



Gateway PicoWAN Archos

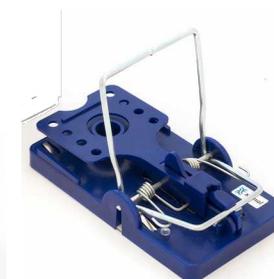


Sigfox Access Station Micro



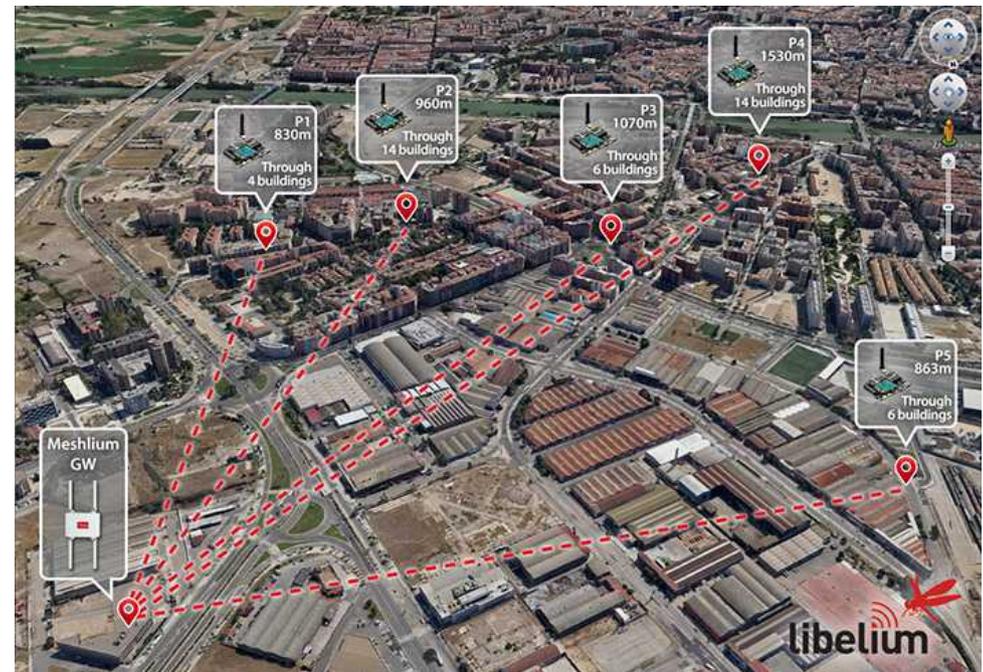
Endpoints

- Development kits
 - For rapid prototyping purpose
 - C/C++, μ Python, Javascript, Lua, ...
- Modules
 - Bare metal
 - Firmware should include the program and the radio stack (open-source or licensed)
 - Modem
 - Pre-certified
 - Require a host μ C
 - Mono-protocol, Multi-protocol (Sigfox, LoRa)
- End products
 - Certified (ETSI, FCC, ...)
 - Ready to use after personalization
 - AES Keys, factory default parameters



Range and Coverage Line Of Sight

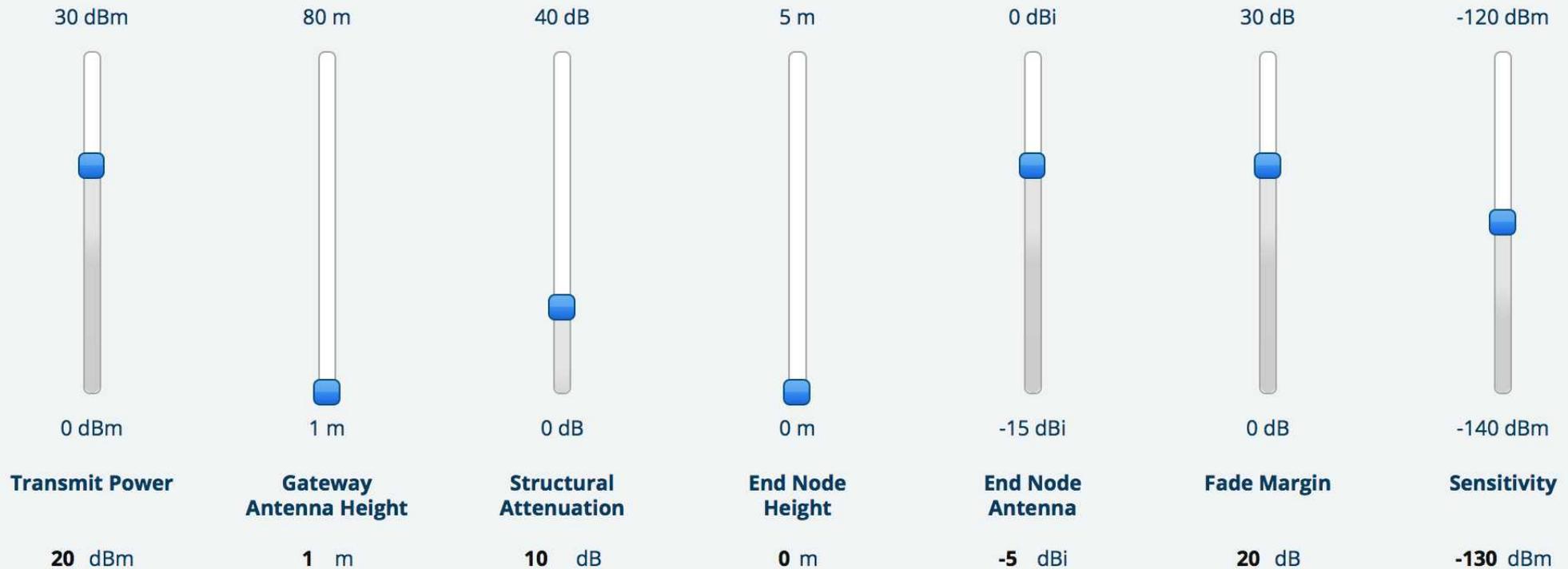
- 22km (13.6 miles) in LOS links
- up to 2km (1.2miles) in NLOS links in (Paris) urban environment (going through buildings).



Source : Libelium waspmote_technical_guide.pdf
https://en.wikipedia.org/wiki/Line-of-sight_propagation

