New developments in Satellite LoRa for Science, IoT Applications and Telemetry

SANOG 43, Bhutan 2025 08 22

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About me

Sebastian Büttrich

Background: PhD in Physics
Atomic physics, optical and RF spectroscopy
Quantum physics

25+ years (wireless) networker and developer,
Internet-at-large,
Community Networks, IoT, Sustainable Energy,
TinyML, Satellite Networking

Research Lab Manager at
IT University of Copenhagen,
PI DISCO (Danish Student Cubesat Project)

IT UNIVERSITY OF COPENHAGEN

Network Trainer and developer at the NSRC
(Network Startup Resource Center)

NSRC
Network Startup Resource Center

Connected Conservation Foundation

Connected Conservation FOUNDATION

Institutional Member LoRa-Alliance

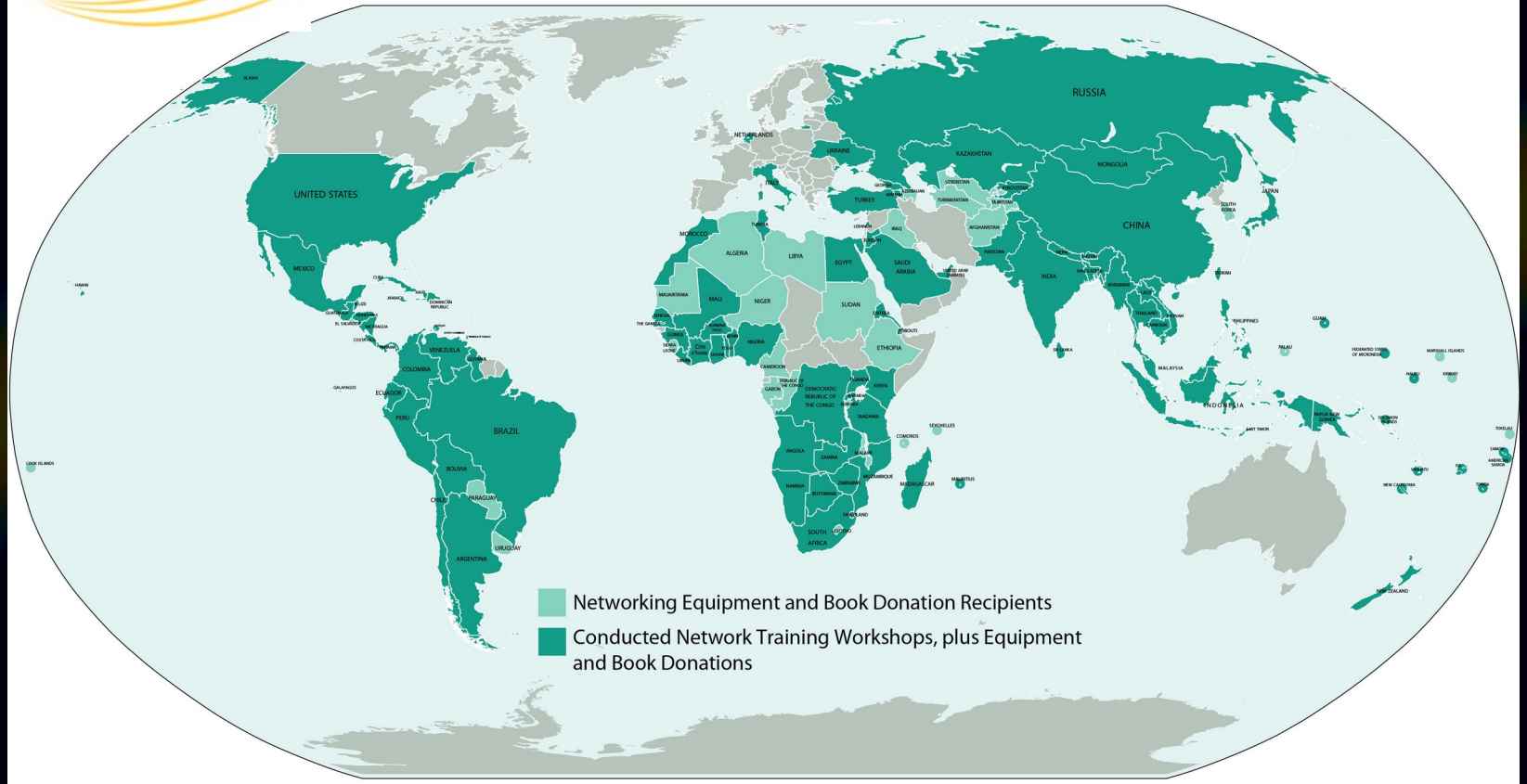
LoRa Alliance®

Context & Motivation: Global IoT connectivity for R&E

NSRC
Network Startup Resource Center

Network Startup Resource Center (NSRC)
University of Oregon

Internet Infrastructure Development and Technical Assistance



*From 1992 to March 2017, the NSRC has facilitated the distribution of more than 650 tons of network equipment and technical reference books to engineering and computer science departments, university libraries, teaching hospitals, research facilities, non-governmental organizations (NGOs), and Internet training facilities in more than 120 countries around the world. Contributing sponsors and supporters are acknowledged at https://nsrc.org/supporters.

Keywords for this talk

Things, not people

Things that are *far away* (remote, autonomous, constrained)

Low power

Low cost

Small footprints

(Side remark: wherever possible, we still favor terrestrial!)

Something new is happening in satellite connectivity for IoT

Driven mainly by

a convergence of progress in

1/ IoT networks (LPWAN)

2/ Tiny sats
3/ Launch industry

But ...

“we have had satellite communications for decades (Iridium etc)”

yes, but not at low power and low cost

“we have Starlink?”

same answer – Starlink terminals are 100 W / $100 units,
its satellites are 1 ton, multi-million $

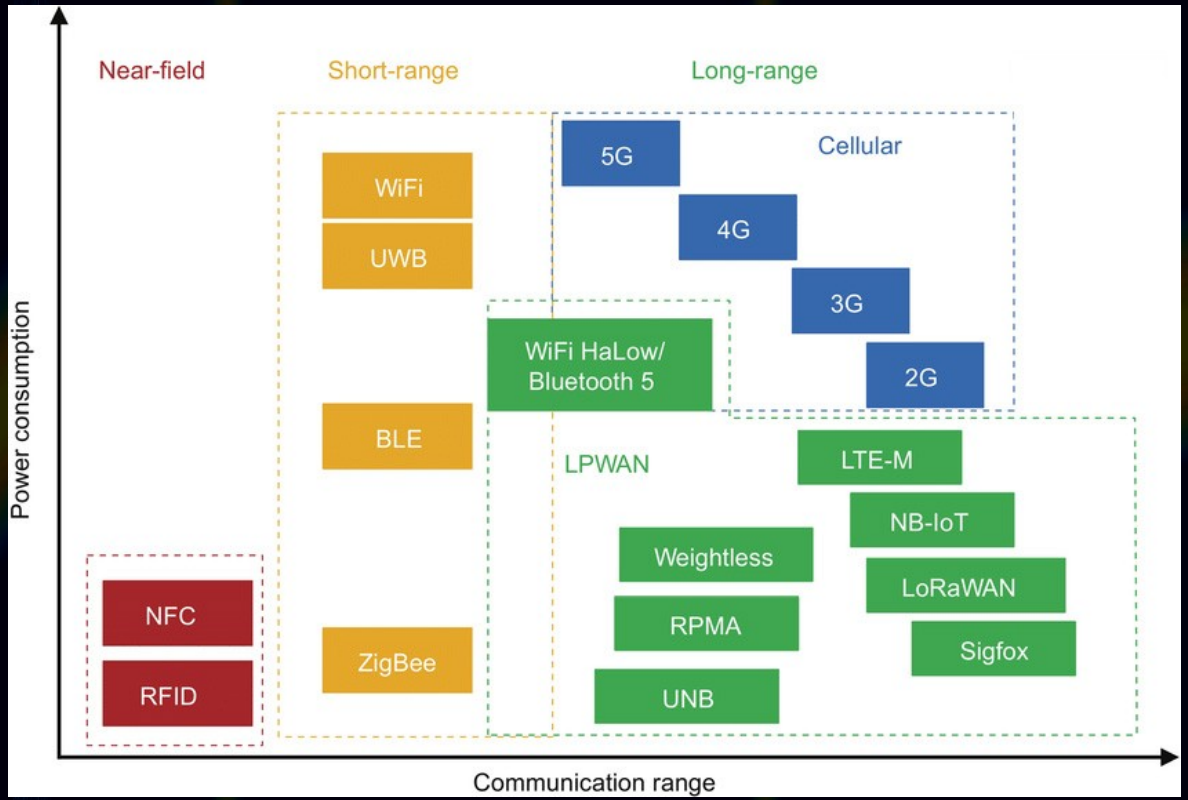
“we soon will have direct-to-satellite” messaging on every phone?”

yes, at 1 Watt and sparse usage

Satellite LoRa = low power, low cost, long distance

Let’s start on earth – terrestrial LPWANs

It is all about range and power



source: groundcontrol.com

What makes LoRa & LoraWAN so special?

LoRa offers unrivalled link budgets for long distance

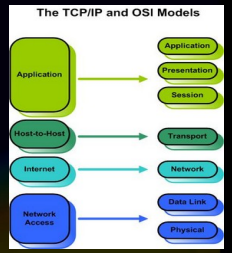
150 and more

due to a clever modulation technique (chirp spread spectrum)

LoRaWAN on top of LoRa offers a very open development environment

notably on ISM / license-free frequencies (but not limited to these)

A closer look at LoRa



LoRa is a **proprietary Layer 1 (physical layer) standard** owned by Semtech
Chirp Spread Spectrum (CSS)

Bandwidth 125/250/500 kHz

Frequencies in Europe initially*: mostly **ISM 433/868 Mhz**

Data Rate up to 11 kbps (50 kbps, 250 kbps at 2.4 GHz)**

Focus is on **long range, power efficiency, robustness.**

2.4 Ghz added 2021 (de-facto, not in standard officially yet), other regions have other frequencies

** De-facto limits from **duty cycles** and LoRaWAN max payload, not technical limitations

https://www.semtech.com/lora/what-is-lora

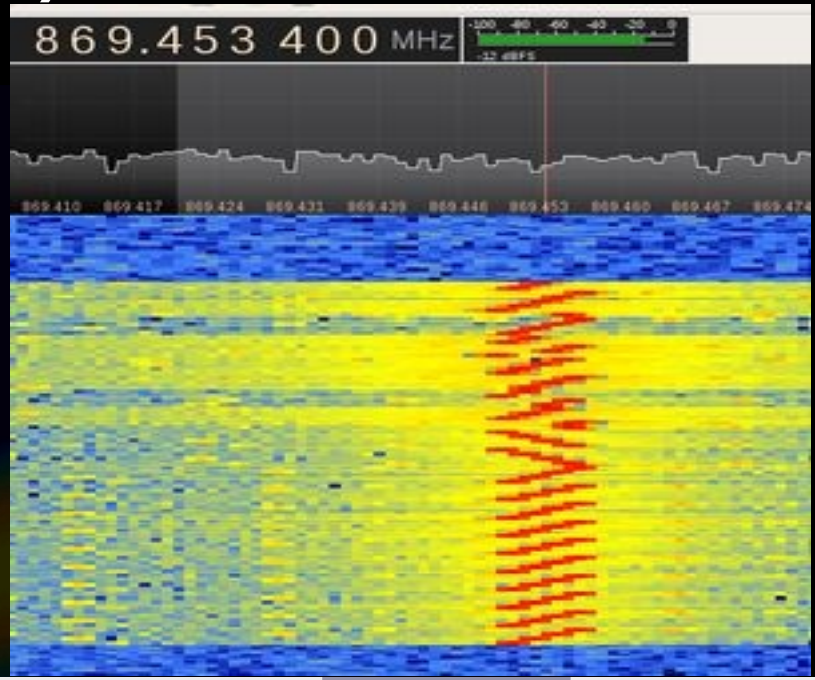
LoRa: Chirp Spread Spectrum (CSS)

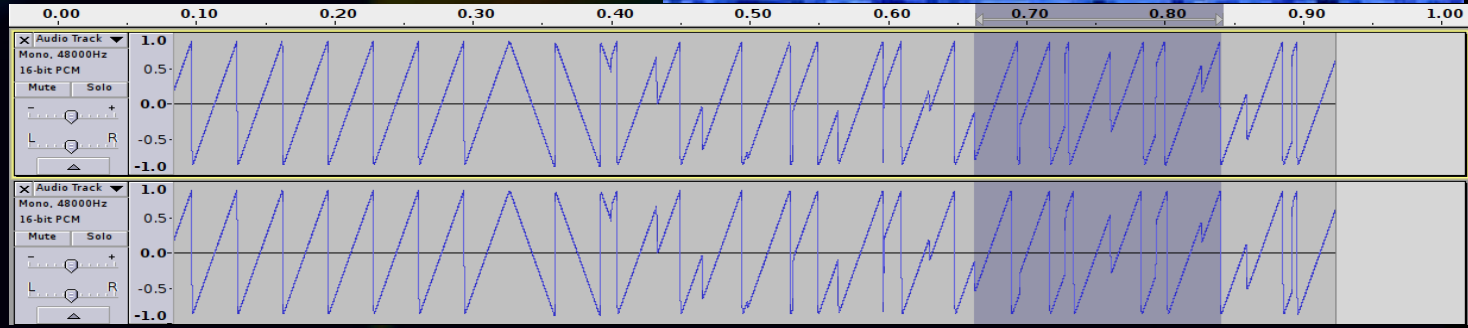
What is a **chirp**?

Sources: Semtech: AN1200.22 - LoRa Modulation Basics
https://lora-alliance.org/lorawan-for-developers/

https://revspace.nl/DecodingLora
https://myriadrf.org/blog/lora-modem-limesdr/

GNU Radio SDR implementation of LoRa:
https://github.com/tapparelj/gr-lora_sdr





LoRaWAN

LoRaWan is an open LPWAN standard

(layer 2, MAC layer)

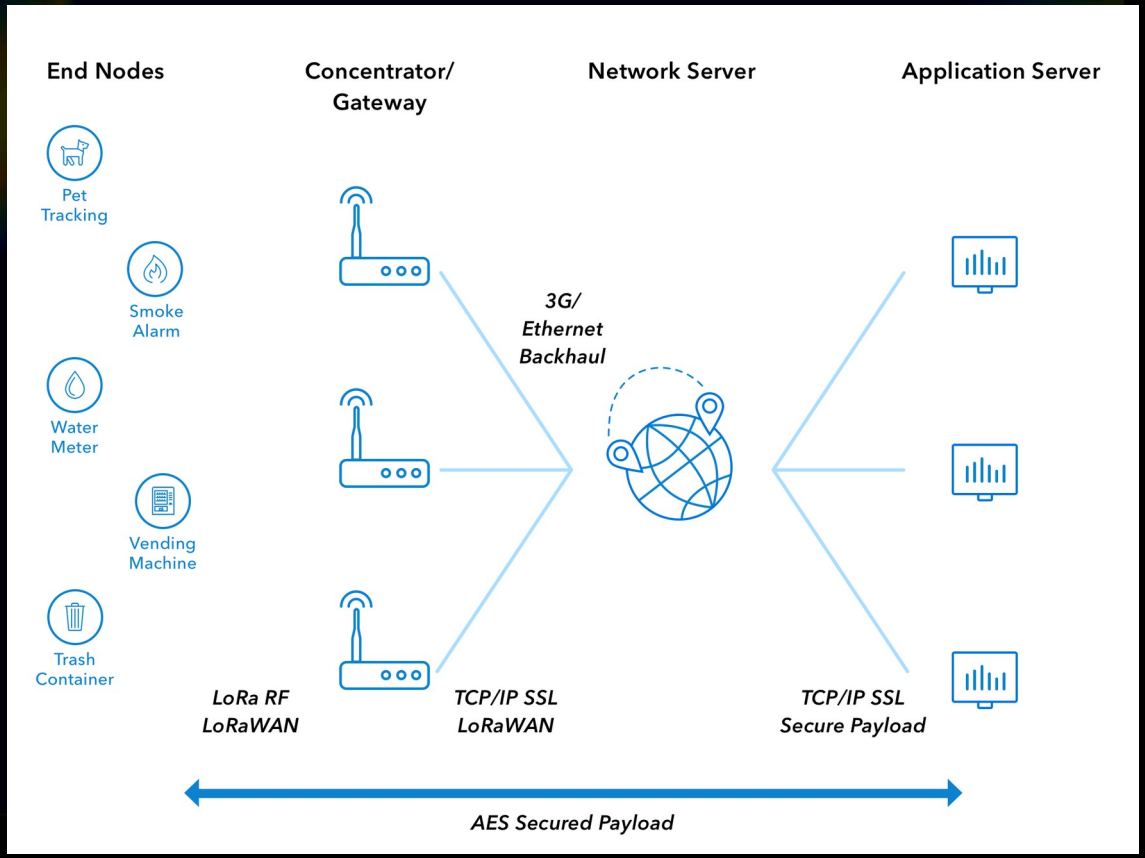
building on top of LoRa

https://www.lora-alliance.org/

Public, private, commercial, community and hybrid networks

incl.

The Things Network
Helium
LORIOT
Senet
Thingpark / Actility
Unabiz



LoRaWAN: The Things Network

Community network maintained by The Things Industries,

With about 20,000 gateways globally (yet with strong bias towards Europe).

From the Manifesto:

Anyone shall be free to set up "Things"
and connect to "Things Gateways"
that may or may not be their own.

Anyone shall be free to set up "Things Gateways"
and connect to "Things Access"
that may or may not be their own.
Their "Things Gateways" will give [free] access
to all "Things" in a net neutral manner,
limited by the maximum available capacity alone.

LoRa & LoraWAN terrestrial

Tracking a sea cruise

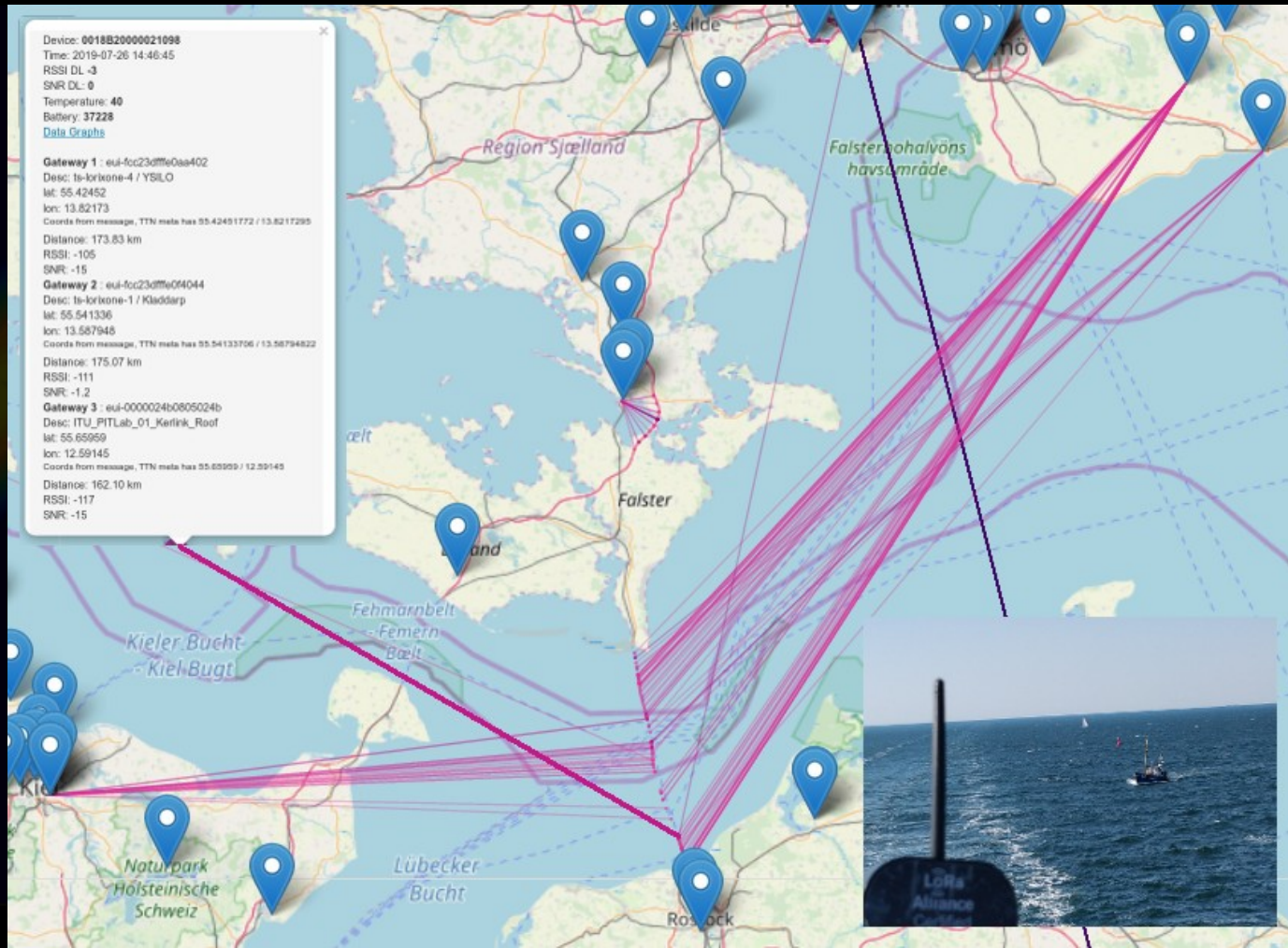
Denmark to Germany

utilizing

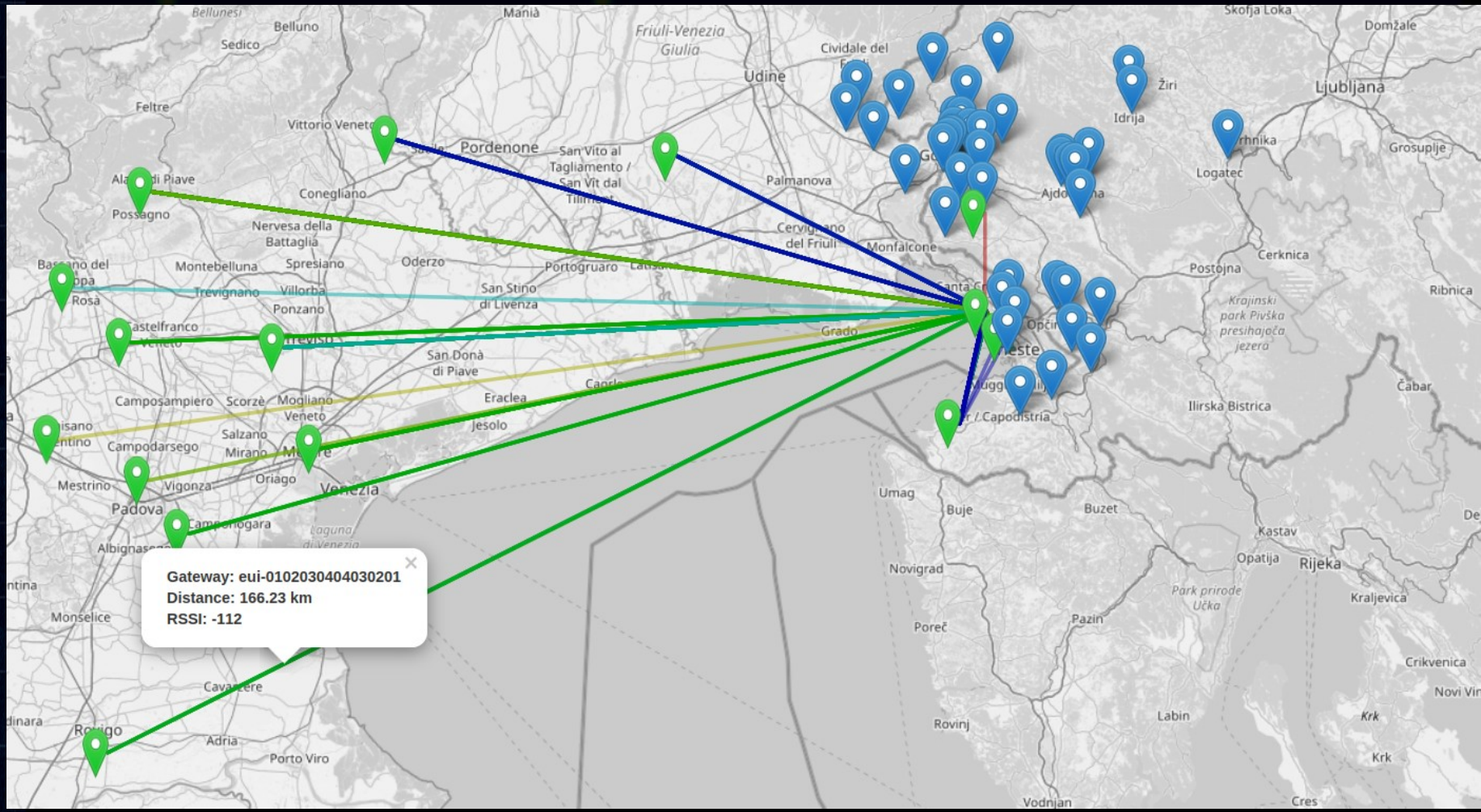
The Things Network

Links up to

200 km



LoRa & LoraWAN terrestrial: At ICTP Trieste, Italy



LoRa & LoraWAN terrestrial

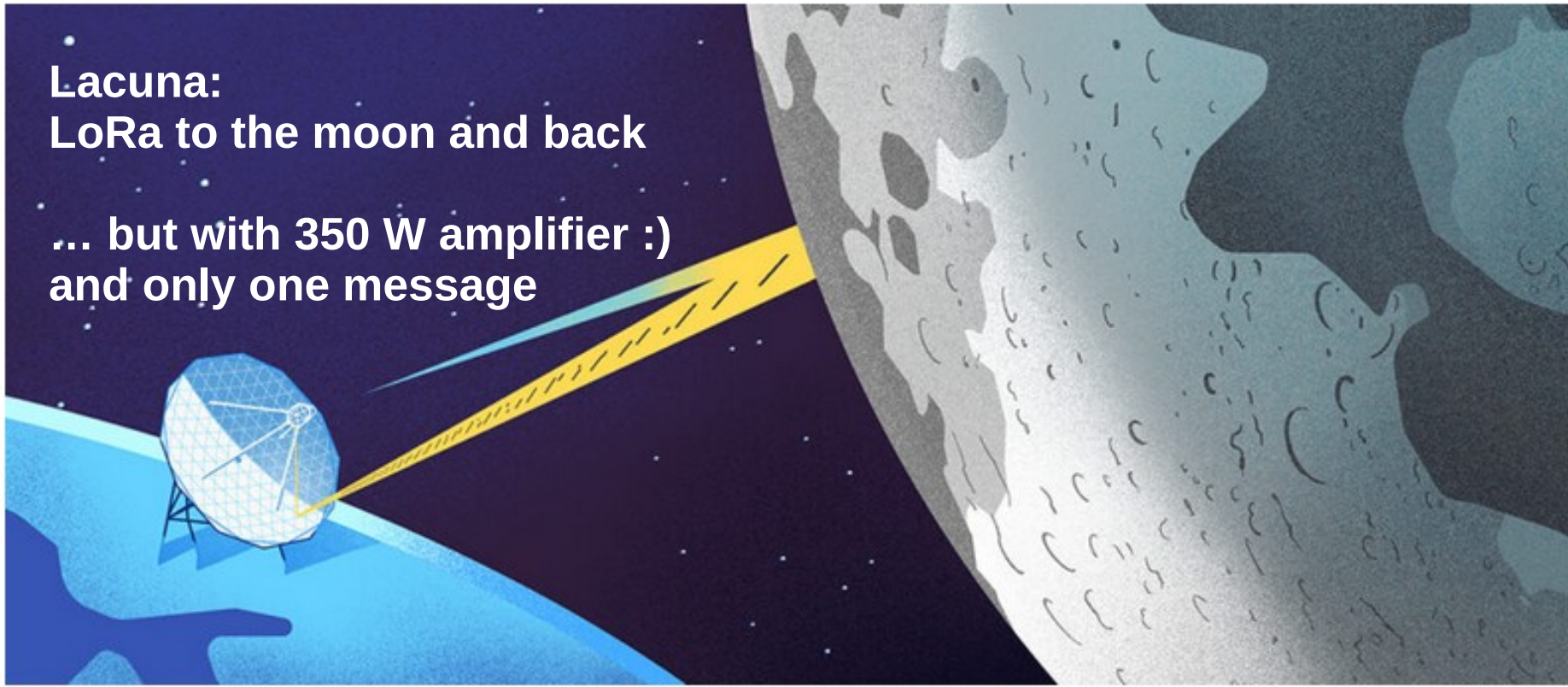
New LoRa world record 2023: 1336 km / 830 mi