Range : LOS vs NLOS

1m ← → 0m

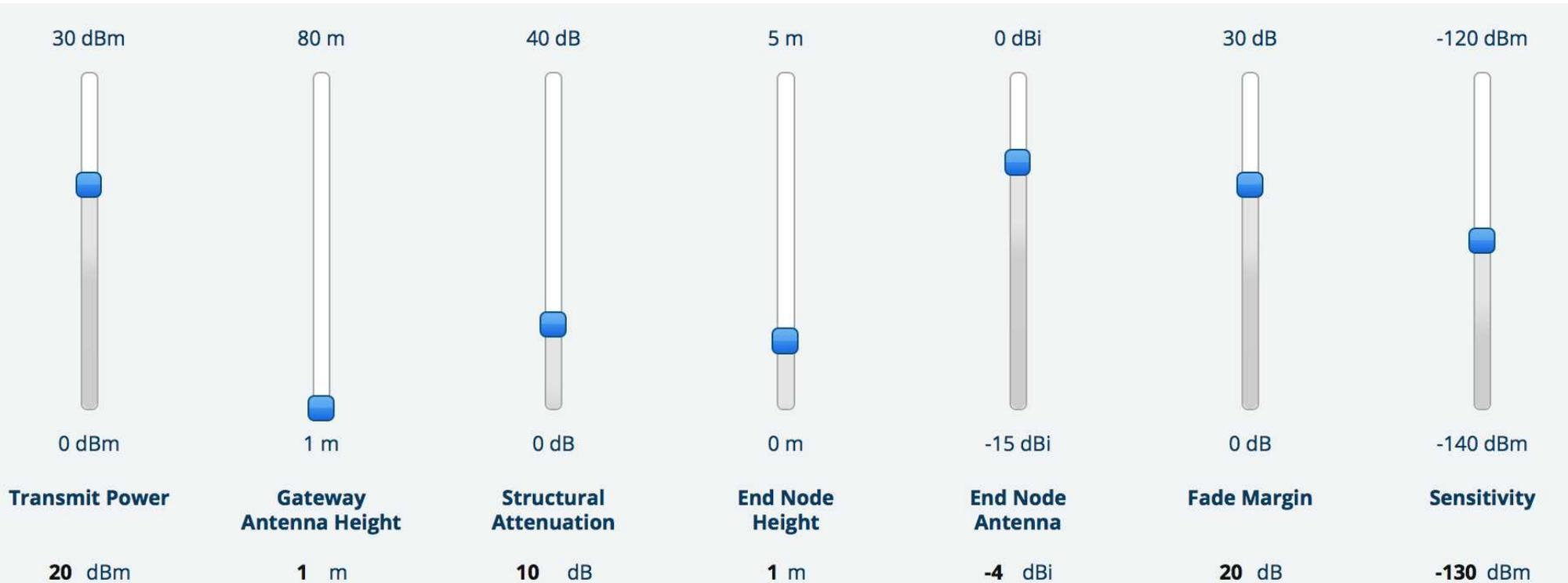


 **MAXIMUM RANGE**
375.84 m

Source : <http://www.link-labs.com/walop/>

Range : LOS vs NLOS

1m ← → 1m

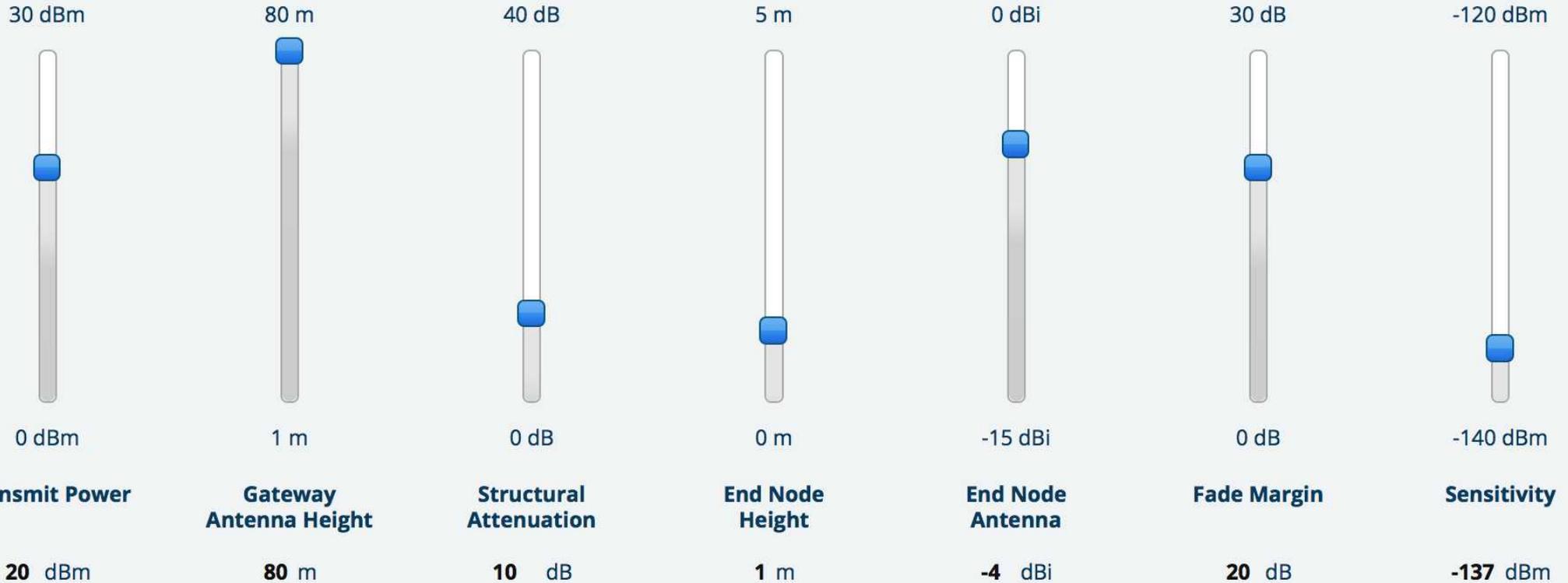


 **MAXIMUM RANGE**
1258.93 m

Source : <http://www.link-labs.com/walop/>

Range : LOS vs NLOS

80m ← → 1m

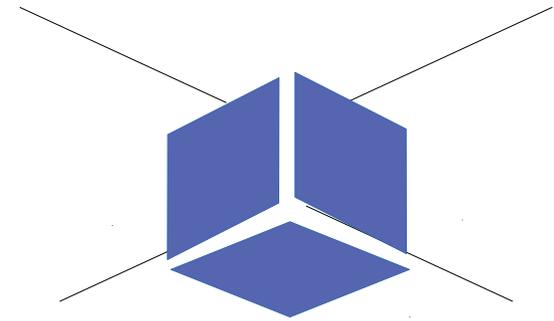
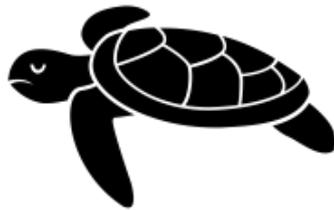


 **MAXIMUM RANGE**
16847.87 m

Source : <http://www.link-labs.com/walop/>

Range : LOS vs NLOS

0 m \leftarrow \rightarrow 500 000 m (LEO)



Projet
ThingSat

Preliminary radio tests

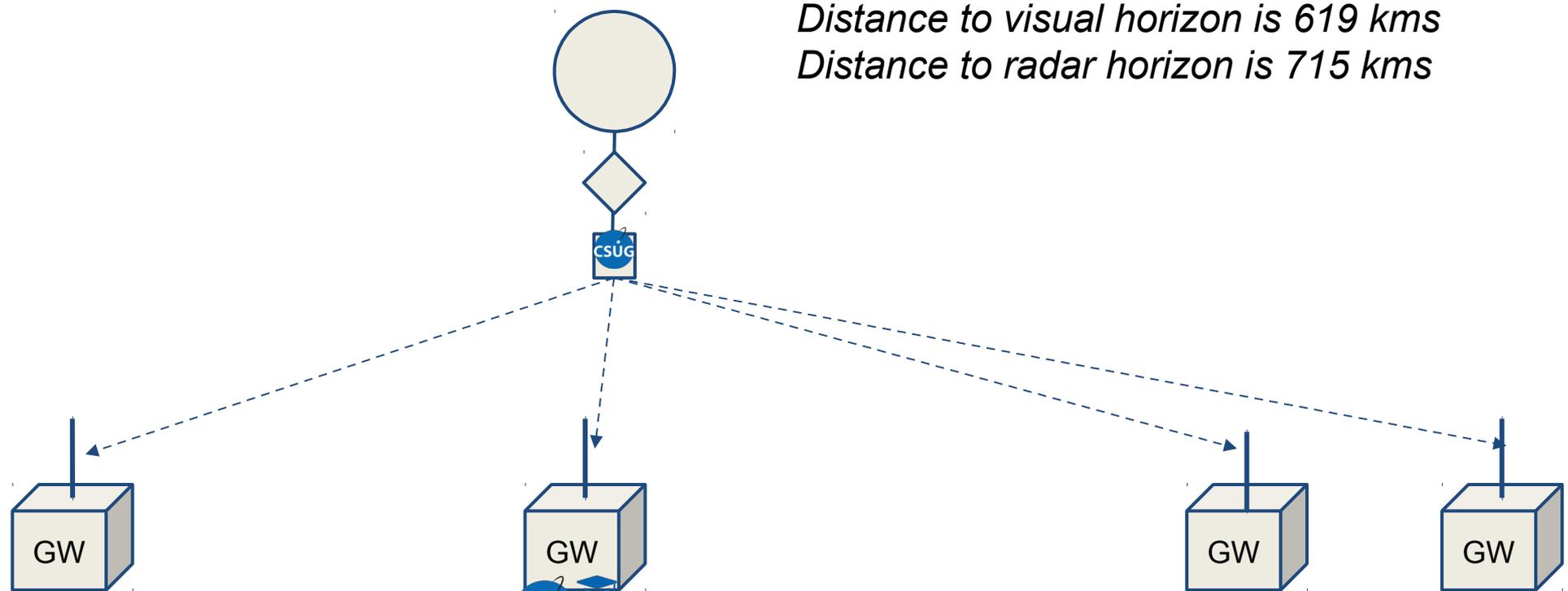
LoRa in the Near Space

Goal

- Benchmarking LoRa™ modulation link margin and distance per LoRa radio parameters (TxPower, SF and BW)

How

- EP into a sounding balloon (up to 30000 meters of altitude)





Preliminary radio tests

LoRa in the Near Space

Our endpoint

- *Off-the-Shelves* board (STM32+SX1272+GPS)
 - RIOT OS
 - ADR is off. Transmit frames with various combinations of SF (7 .. 12) and TxPower (2 .. 19)
 - SF, TxPower, Temperature, GPS (latitude, longitude, altitude)
- Registration on multiple LoRaWAN Networks
 - Orange LiveObject (5500 gateways with/without TDOA in France)
 - The Thing Network (+4700 gateways in Europe)
 - CampusIoT (1 mobile gateway in a car roof top)
- Live tracking with NodeRED (GPS, TDOA)

Max link budget = **157** dB

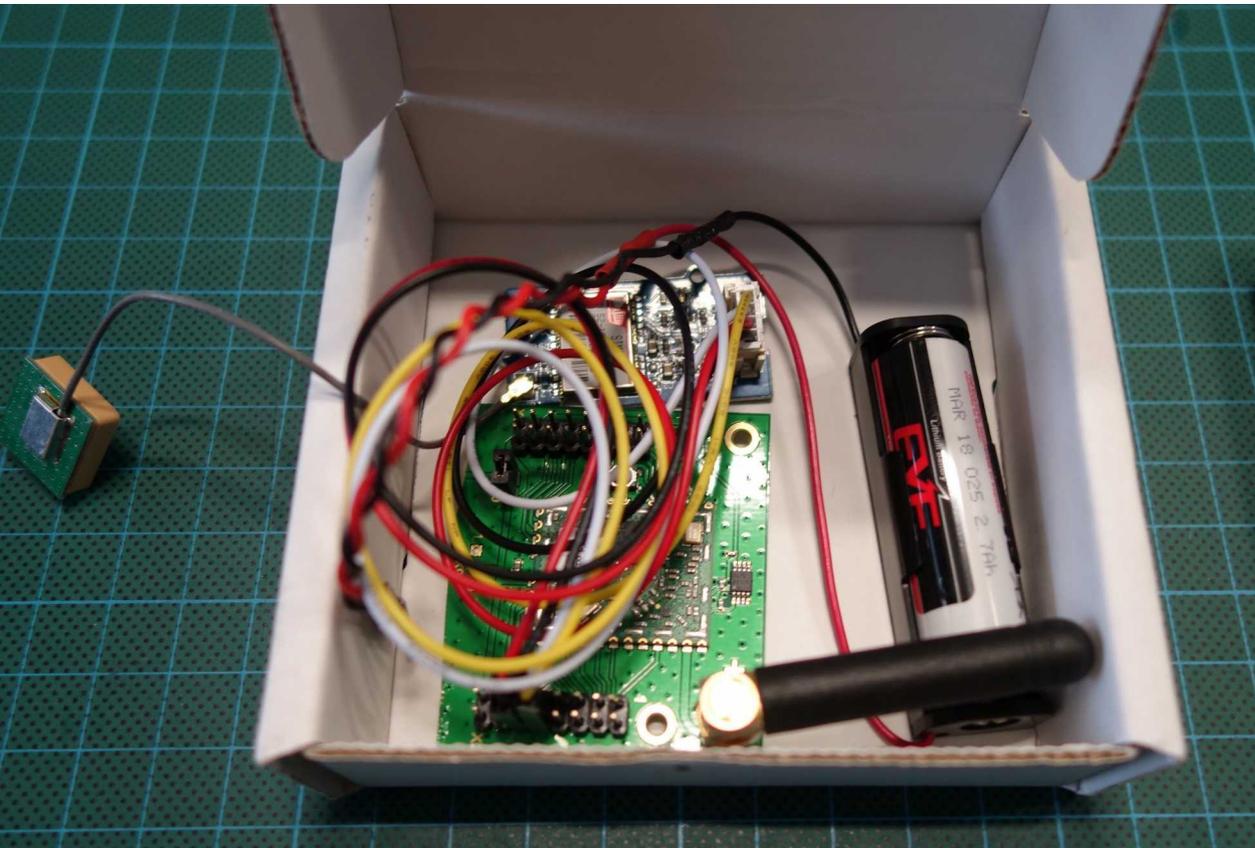
Flight #1

“L’envol d’Albert”, May 9th, 2019

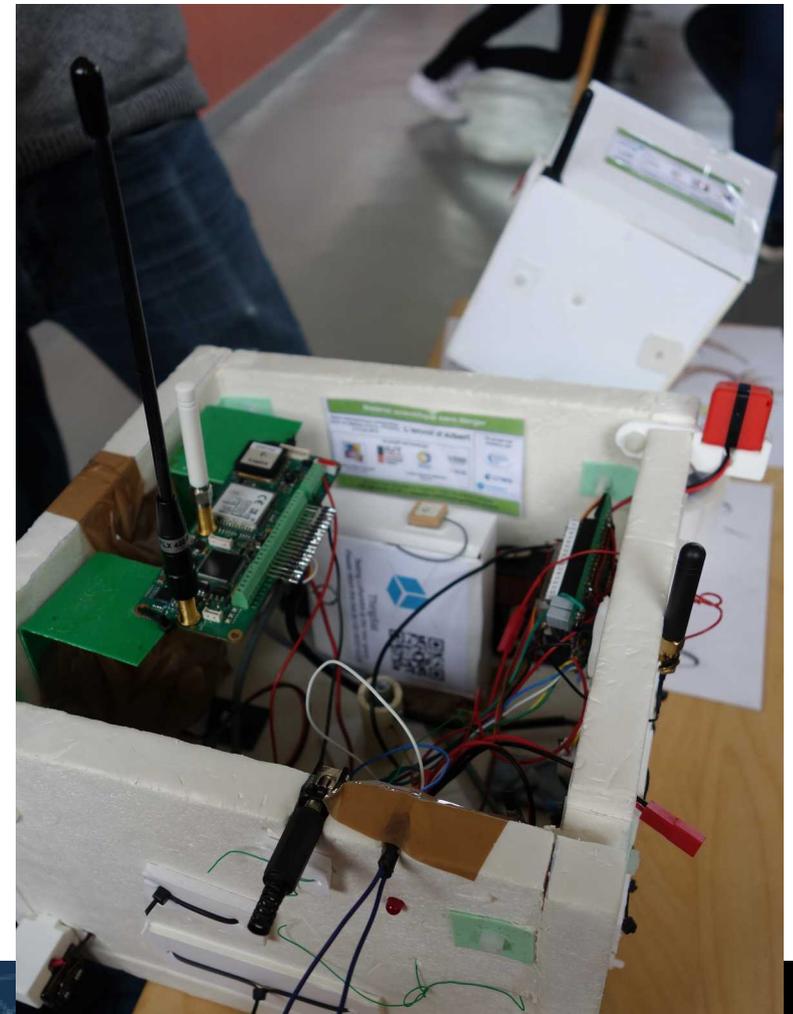
Planète Sciences

IUT Valence, Lycée Triboulet (Roman/Isère), Collège XX

80 grams



1800 grams max



Flight #1

“L’envol d’Albert”, May 9th, 2019

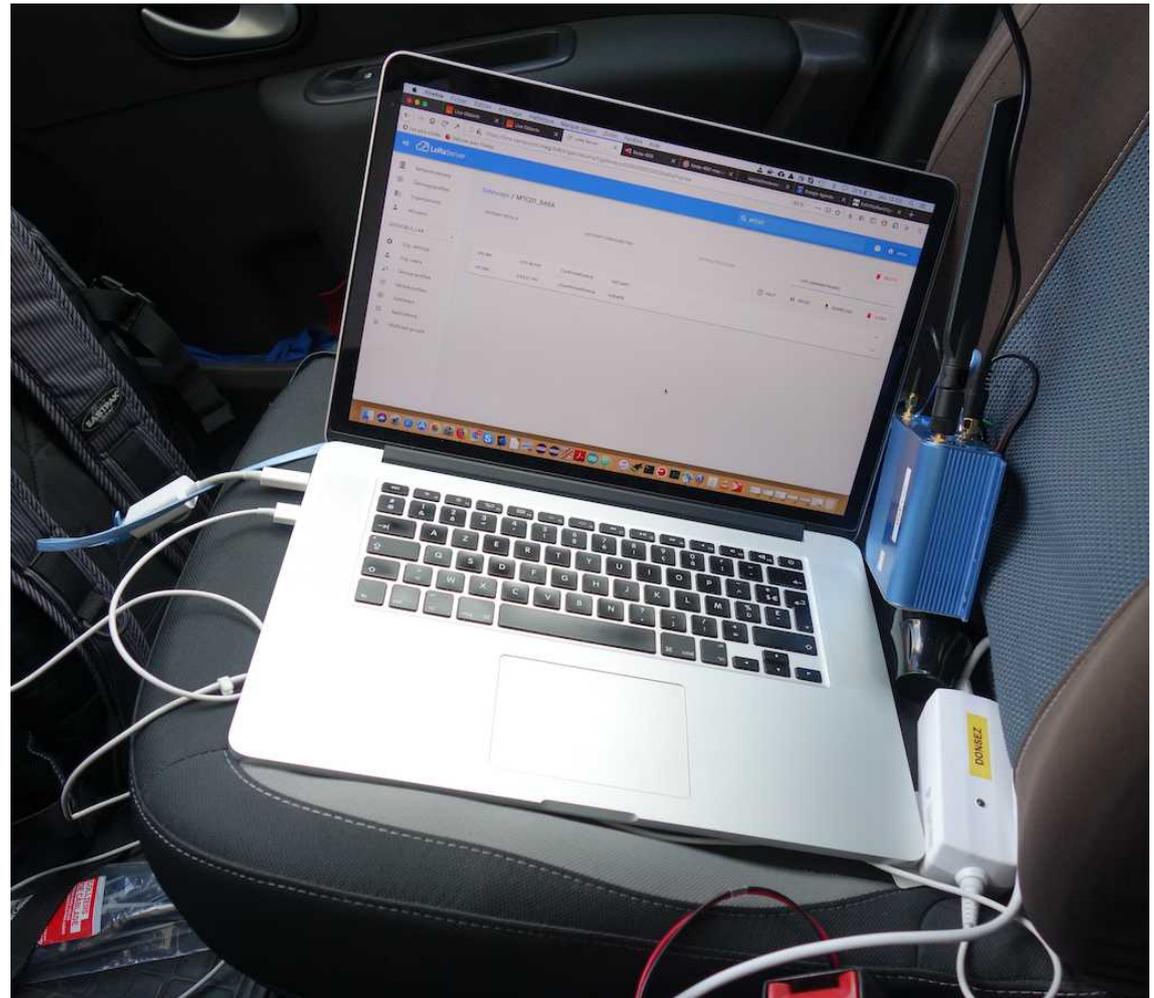
Valence (26) → 140 kms (2h30) → Méolans-Revel (04) à 2200m alt.
Weather conditions: cloudy



Flight #1

“L’envol d’Albert”, May 9th, 2019

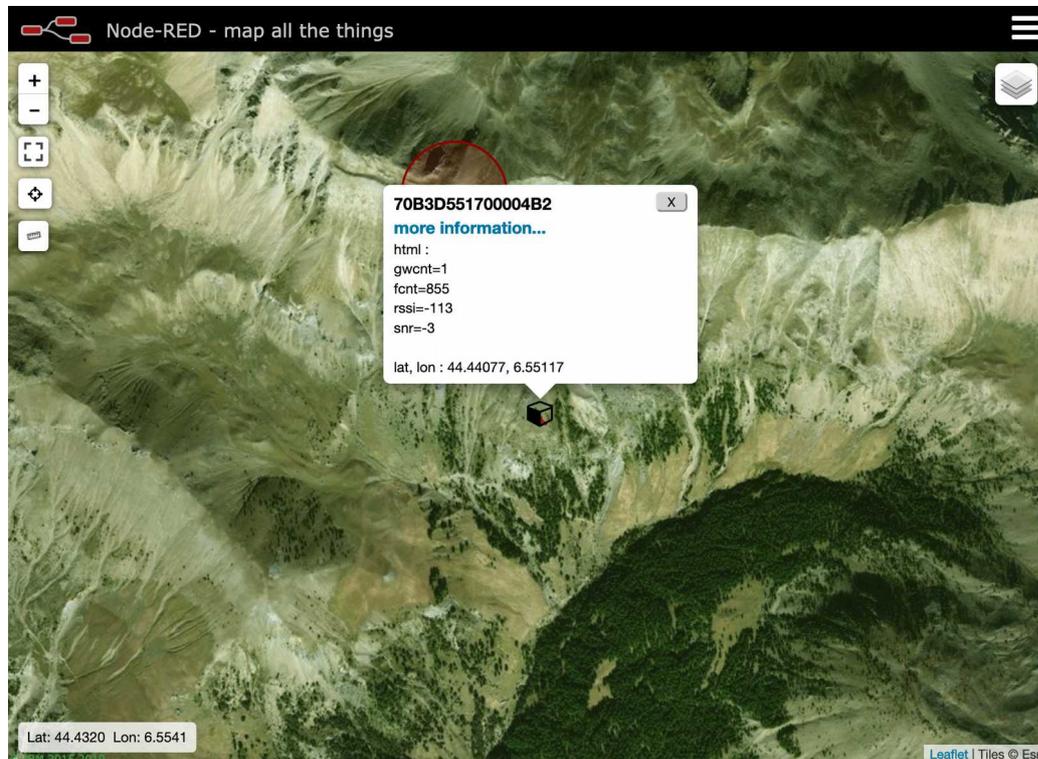
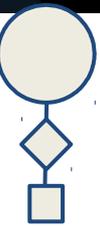
LoRa Sniffer Car