Earth curvature setting the limits

source: https://www.thethingsnetwork.org/

First message bounced off the moon using LoRa

24 November 2021



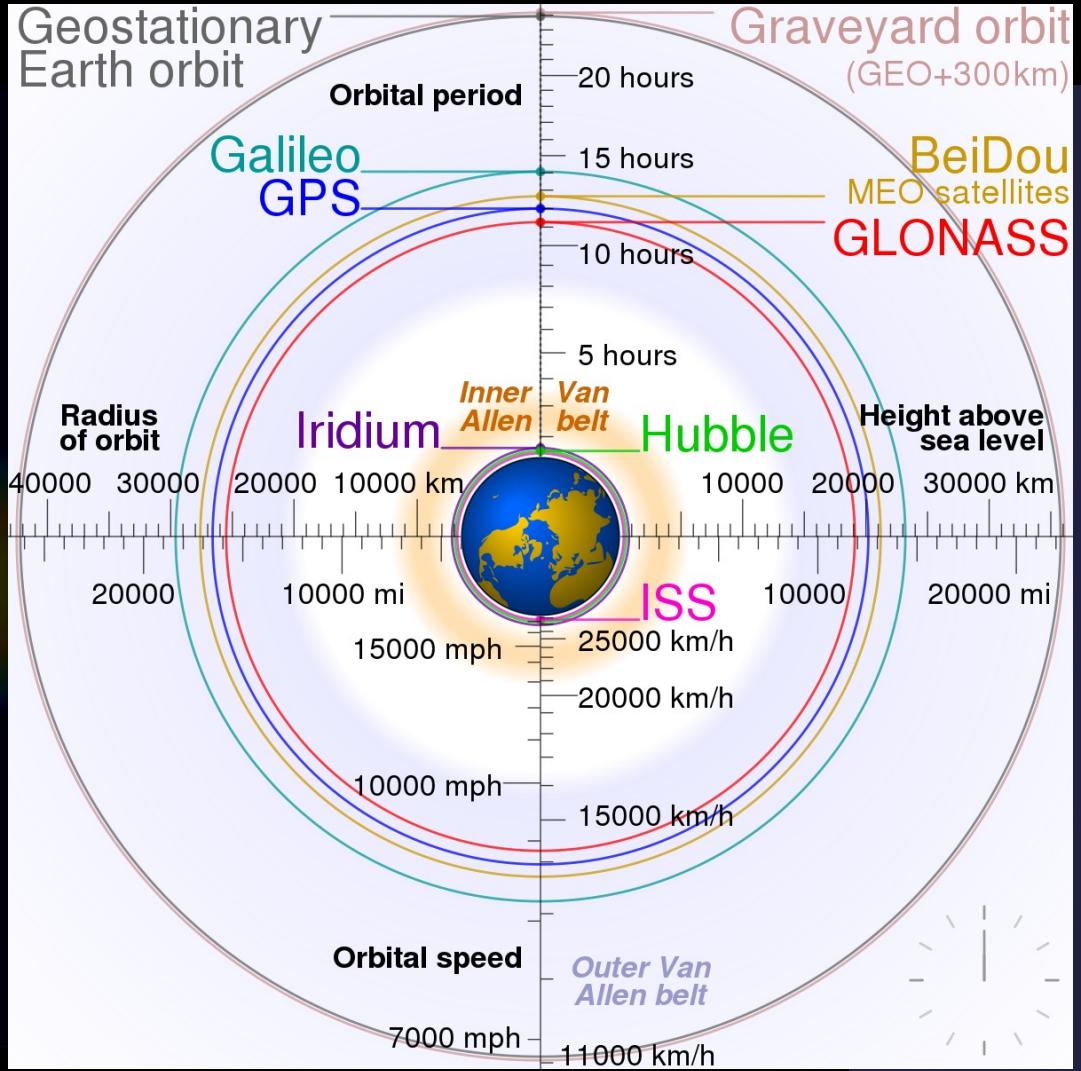
https://lacuna.space/lora-moon-bounce/

Satellite orbits

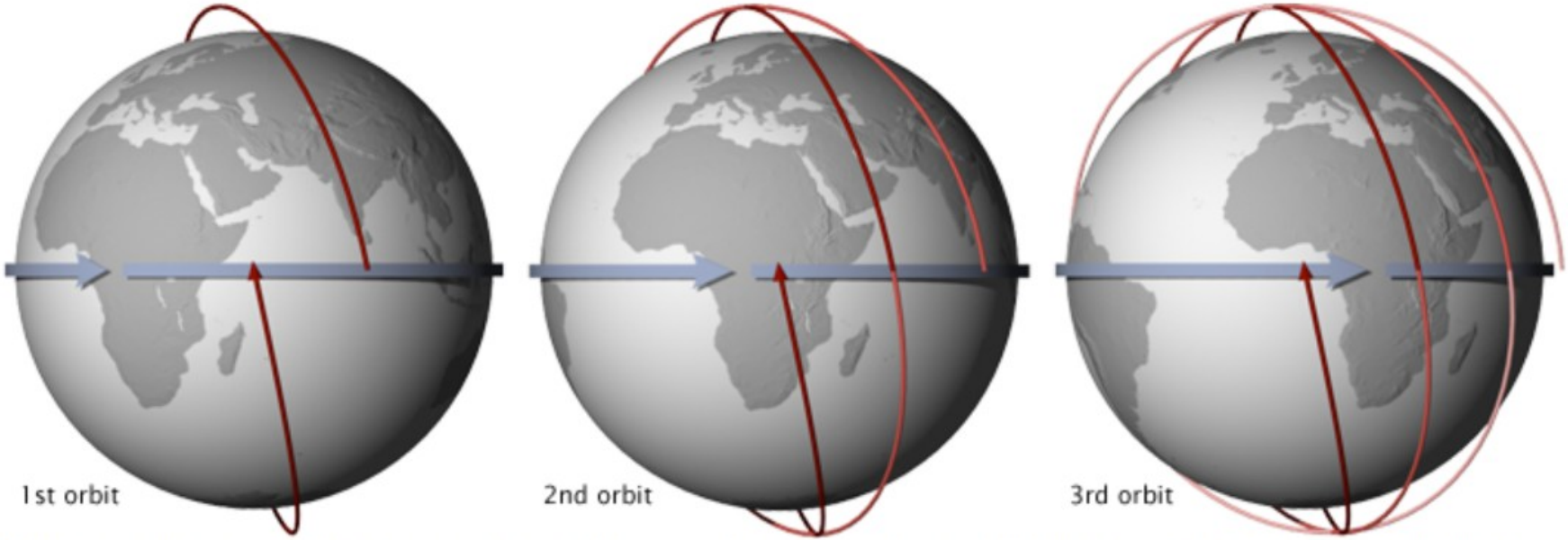
Low Earth Orbit
LEO (160 – 2000 km)
Mostly 400-600 km

Mid Earth Orbit
MEO
2000 – 35786 km

Geostationary
GEO
35786 km



LEO Polar orbits



A Sun-synchronous orbit crosses over the equator at approximately the same local time each day (and night). This orbit allows consistent scientific observations with the angle between the Sun and the Earth's surface remaining relatively constant. These illustrations show 3 consecutive orbits of a sun-synchronous satellite with an equatorial crossing time of 1:30 pm. The satellite's most recent orbit is indicated by the dark red line, while older orbits are lighter red. View animation. (NASA illustration by Robert Simmon.)

Roles of satellites in IoT context

Communication / relay of terrestrial data

Earth observation

LoRa not suitable for image or other big file transfer → process locally → good use cases for TinyML

A lot of data already exists: Commercial (Planet, Maxar, etc), Scientific (Landsat, Copernicus, etc)

Operations/Telemetry

downlink & uplink

And any mix of those

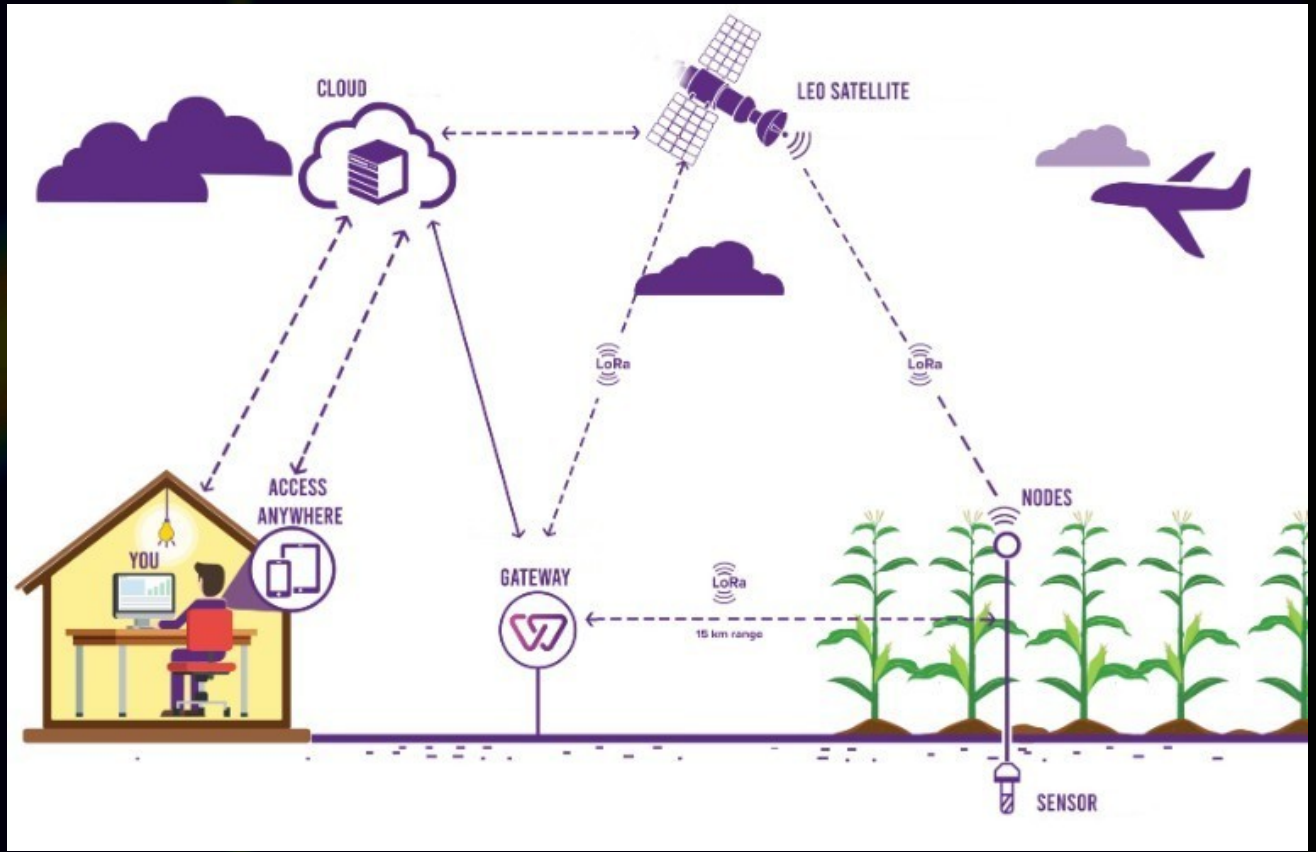
Satellite IoT - principle

From sensor node to satellite

Direct (DTS)