Flight #1

“L’envol d’Albert”, May 9th, 2019

Valence (26) → 140 kms (2h30) → Méolans-Revel (04) à 2200m alt.
Weather conditions: cloudy

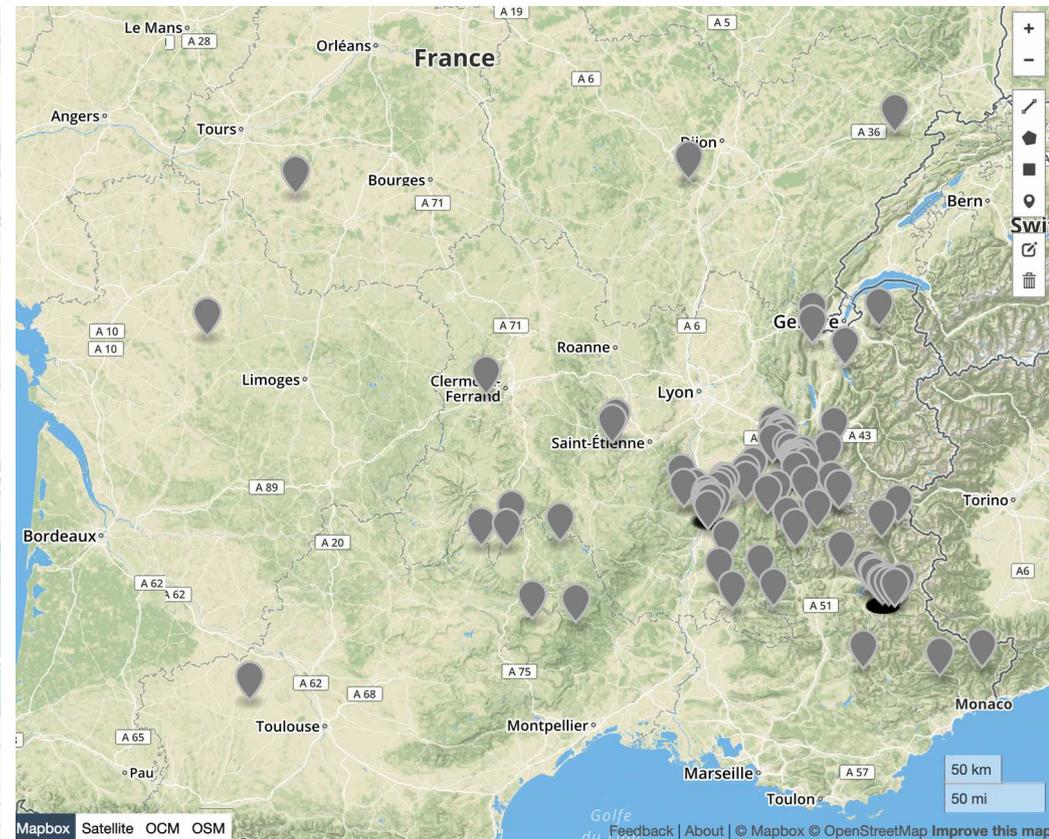
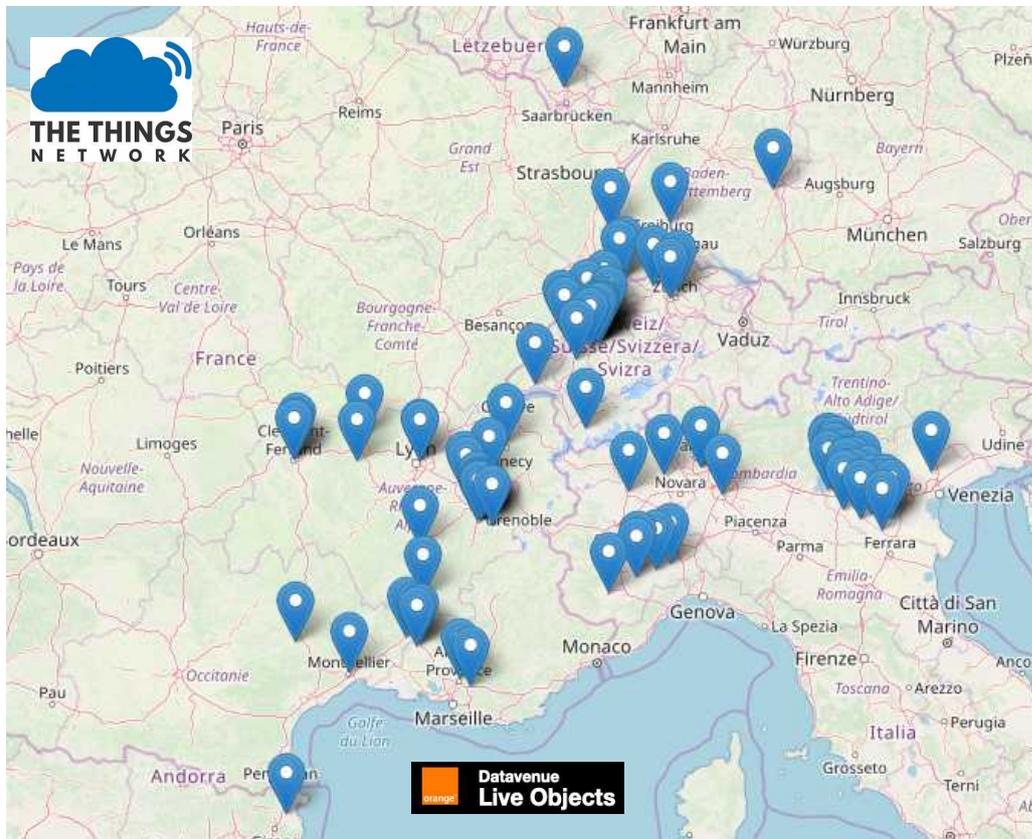




LoRa in the Near Space

Preliminary results of flight #1

Distance, RSSI/SNR, Packet Error Ratio (per SF and per Tx Power)
UNDER ANALYSIS (550 kms on TTN, 400 kms with Orange LiveObject)

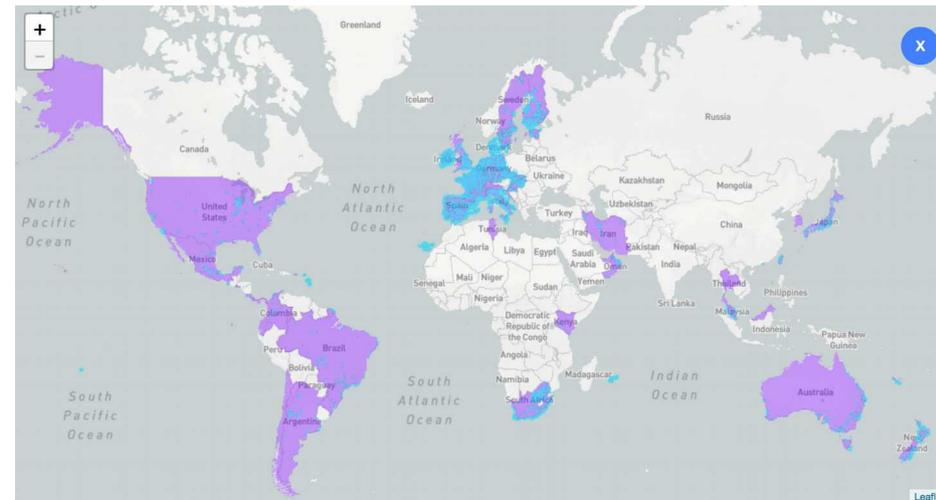


Sigfox



- Public Network Operator

- Operates a network of Sigfox stations on several countries (Europe, USA, ...) with SNOs
- ISM 868 and 915
- 7 millions of endpoints (Sept. 2016)
- Coverage
- Ecosystem
 - IoT Startups



Sigfox



- Radio communication technology
 - Star network
 - ISM 868 and 915
 - Ultra Narrow Band
 - Uplink (up to 144 msg/day) and Downlink (up to 4 msg/day)
 - Messages : 12 bytes for uplink, 8 bytes for downlink
 - Each message is sent 3 times on different channels.
 - ABP, No ADR (Adaptative Data Rate), No Adaptative Power
 - Radio chip makers : TI, Atmel, SILabs, Axsem ...
 - Modem makers : Adeunis, Murata, ...
 - Cost : 7 or 14 euros/EP/Year
 - Network-derived geolocation service (TDOA)

Ultra Narrow Band

- UNB
- DBPSK → car chipset moins cher
- ~100Hz wide
- Each station watch a 200 KHz part of the spectrum
 - 800-900 messages en parallele à un instant t
 - Collision possible → repetition 3 fois
- Hard part : detect message without knowledge of

Protocol

Uplink

- 100 bits/sec
- Available payload 12 bytes per message
- (13 bytes for header)
- 140 messages per day → ETSI regulation of Duty Cycle
 - 1 % on 1 hour36 seconds / hour
- 5 seconds per message (each message sent 3 times for improving reliability)

Downlink

- 20 seconds after the transmission of the 3 frames
- RX on during 25 seconds

Security

- Unique ID
- Signed Message (AES128)
- Payload is not encrypted (application have to encrypt payload)

LoRa



- Radio technology
 - Modulation patented by Semtech (Spread spectrum).
 - Radio chip maker : Semtech
 - Chips : SX127x/8x/6x for endpoints, SX130x for concentrators (gateway)
 - Power, Spreading Factor, Coding Rate, Bandwidth, CAD
- Ecosystem
 - Public and Private Networks
 - Public networks : Orange, Objectnious (Bouygues Telecom)
 - Private networks : Smart city, Industrial IoT (mine, oil platform, ...), sovereign nw , ...
 - LoRaWAN Alliance
 - LoRaWAN specification
 - Open source implementations

LoRa Bitrate, Range, 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%)

Fig 5. LoRaWAN protocol Spreading Factors (SF) versus data rate and time-on-air

LoRaWAN Specification



- Open specification (edited by the LoRa Alliance)
- Endpoint classes : A, B, C
- Protocol for Uplink and Downlink between Endpoints and Access Points
 - Data and MAC commands
- Activation
 - OTAA : IEEE 64Bit GUID
 - ABP
- Messages
 - Size up to 64 and 256 according the datarate
- ADR Adaptive Data Rate
 - Power, Spreading Factor, Bandwidth (Fixed coding rate)
 - Througput from 250 bits/sec to 50000 bits/sec
- No LBT and No AFA (in spec 1.x)
- Security
 - AES 128 bits
 - Keys for OTAA, Keys for Uplink and Downlink
- Beaconing for class B
- Evolution: LBT, Class C Multicast, TDOA, Roaming (1.1), FOTA, Repeater ...