Or

Via aggregator (gateway/relay)



source: https://wyldnetworks.com//

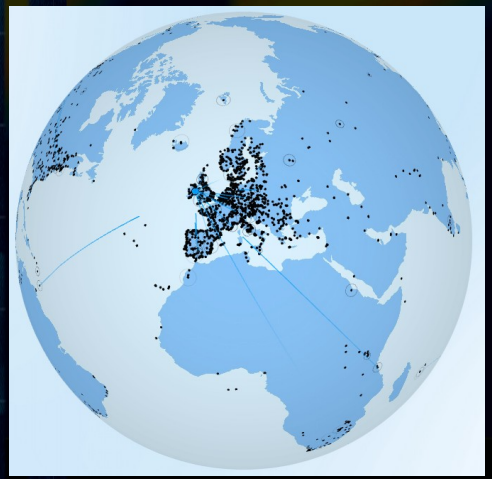
Integration with terrestrial LoRaWAN

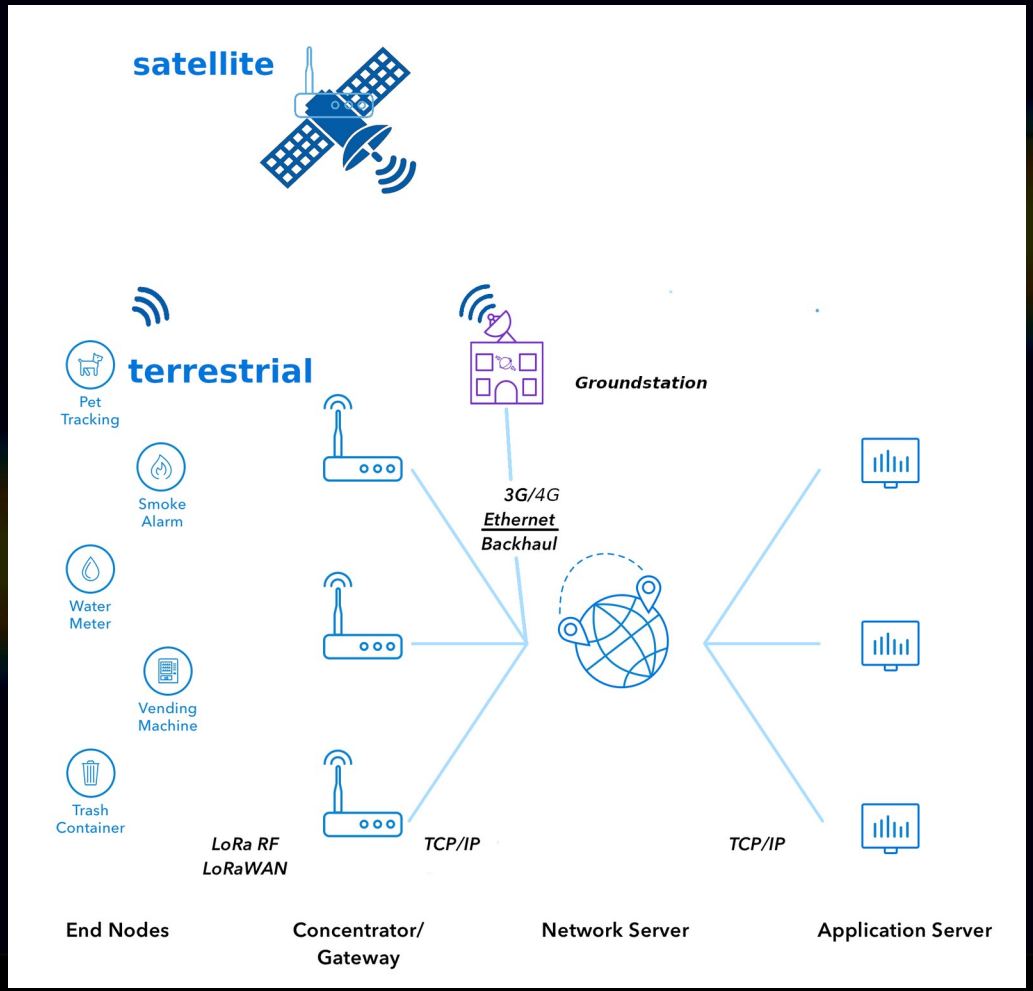
Satellite gateways as

“just another tower”

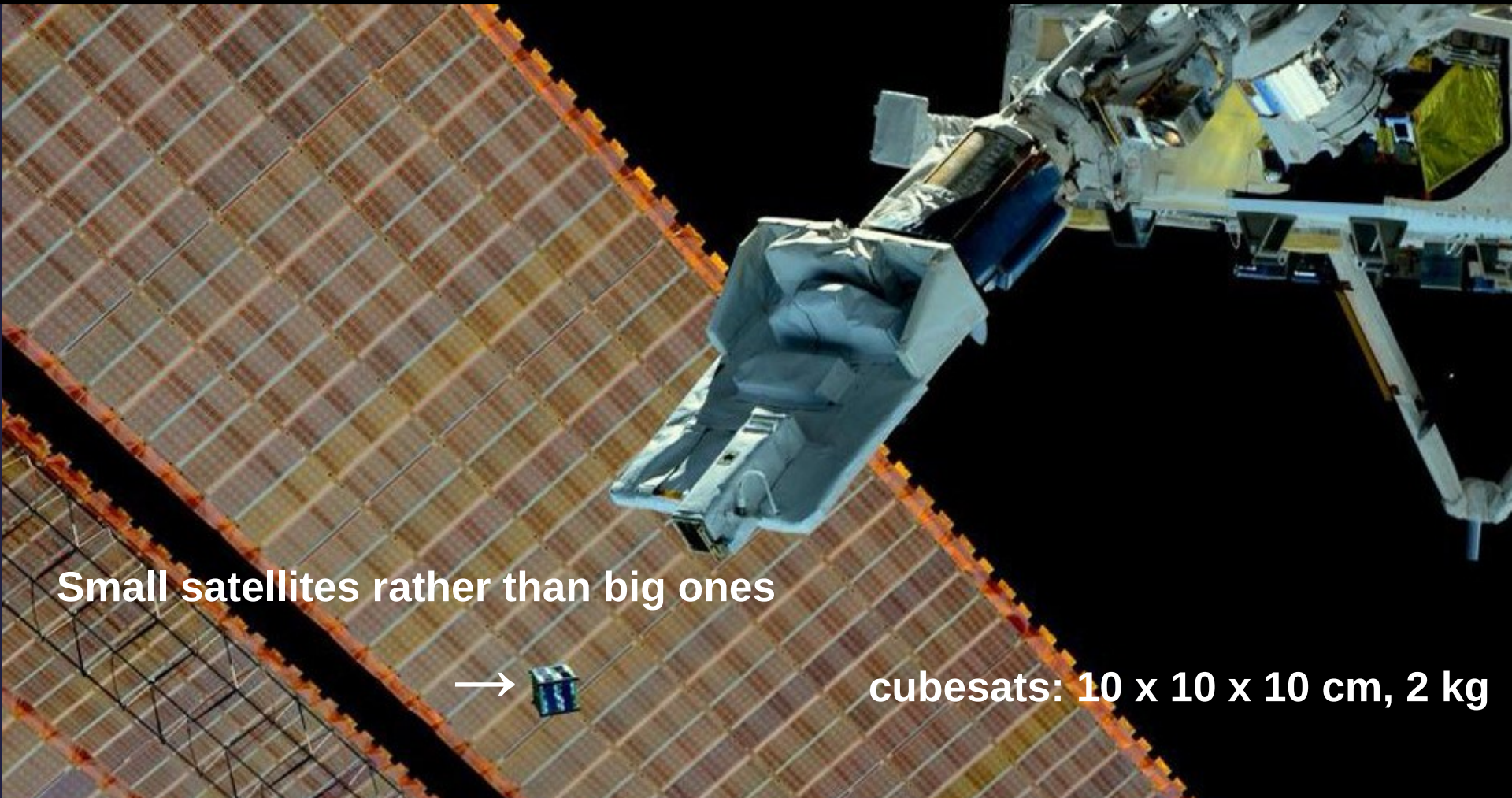
Integrate seamlessly into e.g.

The Things Network





What kind of satellites? Cubesats of 1U … 6U



Small satellites rather than big ones

→

cubesats: 10 x 10 x 10 cm, 2 kg

Use cases for satellite LoRa

- Agriculture
- Energy
- Science
- Environmental
  - Conservation
  - Tracking
- Logistics
- Pipelines
- Maritime
- Tourism
- Utilities

source: https://lacuna.space//

Use cases for satellite LoRa

Special interests – from East Africa to Greenland to the Himalayas:

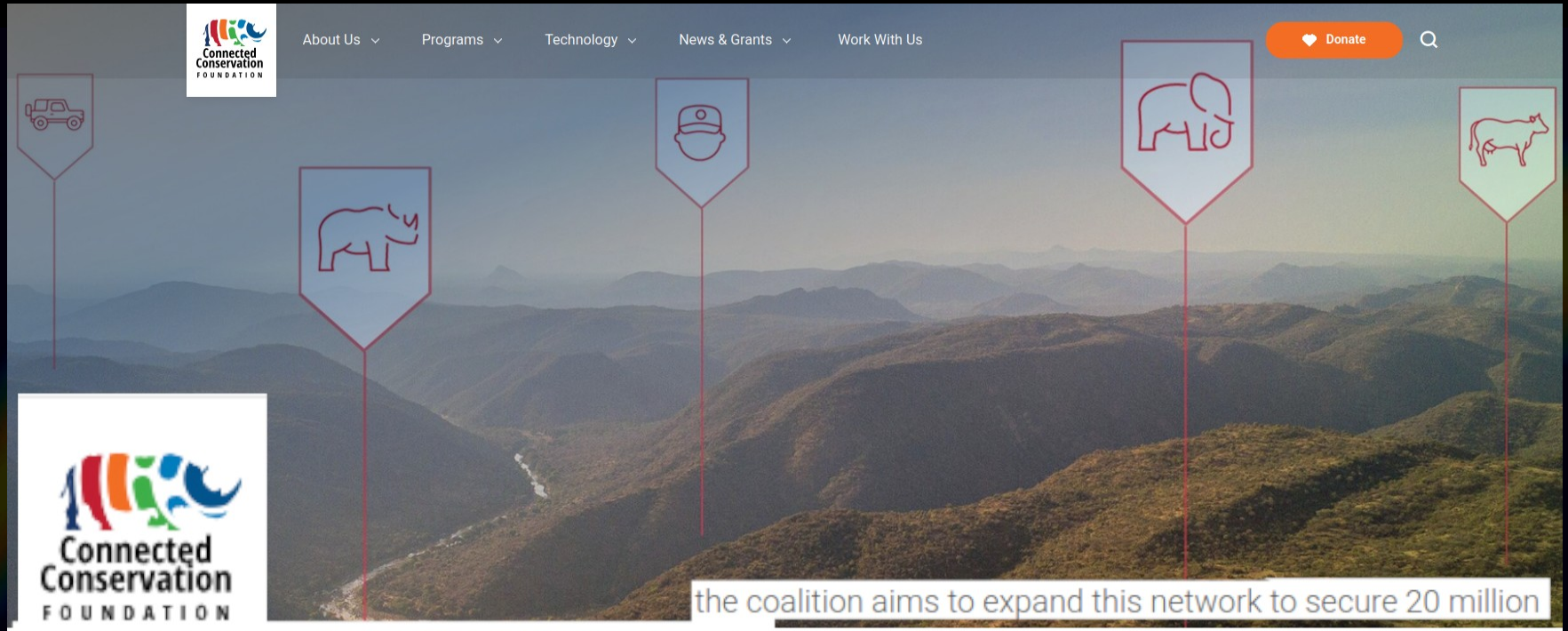
Maritime

Mountain

Polar

environments

Use case: Environment & Conservation



Actility and CCF Break Records with Largest LoRaWAN Biodiversity Network — Targeting 20+ Million Hectares of Protection by 2030

East and Southern Africa's conservation landscape is undergoing a digital revolution, fueled by a partnership between Actility and the Connected Conservation Foundation (CCF). Advanced Internet of Things (IoT) technology already enhances protection across 2.8 million hectares, enabling Protected Areas to monitor and safeguard iconic biodiversity and ecosystems. Ambitiously, the coalition aims to expand this network to secure 20 million hectares through IoT and satellite monitoring by 2030.

Feature article

Satellite LoRa: companies & constellations

Many companies and projects – changing fast!

[last update: August 2025]

Asiasat GEO/LEO (LoRa?)
Astranis GEO
Astrocast LEO
Connecta / Plan-S
Echostar GEO (S-Band LoRa))
eSat global GEO
Eutelsat GEO/LEO
Fleet LEO LORA (backhaul)
Fossa
Globalstar LEO
Hello Space
Hiber (backhaul)
Inmarsat GEO/LEO
Iridium LEO

Kineis LEO LORA
Lacuna LEO LORA
Mokolora (?)
Myriota
Orbcomm LEO
Skylo GEO
Swarm LEO (stopping)
Thuraya GEO
Wyld (-→ Lacuna → Eutelsat)

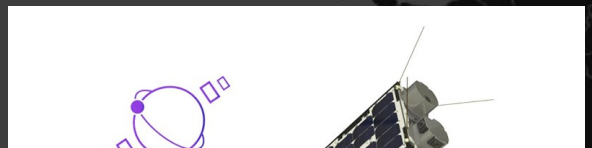
Satellite LoRaWAN at IT University: Lacuna.space