Class A : Downlink after an Uplink

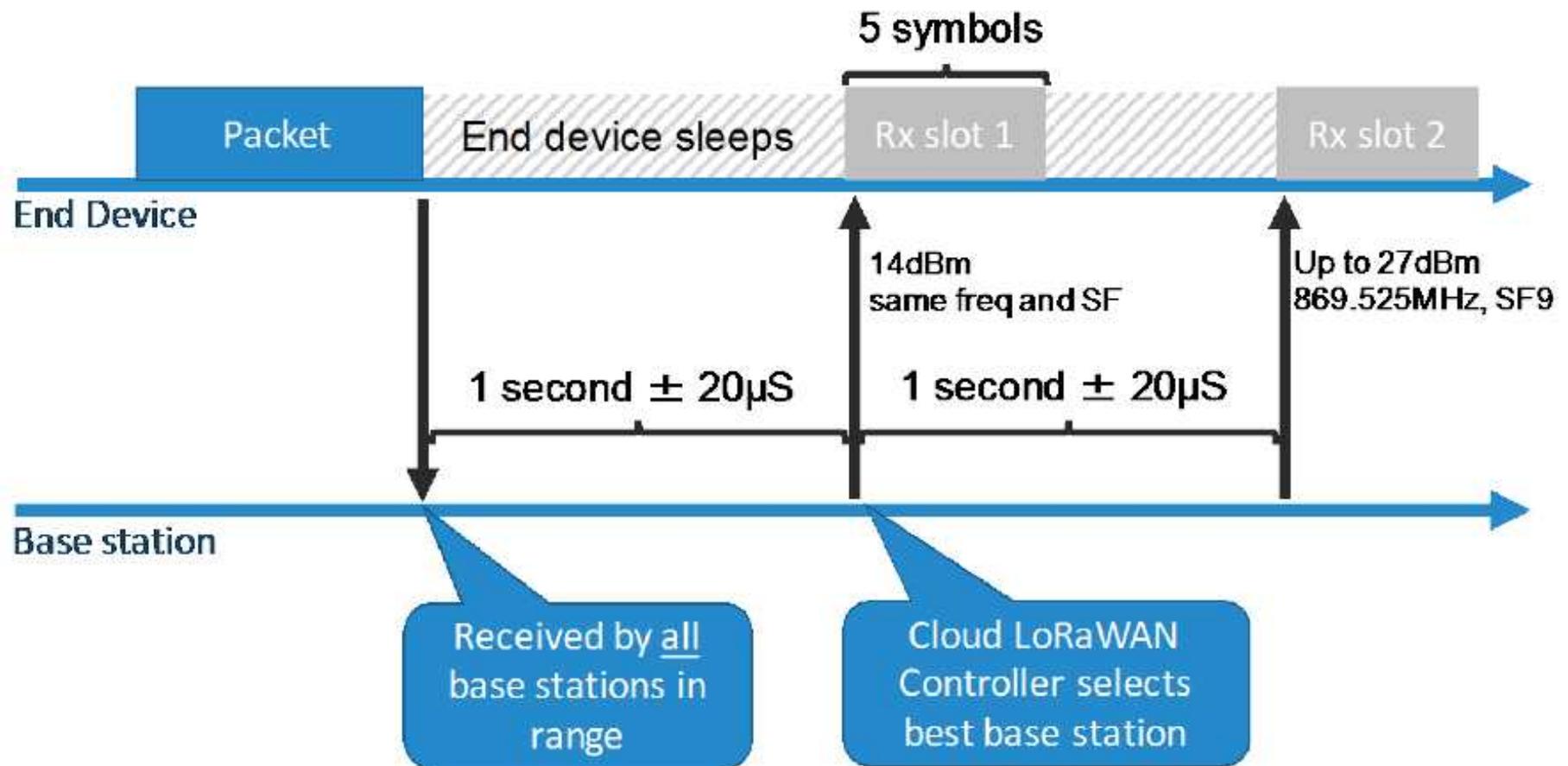


Fig 8. Class A default configuration profile

Class B : Downlink on synchronized Rx slots

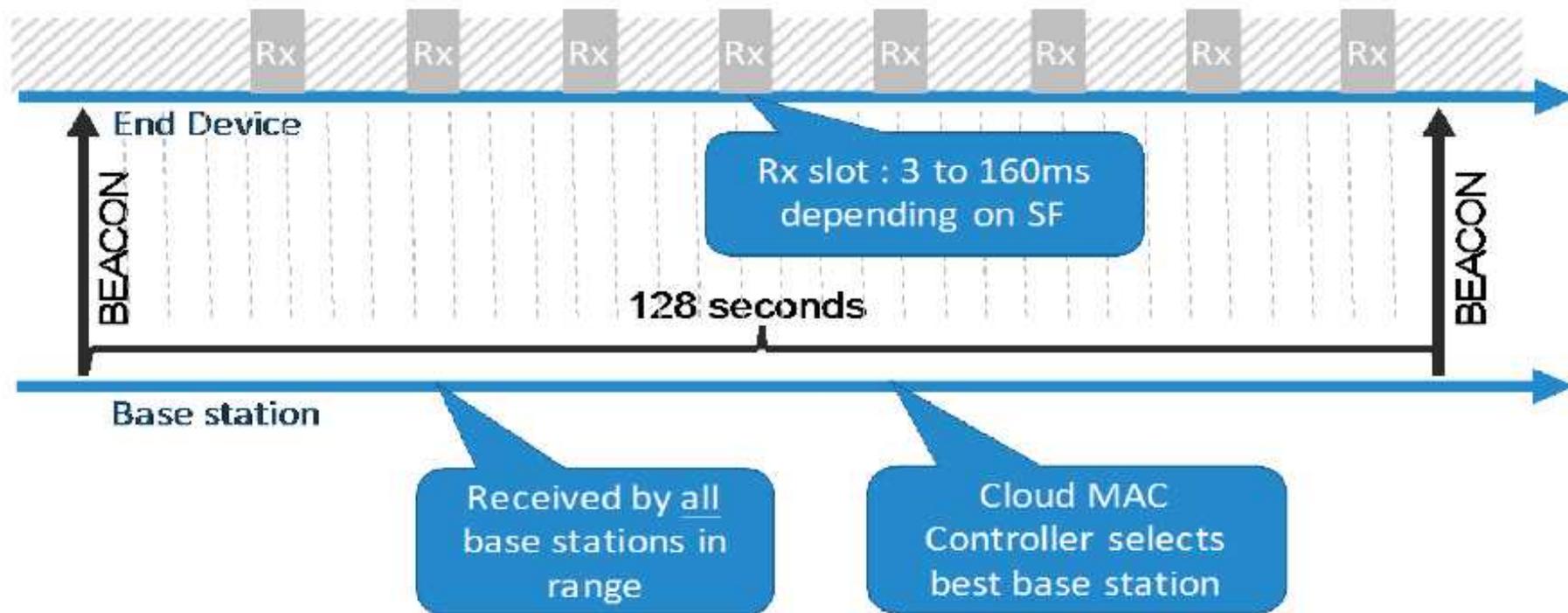


Fig 9. Class B default configuration profile

Class C : Continuous Rx

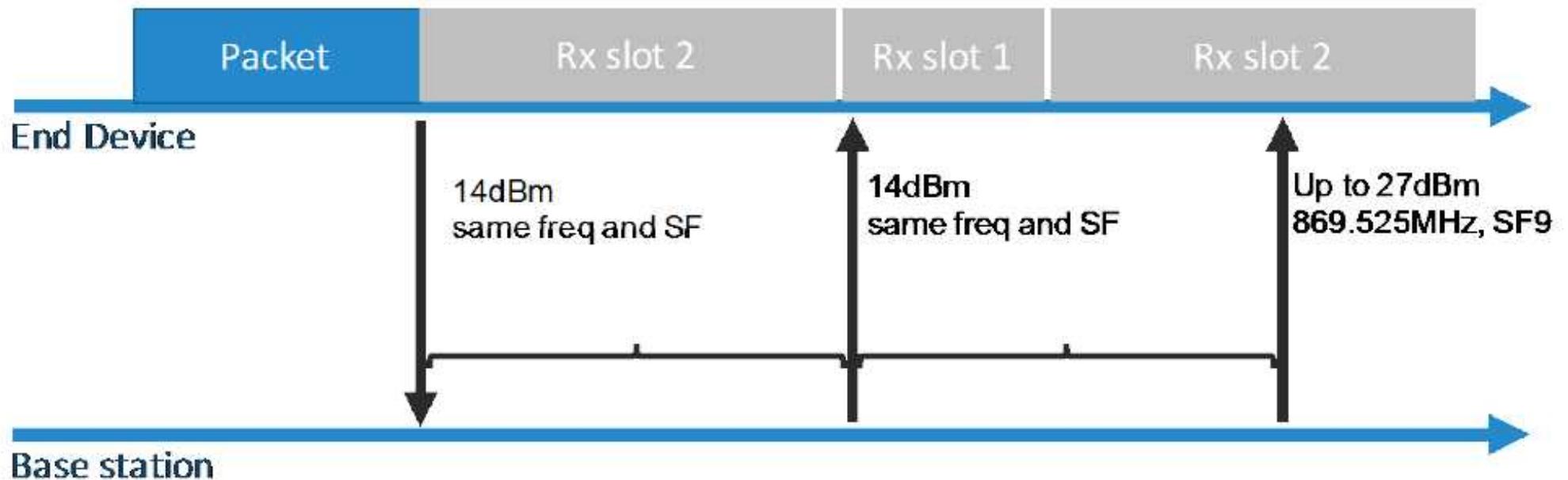
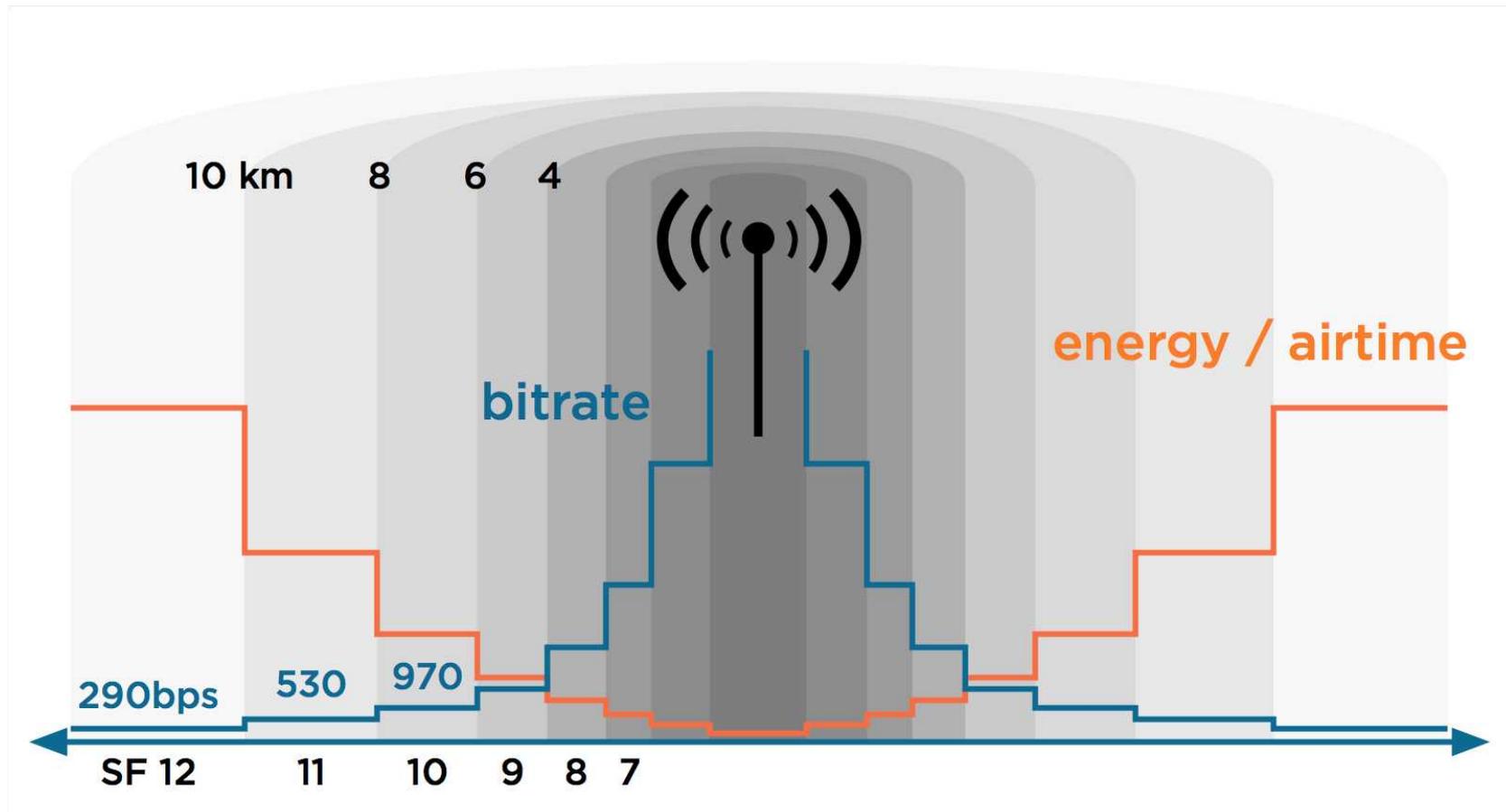


Fig 10. Class C default configuration profile

LoRaWAN

Adaptive Data Rate (ADR)

- Goal
 - Improve endpoint battery lifetime
 - Maximize channel usage (in respect of the local regulation)



Network Derived Geolocation

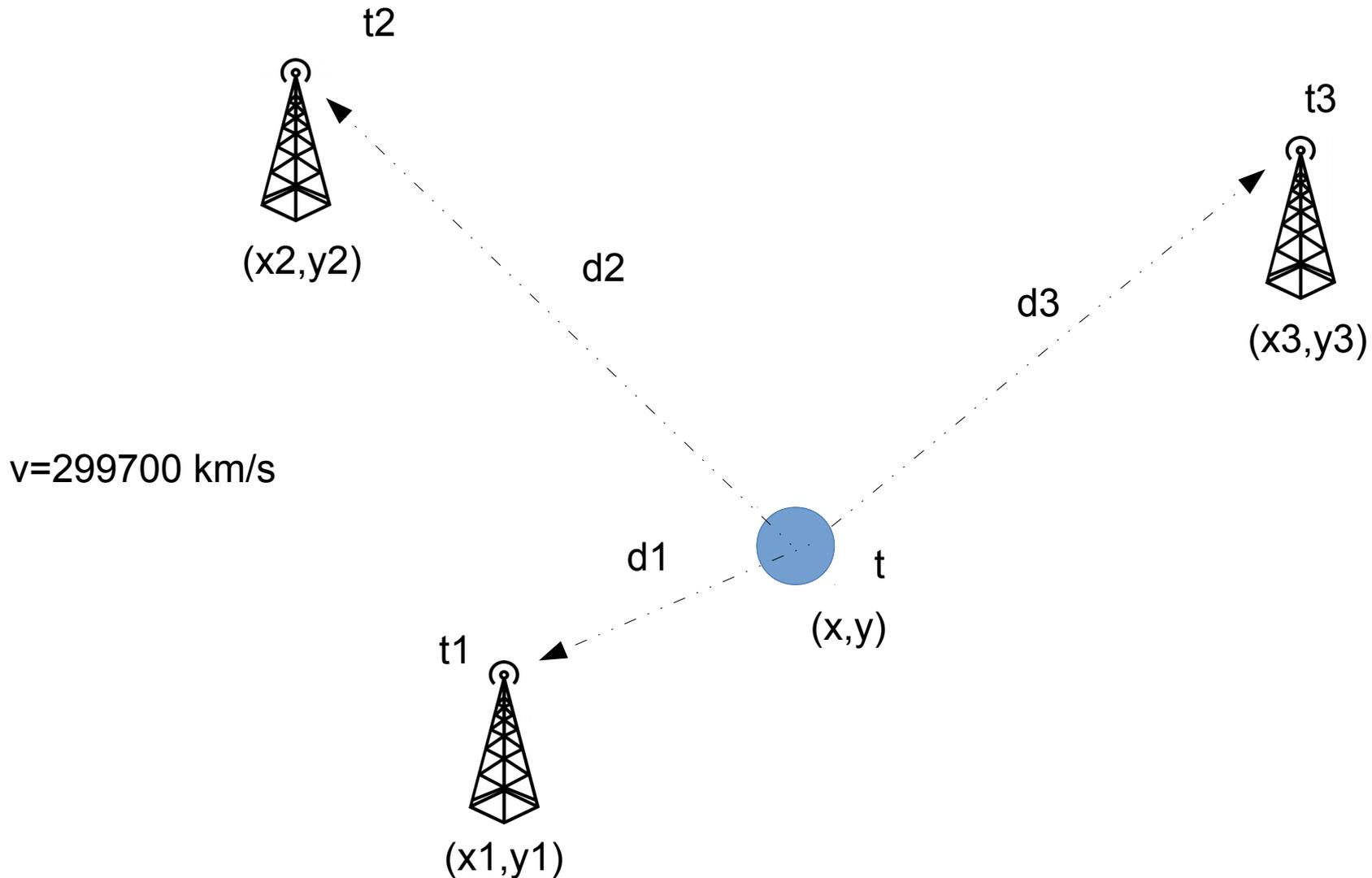


- Fact
 - *By the end of 2020, there will be more than 15 Billion connected devices in IoT. Of those, approximately **one-third will be critically dependent on geodata**, and **60% will** potentially include geodata in the application, according to Machina Research.*
- Goal : GPS-free solution
 - No GNSS into end points (battery lifetime, cost, size)
- Technics
 - RSSI Attenuation
 - Time difference of arrival (TDOA)
 - RF Stations use high precision timestamping for each received packets.
- Links
 - <http://www.link-labs.com/lora-localization/>
 - Semtech Collos <https://www.semtech.com/wireless-rf/lora-geolocation>