5 years of satellite LoRa on EU868

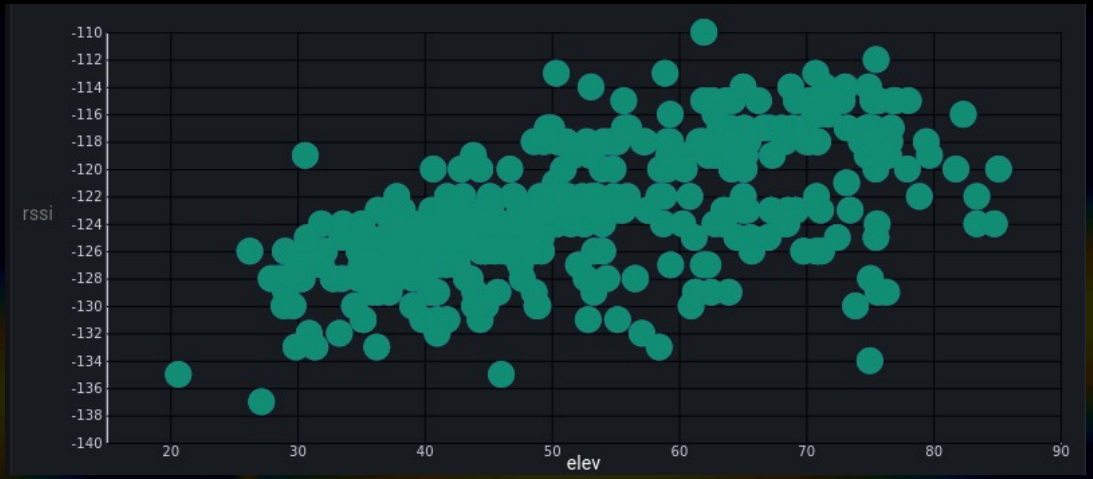
with Lacuna.space

Distance up to 1700 km

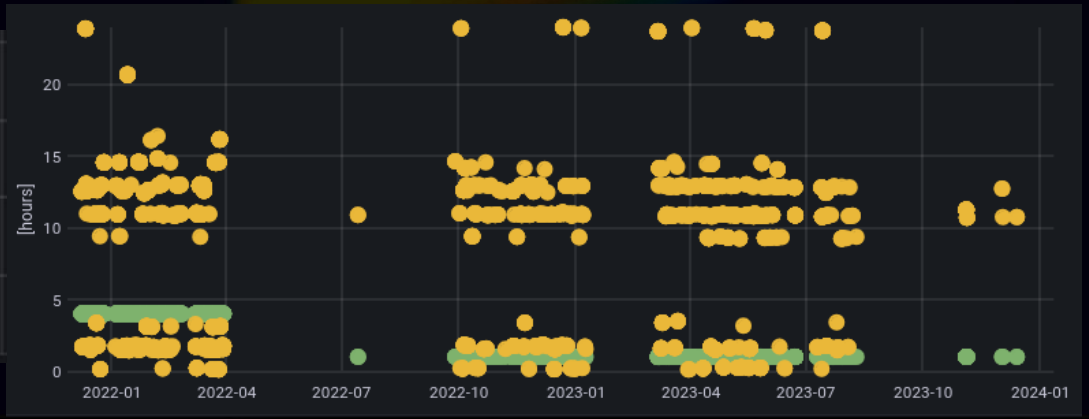
Denmark
Italy
Nepal
Uganda
Kenya



Satellite LoRaWAN: Lacuna.space



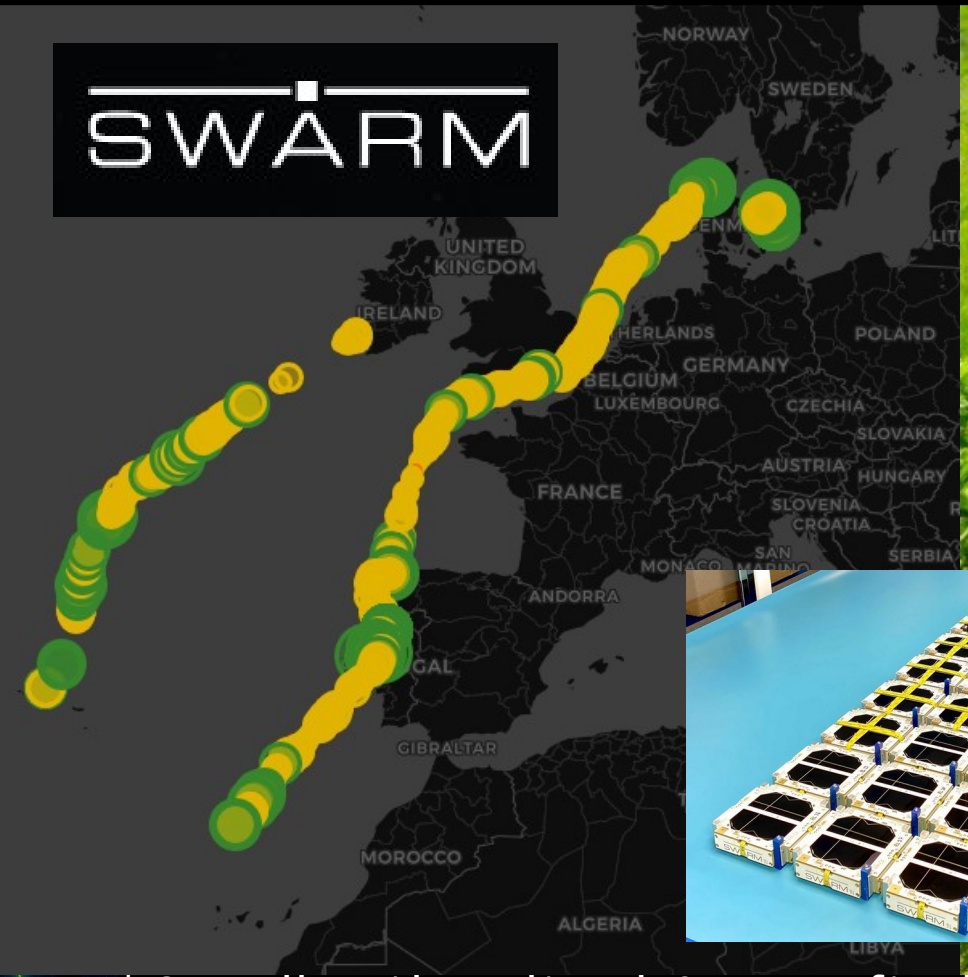
Detail metrics
from single passes
to long term data



Satellite LoRaWAN w Lacuna: in different climates (latitudes)

Satellite LoRaWAN with Lacuna : Kenya

Satellite LoRaWAN at ITU: swarm.space



* Swarm discontinues its sub-GHz IoT, after having been bought by SpaceX:

Satellite LoRaWAN: Regulations

Importance of Regulations – Satellite networks are global

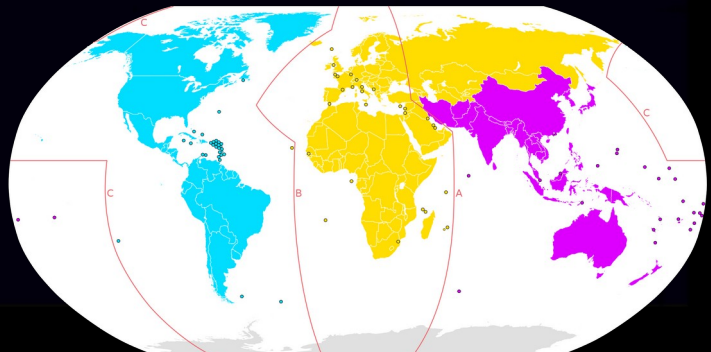
Satellite IoT currently governed by SRD (Short Range Device) rules -
which is kinda funny … short range ...

ITU, ETSI (European Telecommunications Standards Institute),
FCC (US), …

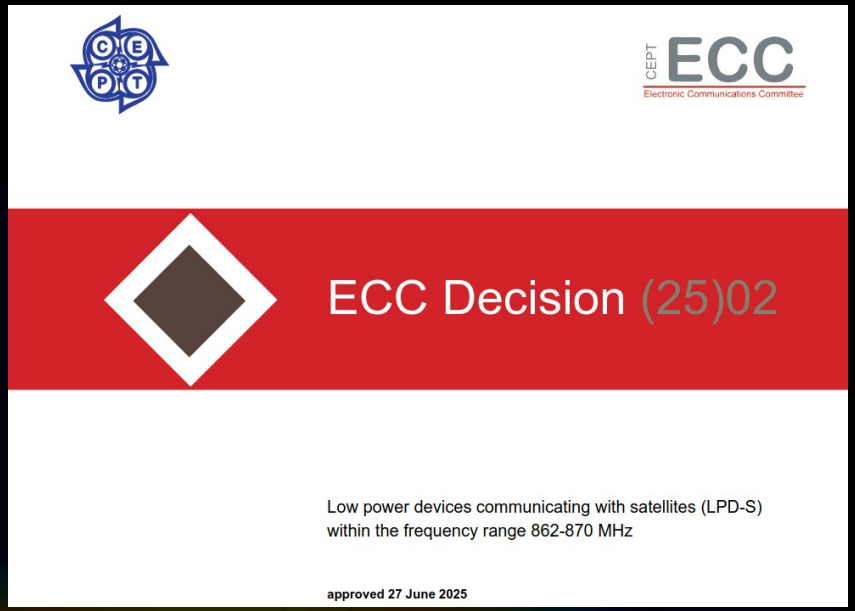
Does Satellite IoT need separate treatment from terrestrial IoT?
Consider uplink/downlink!

EU: Revision of ERC/REC 70-03
– now amended!

Global harmonization?



Regulations – EU breakthrough: ECC DEC decision June 2025



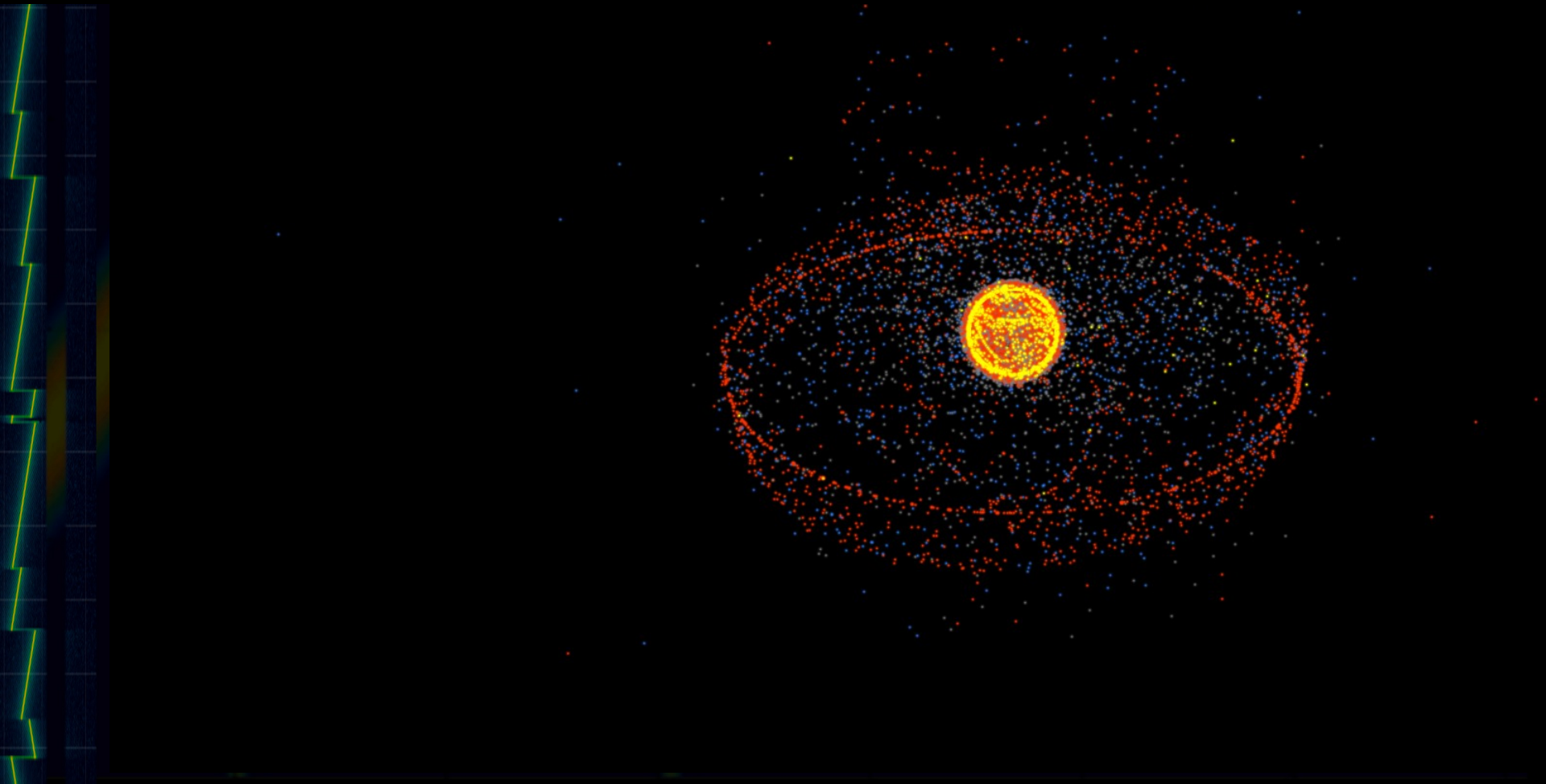
The Electronic Communications Committee (ECC)
of the
European Conference of Postal and Telecommunications Administrations (CEPT)
has officially approved the Decision ECC DEC(25)02[1], confirming the regulatory framework enabling

Satellite-to-low power device communication with satellites (LPD-S) communications within the short-range device (SRD) 862-870MHz frequency band in Europe.
The framework ensures coexistence with existing terrestrial SRD users while opening new avenues for non-terrestrial network (NTN) deployments.
Technically, “no unacceptable interference to SRD applications if a PFD limit of -142 dB(W/(m2.4kHz)) in the 862-870 MHz frequency band is not exceeded on the Earth’s surface.”