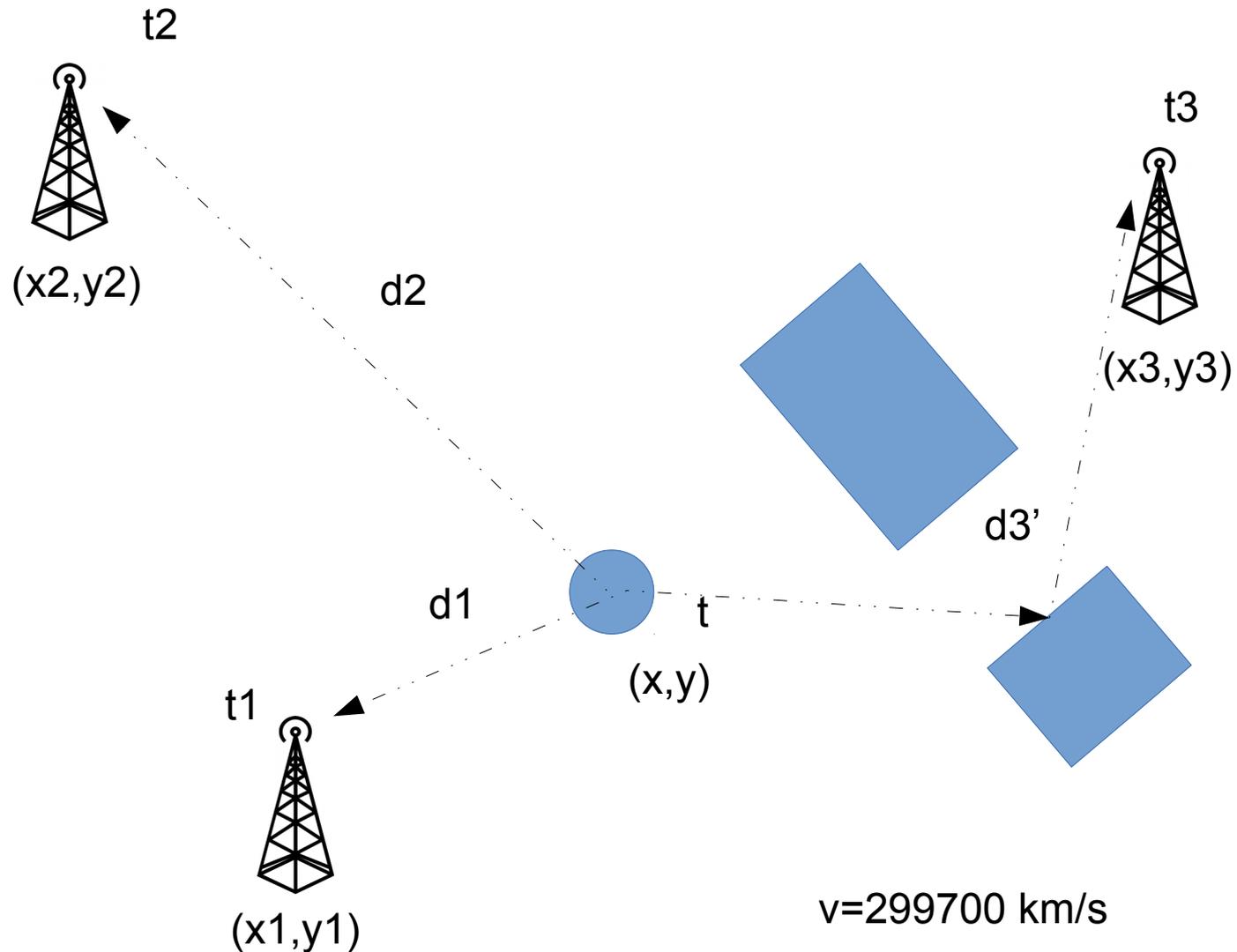
Time difference of arrival (TDOA)

- Données
 - Chaque gateway utilise une horloge absolue très précise pour dater l'arrivée d'un paquet LoRa (t_n).
 - Le LS qui connaît la position absolue des gateways (x_n, y_n)
 - Le LS calcule la position de l'objet (x, y) dans l'espace.

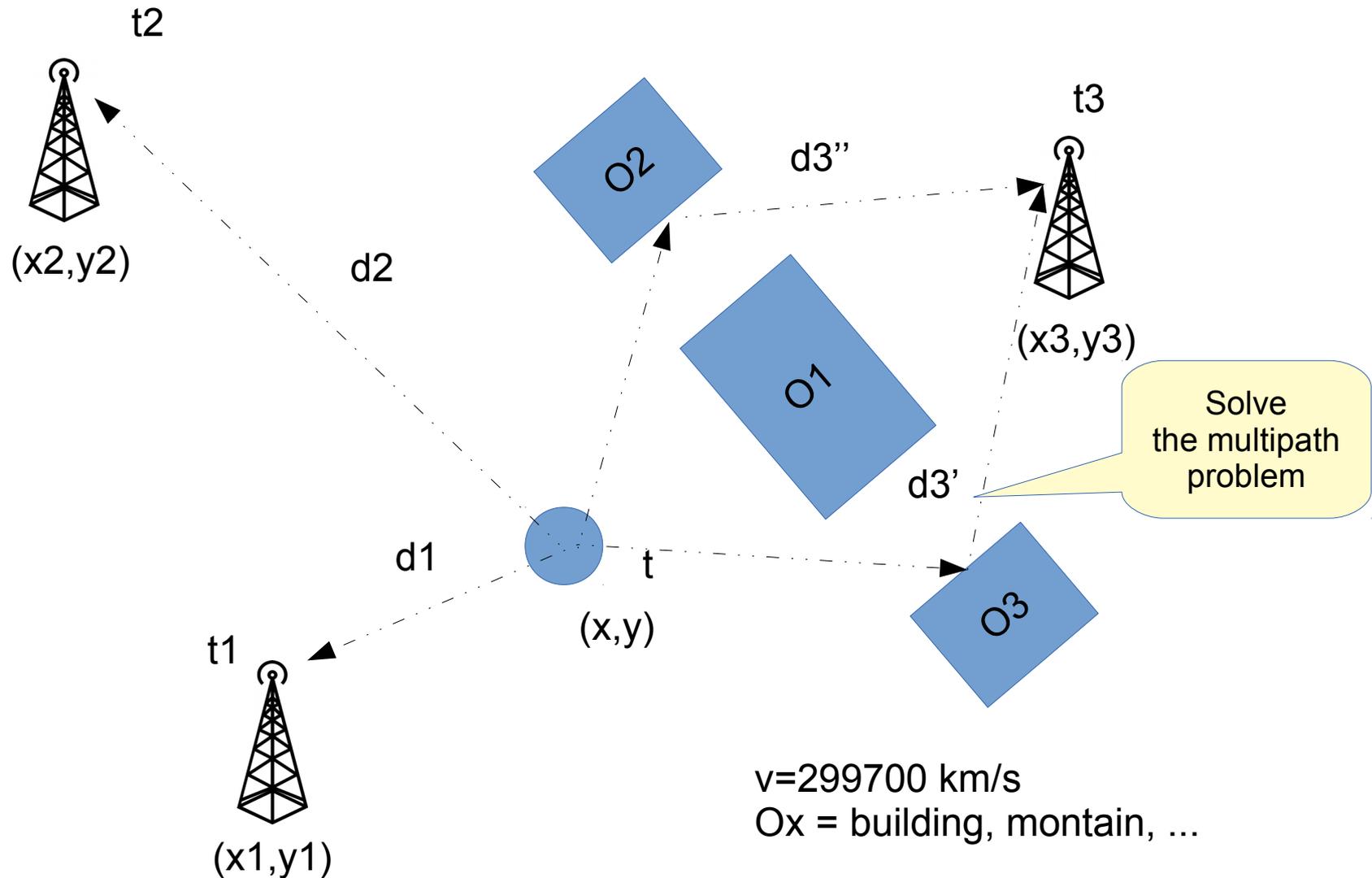
Time difference of arrival (TDOA)



Time difference of arrival (TDOA)