https://docdb.cept.org/download/4784

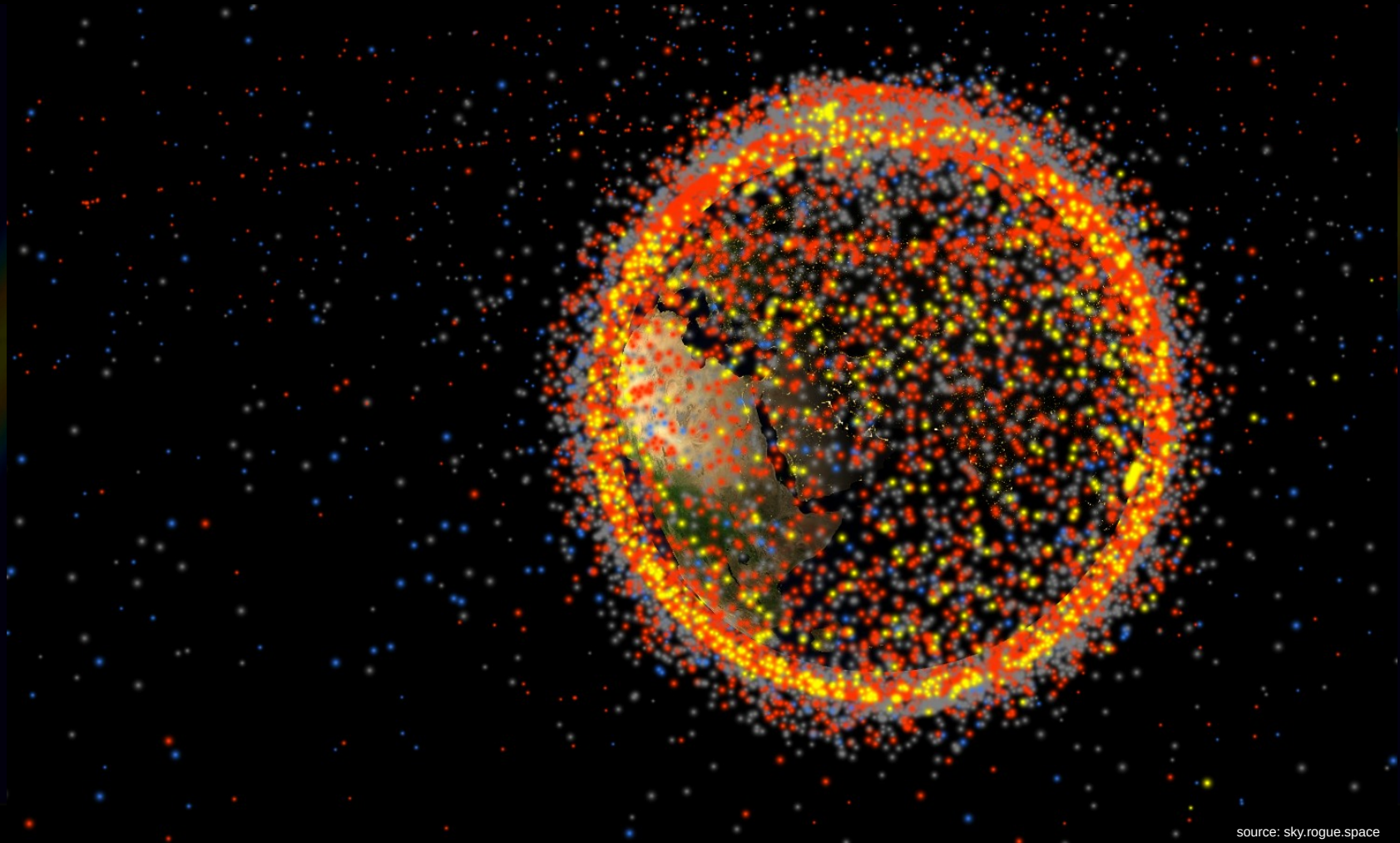
For more info, pls contact me: sebastian@nsrc.org

A few warnings: Is there space in space?



source: sky.rogue.space

Not a lot of space ...



source: sky.rogue.space

Not a lot of space …
not forever …

copy

MISS_DISTANCE	=777	[m]
MISS_DISTANCE	=179	[m]
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MISS_DISTANCE	=335	[m]
MISS_DISTANCE	=438	[m]
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MISS_DISTANCE	=303	[m]
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MISS_DISTANCE	=98	[m]
MISS_DISTANCE	=931	[m]
MISS_DISTANCE	=560	[m]
MISS_DISTANCE	=59	[m]

5:08 PM

our lowest score was 59m 5:08 PM

source: space-track conjunctions for DISCO-1

Even tiny pieces of space debris can have catastrophic effects. This image shows the result of a lab-test impact between a block of aluminum and a small aluminum sphere traveling at nearly 7 kilometers per second. Credit: ESA

Even proper de-orbit might cause problems

PLANETARY SCIENCE

Space Junk Is Polluting Earth's Stratosphere with Vaporized Metal

Defunct satellites and other pieces of orbital debris are pumping metals into Earth's fragile upper atmosphere, with effects unknown

By Leonard David, Lee Billings on October 26, 2023

ELSEVIER

Advances in Space Research

Volume 67, Issue 3, 1 February 2021, Pages 1002-1025

On the anthropogenic and natural injection of matter into Earth's atmosphere

Leonard Schulz [a], Karl-Heinz Glassmeier [a b]

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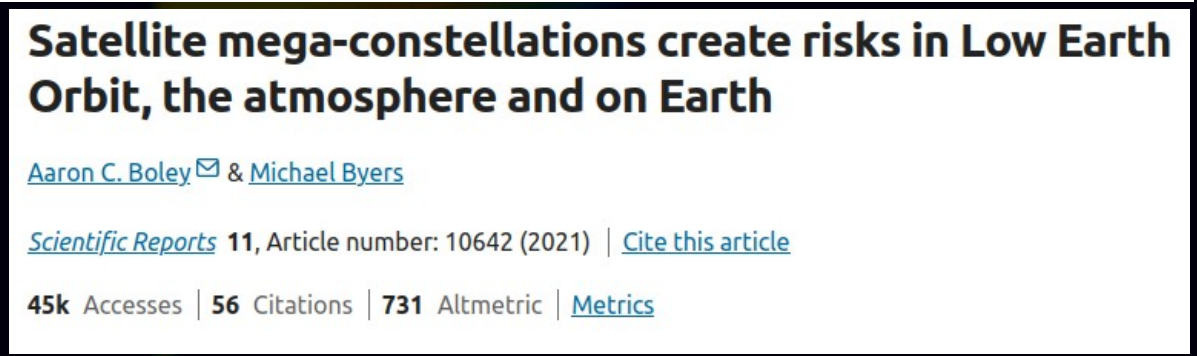
https://doi.org/10.1016/j.asr.2020.10.036 Get rights and content



Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth

Aaron C. Boley & Michael Byers

Scientific Reports **11**, Article number: 10642 (2021) | Cite this article

45k Accesses | **56** Citations | **731** Altmetric | Metrics

Conclusion & Discussion

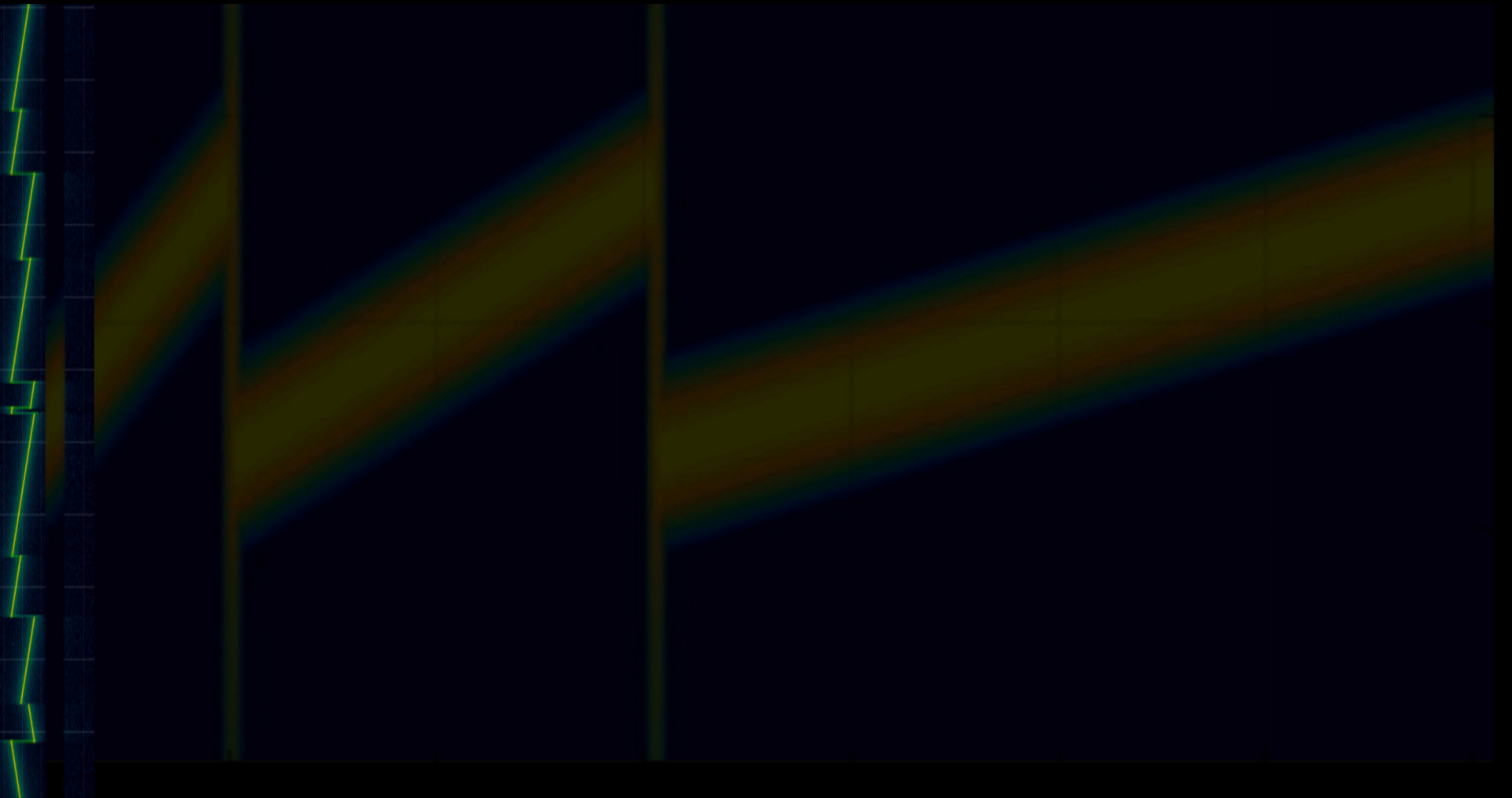
Satellite IoT (especially with LoRa) offers

Connectivity for devices isolated from any terrestrial infrastructure

- **in the budget range of $/month/device**
- **with months/years of battery lifetime or via energy harvesting**
- **with nodes in the lower $100 range readily available**
- **for a wide range of use cases**
- **from many providers**

Thank you! sebastian@nsrc.org

Bonus slides



Duty cycles – regulations in europe

In Europe, duty cycles are regulated by section 4.3.3 of the ETSI EN300.220-2 V3.2.1 (2018-06) standard.

This standard defines the following sub-bands and their duty cycles:

K (863 MHz - 865 MHz): 0.1%

L (865 MHz - 868 MHz): 1%

M (868 MHz - 868.6 MHz): 1%

N (868.7 MHz - 869.2 MHz): 0.1%

P (869.4 MHz - 869.65 MHz): 10%

Q (869.7 MHz - 870 MHz): 1%

In additon to that, there may be fair use and SLA limitations set by network operators.

source: https://www.thethingsnetwork.org/docs/lorawan/duty-cycle/

A shared challenge for all space LoRa: Capacity

CSS has long range and robustness, but does not use spectrum efficiently.

“Based on previous measurements, the single-channel LoRa network with ALOHA channel access can achieve a capacity of 150k packets per day with Adaptive Data Rate (ADR) enabled and mostly SF7 traffic. If the network only utilizes SF12, about 5k packets per day capacity (no ADR) can be achieved.”

= 1.7 messages per second for a single channel gateway
(real gateways are 8- or 16-channel)”

For a time window of some seconds or tens of seconds per satellite pass, this constitutes a tough limit.

To the rescue: LR-FHSS, a new sub-standard within the LoRa family

(= LoRA + Frequency Hopping)