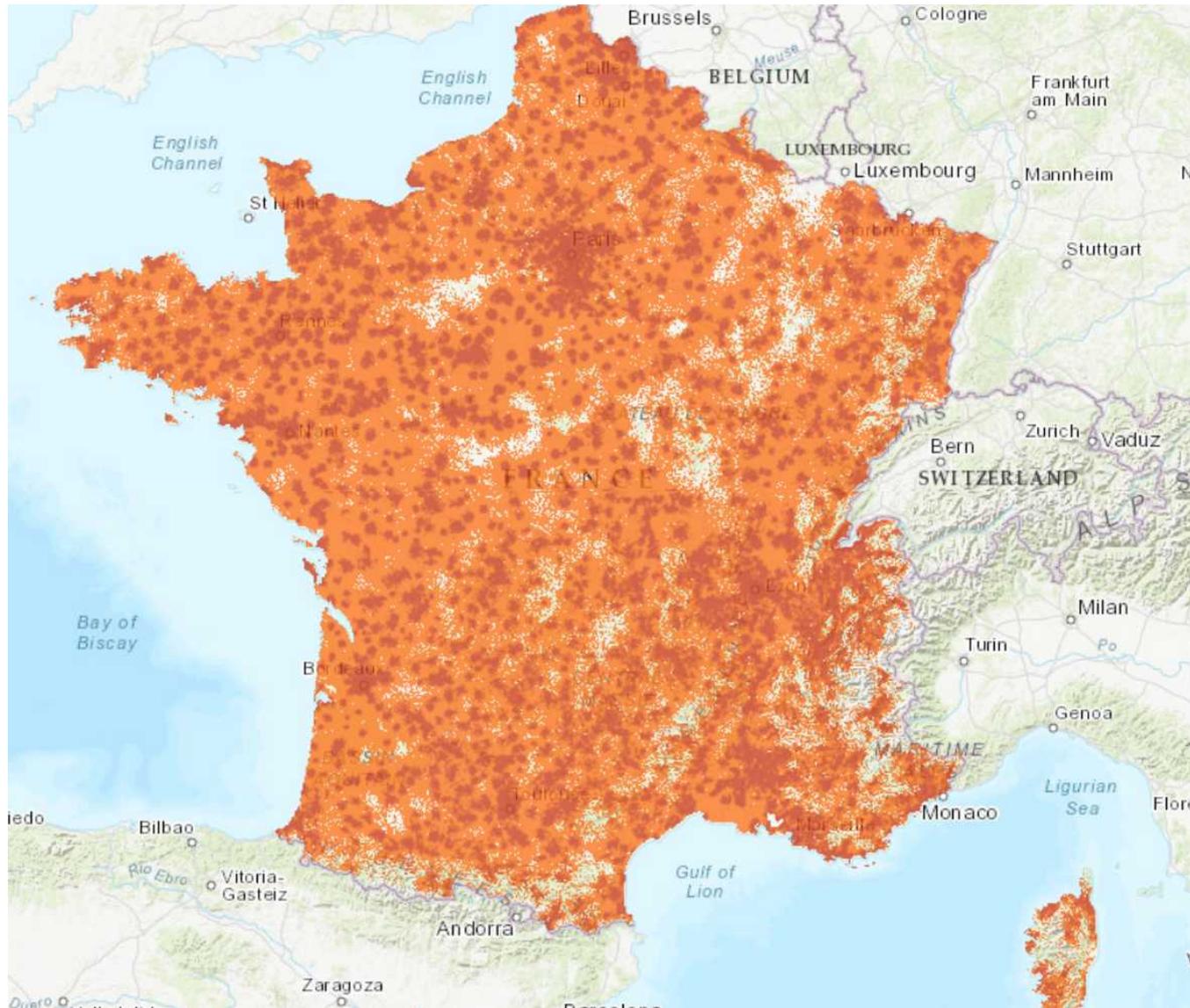
Time difference of arrival (TDOA)



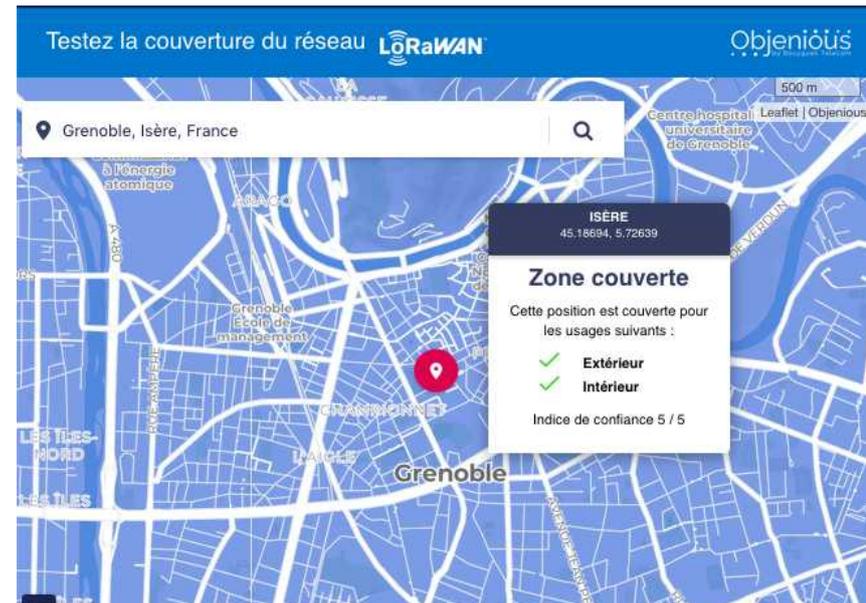
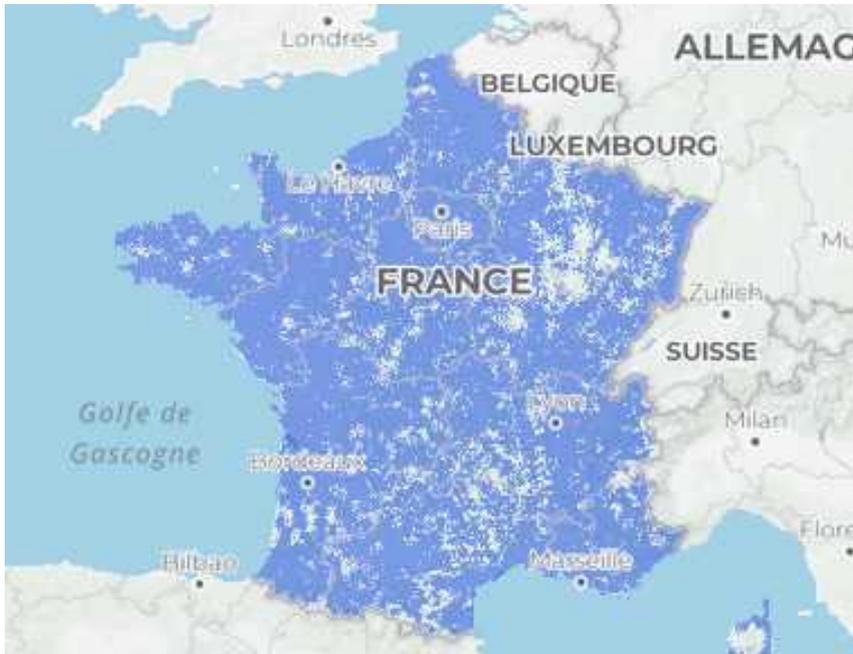
Opérateurs LoRaWAN

- Réseaux privés (on premise)
 - Open-source : TTN, lorasever.io
 - Licenced : Actility, Orbiwyse, Resiot, Loriot, TTN industries ...
- Opérateurs Réseaux privés (on cloud)
 - Actility, Orbiwyse, Resiot, TTN industries ...
- Opérateurs Réseaux Communautaires
 - TTN (TheThingNetwork)
- Opérateurs Réseaux publiques
 - Orange, Objenious, La Poste, ...
 - Extension réseau pour deep-indoor
- Opérateurs Réseaux Publics Non LoRaWAN
 - Archos Picowan
- Opérateurs réseaux Privés non LoRaWAN (legacy)

Exemple : Orange LiveObject LoRaWAN coverage (~5000 BTS)



Exemple : Objenious LoRaWAN coverage (~5000 BTS)



LPWA Module Market

Annual Unit Shipments of LPWA Modules (in thousands)

	2017	2018	2019	2020	2021	CAGR
Sigfox	8,424	14,538	27,951	52,821	85,042	219.5%
LoRa	32,316	57,298	98,162	161,561	249,724	92.3%
LTE Cat-M1	1,978	8,571	20,284	28,801	52,288	--
NB-IoT	16,166	34,062	84,885	161,628	222,902	--
Other	4,022	6,201	8,714	7,069	8,402	14.7%
Totals	62,905	120,667	239,996	411,881	622,358	95.0%

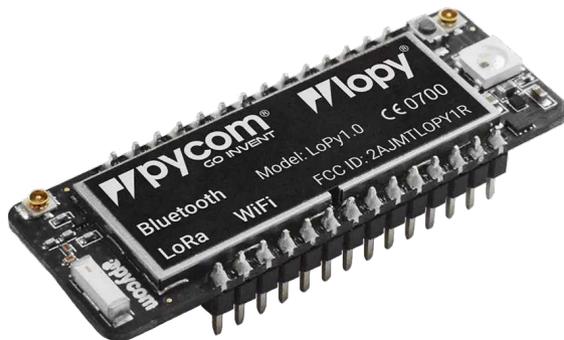
Source: IHS Markit

Comment démarrer son réseau privé LoRaWAN ?

- 1 gateway LoRa par classe/établissement



- Cartes de découverte et de prototypage
 - Programmation : C/C++, Python, Javascript



Traitement de données

Programmation graphique ...

The screenshot displays the Node-RED graphical programming interface. On the left, the 'input' and 'output' node palettes are visible. The main workspace shows a flow named 'Flow 1' with the following components:

- Two MQTT input nodes: 'MQTT PROD 1' and 'MQTT PROD 2', both marked as 'connected'.
- A 'json' node that receives data from both MQTT nodes.
- Five function nodes (orange boxes with 'f') that process the data:
 - 'Extract radios' connects to a 'radio PROD-1' output node.
 - 'Convert stat' connects to a 'stat PROD-1' output node.
 - 'Extract raw data' connects to a 'rawdata PROD-1' output node.
 - 'Decode Nucleo' connects to a 'data PROD-1' output node.
 - 'Decode Adeunis Pulse' connects to a 'msg.payload' output node.

On the right, the 'debug' console shows two log entries:

```
25/10/2017 à 22:35:06 node: 4aa712cf.6f00cc  
xnet/3/31534C5550B21800 : msg.payload : array[2]  
▼ array[2]  
▼ 0: object  
  size: 25  
  confirmed: false  
  payload: "027006F0D5B4870000000000"  
  dr: 0  
  rssi: -86  
  lsnr: 7  
  nblap: 1  
  seqnoup: 9799  
  index_water: 23456  
▼ 1: object  
  dir: "up"  
  object_owner: 3  
  deveui: "EA00010000B21800"  
  appeui: "31534C5550B21800"
```

```
25/10/2017 à 22:38:59 node: 4aa712cf.6f00cc  
xnet/9999/31534C5550B21800 : msg.payload : array[2]  
► [ object, object ]
```