A shared challenge for all space LoRa: Capacity

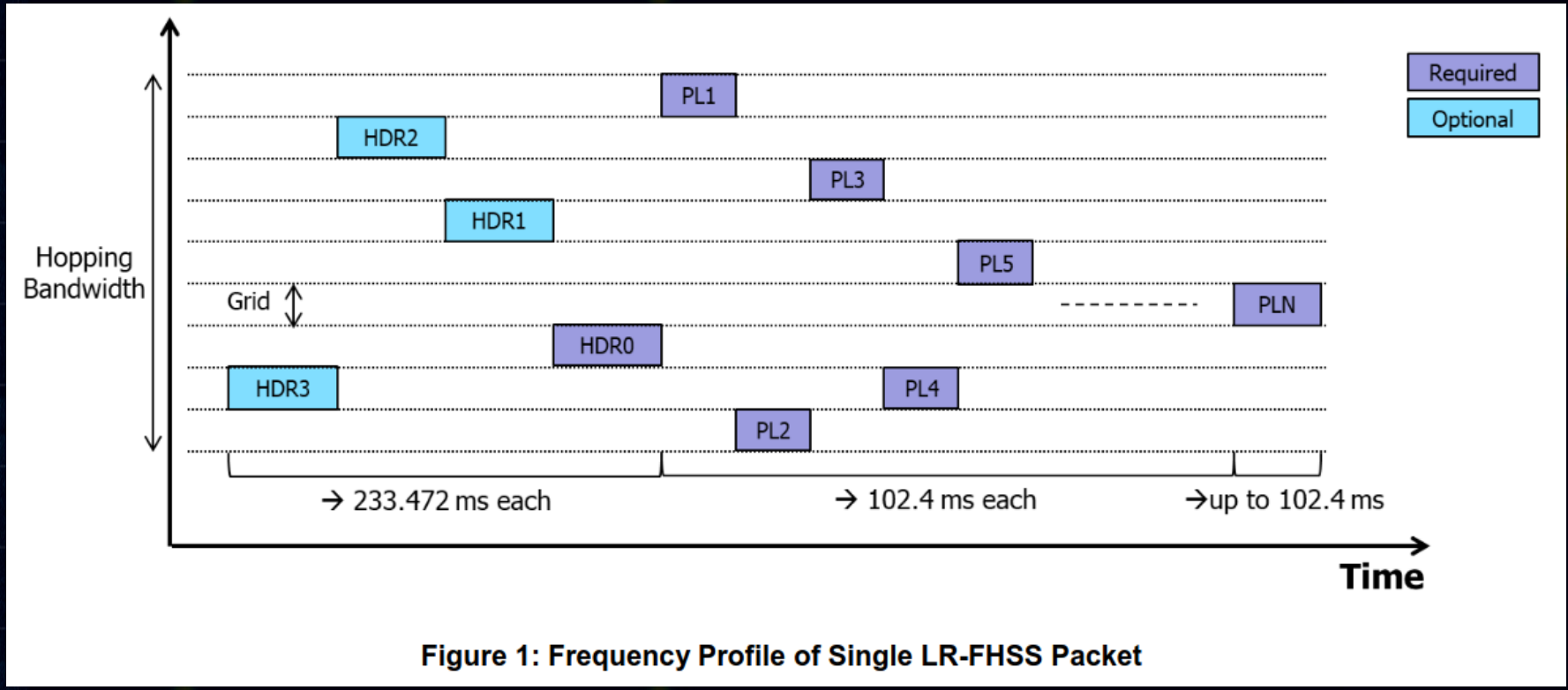


Figure 1: Frequency Profile of Single LR-FHSS Packet

Source: Semtech Application Note (SX1261/62/ LR1110): LR-FHSS System Performance

A shared challenge for all space LoRa: Capacity

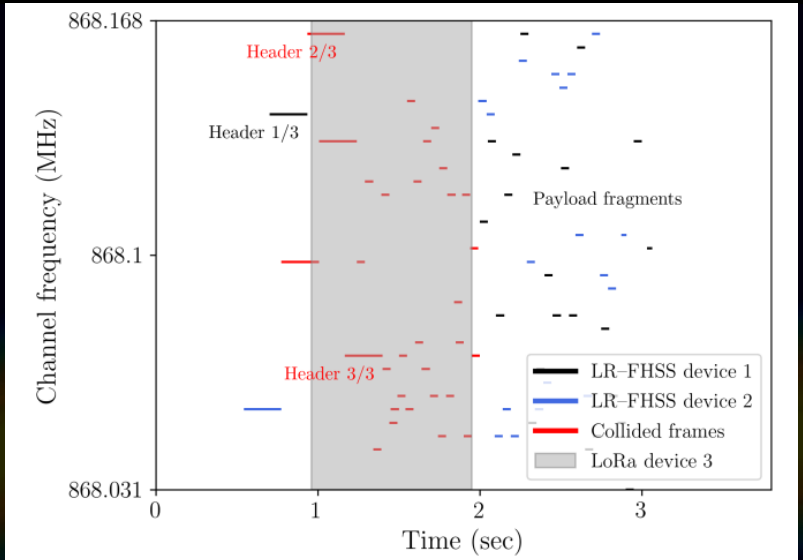


Fig. 1. Two LR-FHSS (DR8) 30-B and one LoRa (DR0/SF12) 10-B packets transmitted simultaneously in the EU 868-870 MHz band (Channel 1). A packet transmission using LoRa occupies the whole channel bandwidth (125 kHz), whereas for LR-FHSS the fragments of a given packet are distributed over time in randomly selected subchannels (488 Hz) within the entire channel bandwidth (137 kHz). Despite several frame collisions, both LR-FHSS packets will be decoded successfully with high probability thanks to its redundancy.

source:

Boquet, G., Tuset-Peiró, P., Adelantado, F., Watteyne, T., & Vilajosana, X. (2021). LR-FHSS: Overview and performance analysis. IEEE Communications Magazine, 59(3), 30-36.

LR-FHSS: LoRA with Frequency Hopping

LR-FHSS allows

the necessary >155 dB link margin for low Earth orbit (LEO) satellite IoT

and

the capacity to receive hundreds of packets simultaneously.

Semtech SX12611, SX12622 , LR11103, and newer chipsets support LR-FHSS packet transmission. SX1261 and SX1262 only perform GMSK modulation with intra-packet-hopping, frame preparation is done by the host MCU.
LR1110 (used e.g. in Lacuna nodes, ed.) includes a full-featured LR-FHSS modem.

Source: Semtech Application Note (SX1261/62/ LR1110): LR-FHSS System Performance

DISCOSAT The Danish Students Cubesat Project

DISCO REDUX: 2nd ITU satellite (2026) will have LoRa onboard

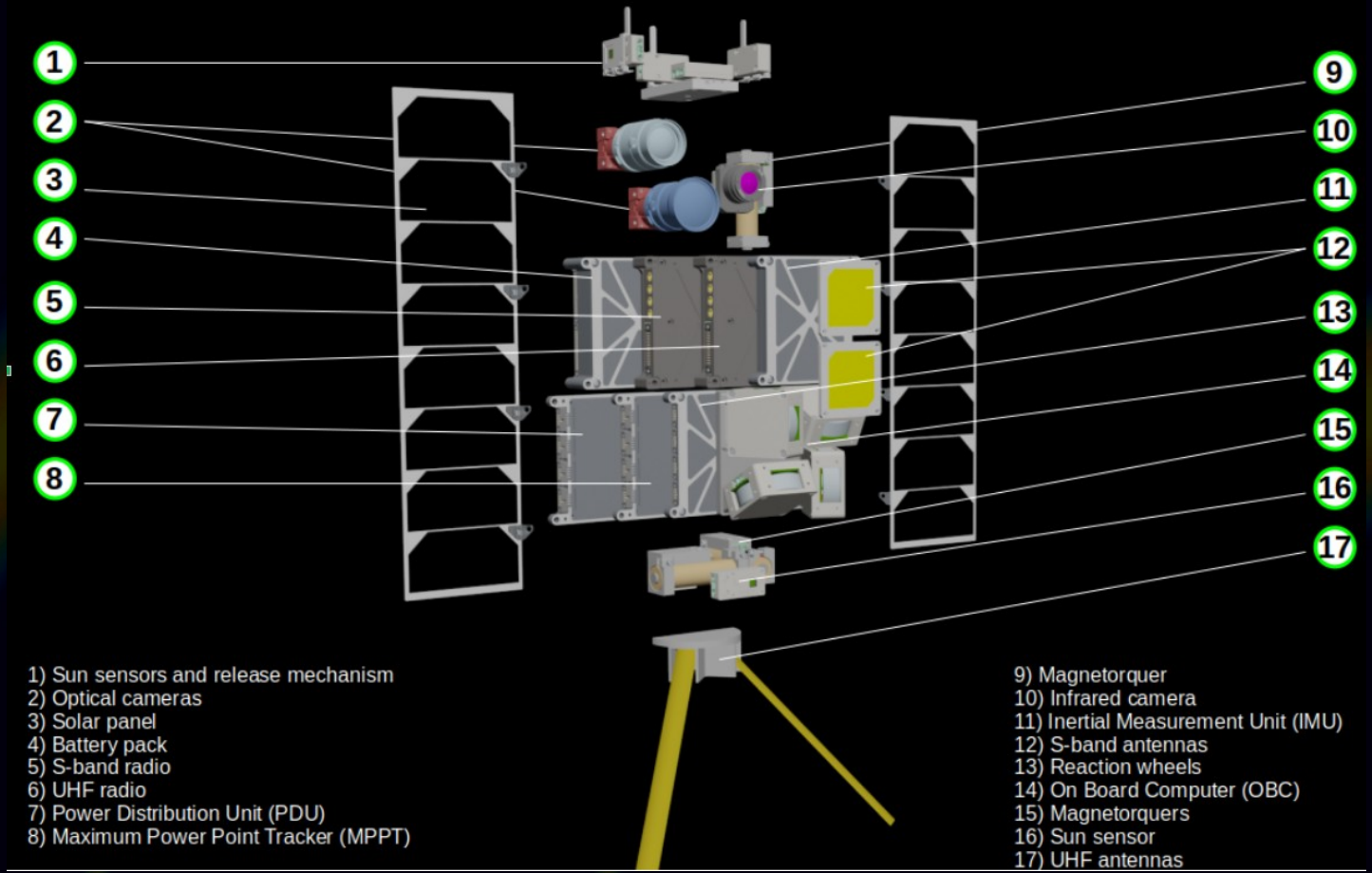
AU, SDU, ITU, (AAU)

Danish Industry Foundation

Preparatory balloon launches
With Spaceline Labs, Odense

IoT Course students fly sensors

DISCO-2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1) Sun sensors and release mechanism
2) Optical cameras
3) Solar panel
4) Battery pack
5) S-band radio
6) UHF radio
7) Power Distribution Unit (PDU)
8) Maximum Power Point Tracker (MPPT)
9) Magnetorquer
10) Infrared camera
11) Inertial Measurement Unit (IMU)
12) S-band antennas
13) Reaction wheels
14) On Board Computer (OBC)
15) Magnetorquers
16) Sun sensor
17) UHF antennas

LoRa for satellite telemetry: TinyGS

Welcome to TinyGS, the Open Source Global Satellite Network

TinyGS is an open network of Ground Stations distributed around the world to receive and operate LoRa satellites, weather probes and other flying objects, using cheap and versatile modules.

This project is based on ESP32 boards and currently it is compatible with sx126x and sx127x LoRa módules but we plan to support more radio módules in the future.

LoRa for satellite telemetry: TinyGS

Ground stations are ESP32 based TTGO T-Beams (~ $30 + Antenna)

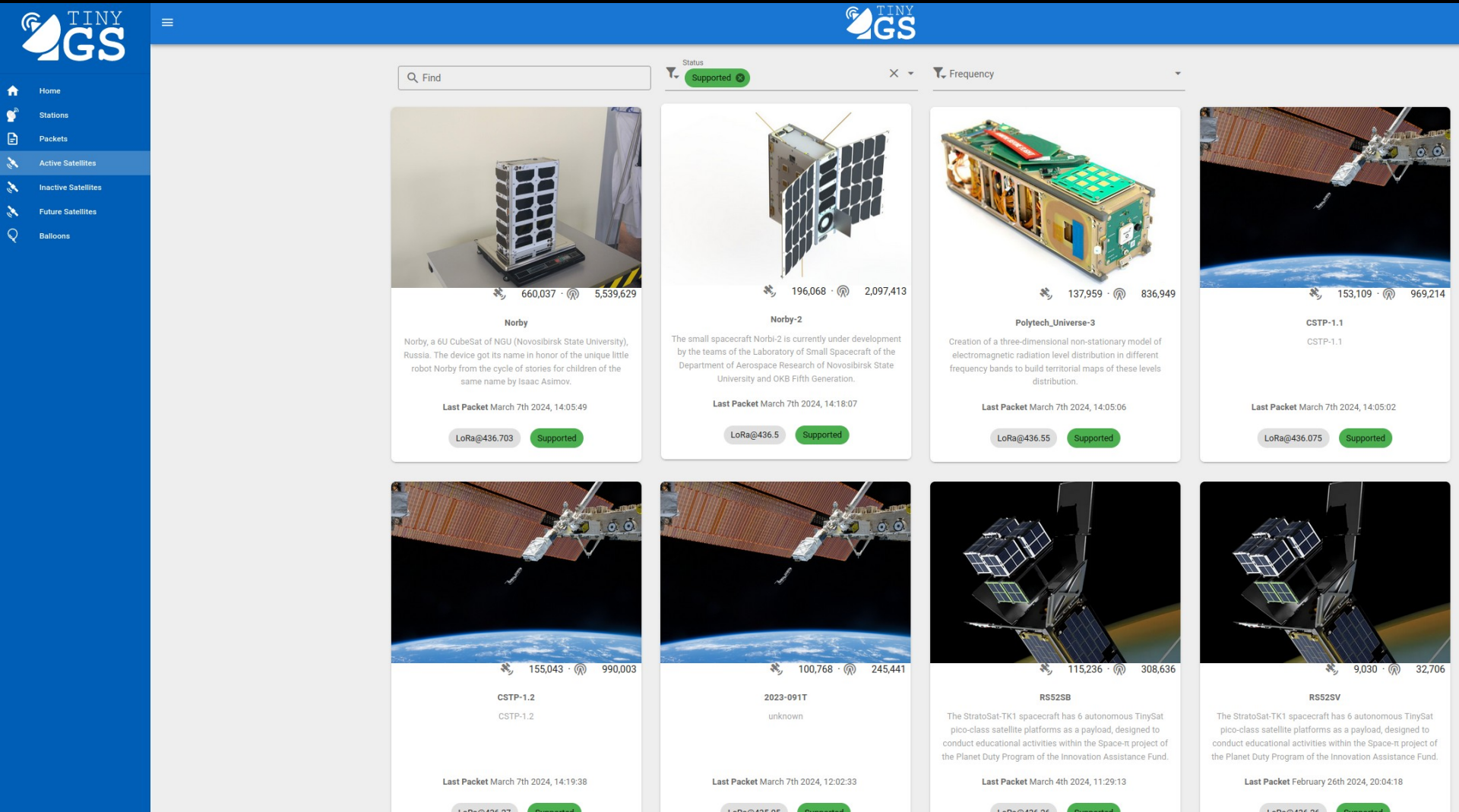
Around 30 satellites - Most around 430 MHZ, some 400, some 915 MHz

2.4 GHz starting soon

1500 stations (2024)

Telemetry, Beacons

LoRa for satellite telemetry: TinyGS



DISCOSAT The Danish Students Cubesat Project

DISCOSAT: 2nd ITU satellite will have LoRa onboard

AU, SDU, ITU, (AAU)

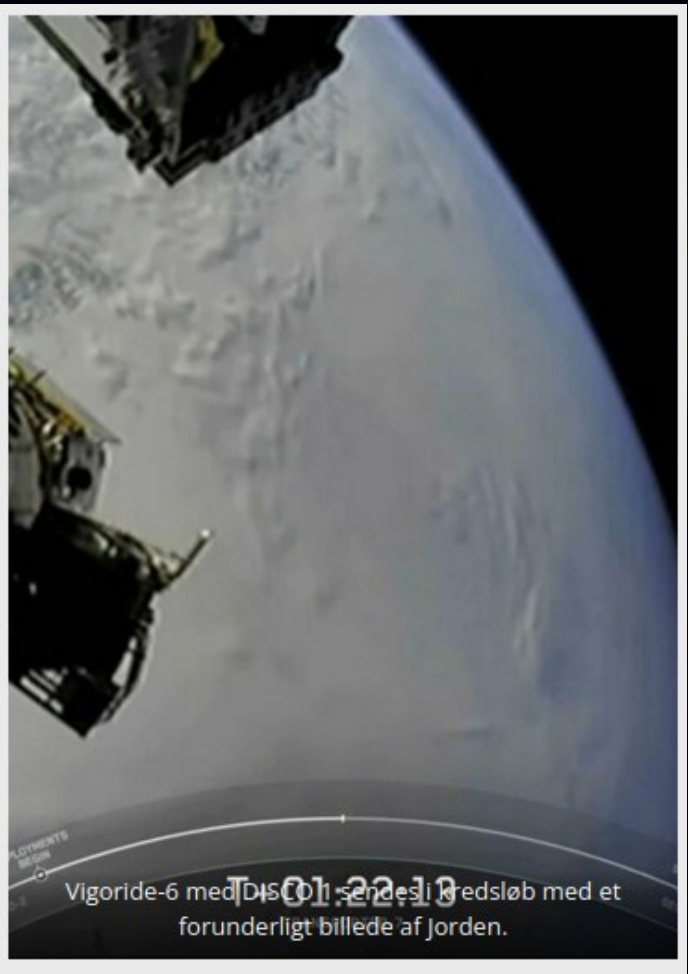
Danish Industry Foundation

DISCOSAT: an educational activity

Students design and build the cubesat

DISCOSAT: DISCO-1 Launch April 2023

Take-off af Falcon-9 raketten med DISCO-1 ombord.


Vigoride-6 med DISCO-1 sendes i kredsløb med et forunderligt billede af Jorden.

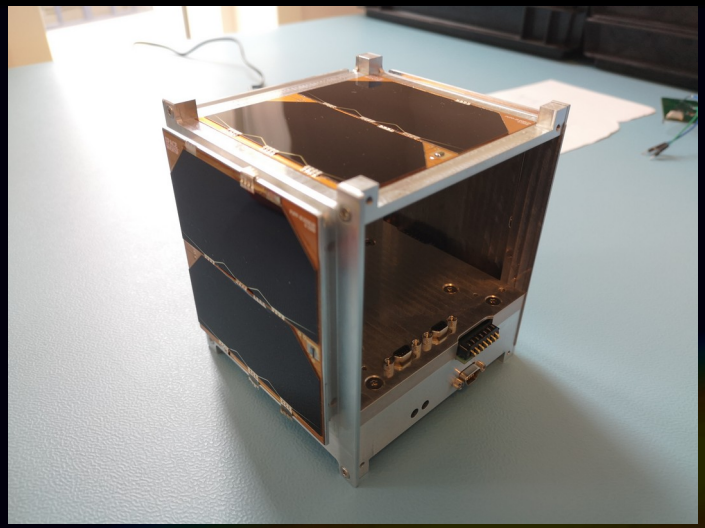
So is there LoRa on DISCO-1?

No.

What is on DISCO-1?

DISCO-1 is a 1U cubesat.

15 mm space for Linux payload :)



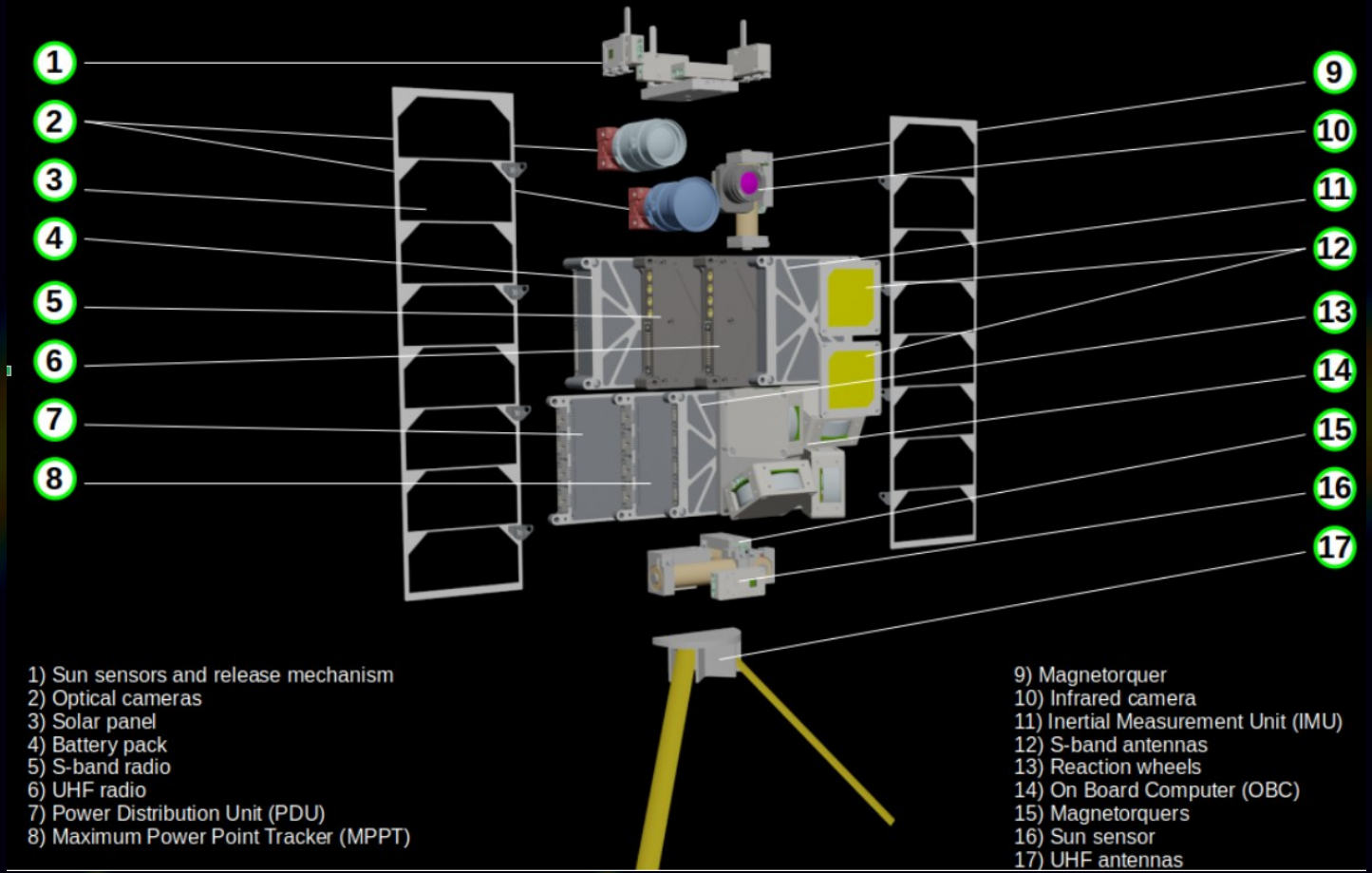
Machine Learning in Space -

A Google Coral Dev Board Mini, TPU,

Looking to learn to identify

Cosmic Ray events on standard CCD camera.

DISCO-2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1) Sun sensors and release mechanism
2) Optical cameras
3) Solar panel
4) Battery pack
5) S-band radio
6) UHF radio
7) Power Distribution Unit (PDU)
8) Maximum Power Point Tracker (MPPT)
9) Magnetorquer
10) Infrared camera
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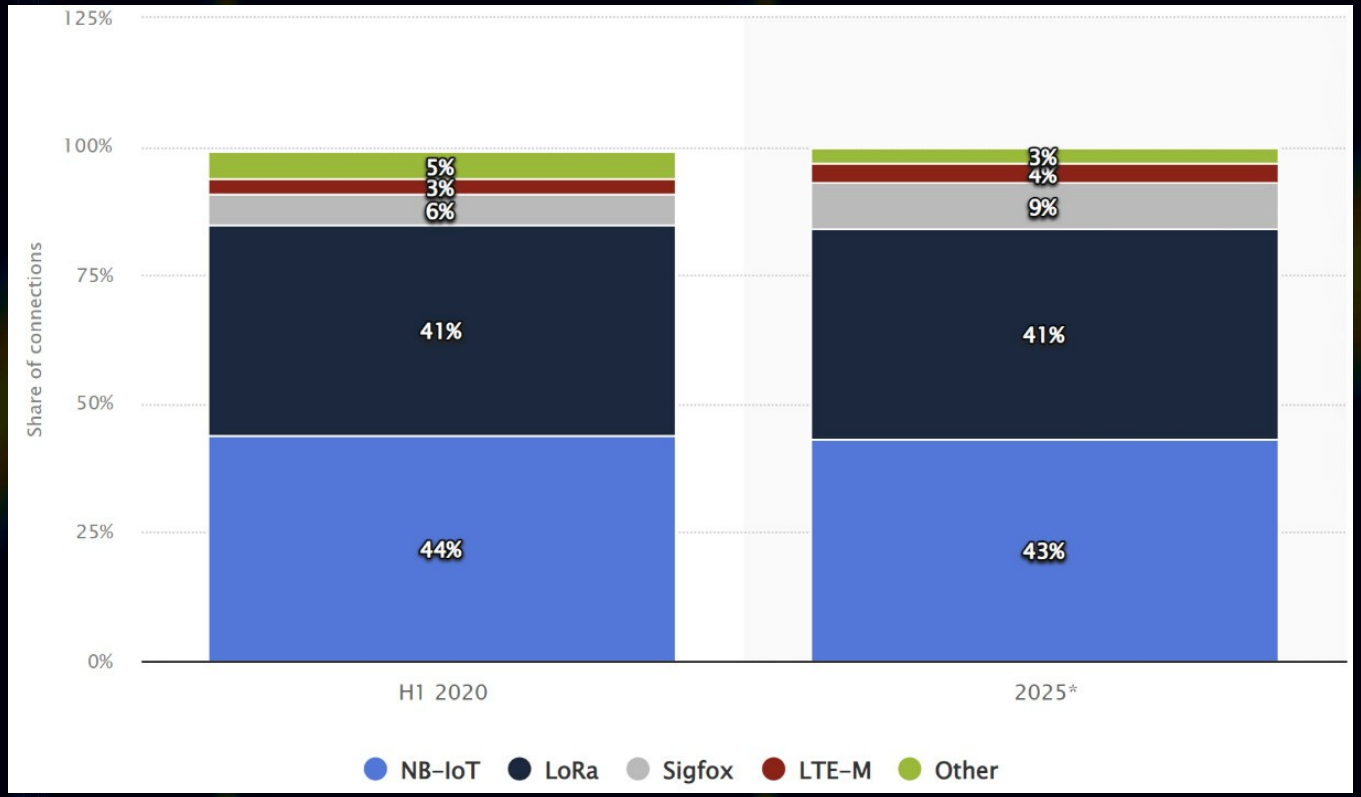
Let’s start on earth – terrestrial LPWANs

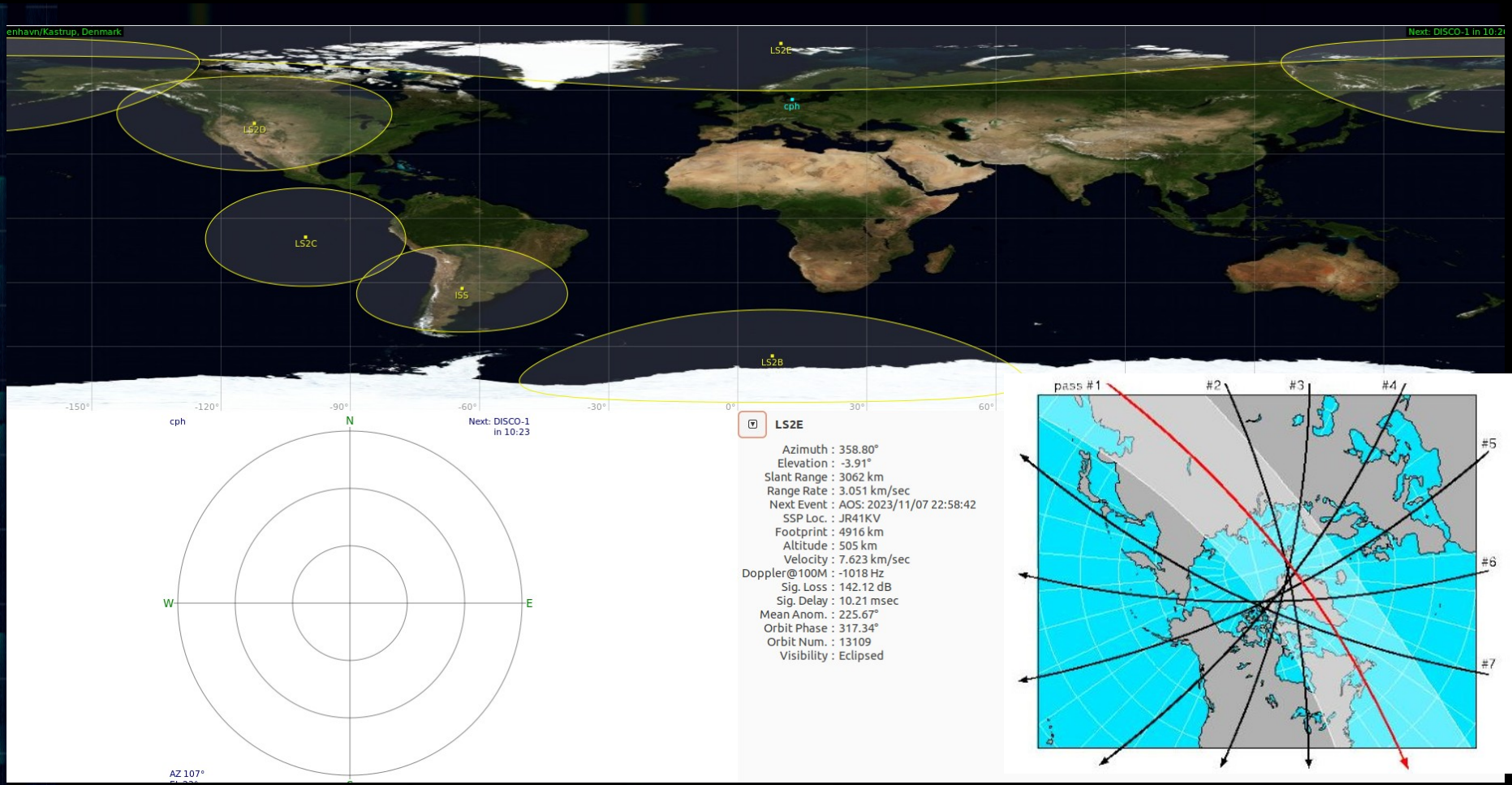
Low power wide area networks – cellular vs. non-cellular



currently LoRa and NB-IoT as market leaders

source: statista / IHS

Polar orbits (and a look at Greenland & the Arctic)



software: gpredict / https://github.com/csete/gpredict