A DECADE OF LPWAN FOR SMART OBJECTS: WHAT'S AHEAD?

KEYNOTE AT GOODTECH 2025
DEC. 18TH, 2025

IOT-SENSING-SYSTEM

Internet-of-Things and Sensing System Research Activities at University of Pau, France

Prof. Congduc Pham
http://www.univ-pau.fr/~cpham
Université de Pau, France

Congduc.Pham@univ-pau.fr

European Commission | Horizon 2020 European Union funding for Research & Innovation

WAZIUP
IoT – from idea to reality
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IN THE MEDITERRANEAN AREA

Intel-IrriS RESICOLINK
Advanced and disruptive IoT/AI technologies targeting the smallholder community for increased resilience

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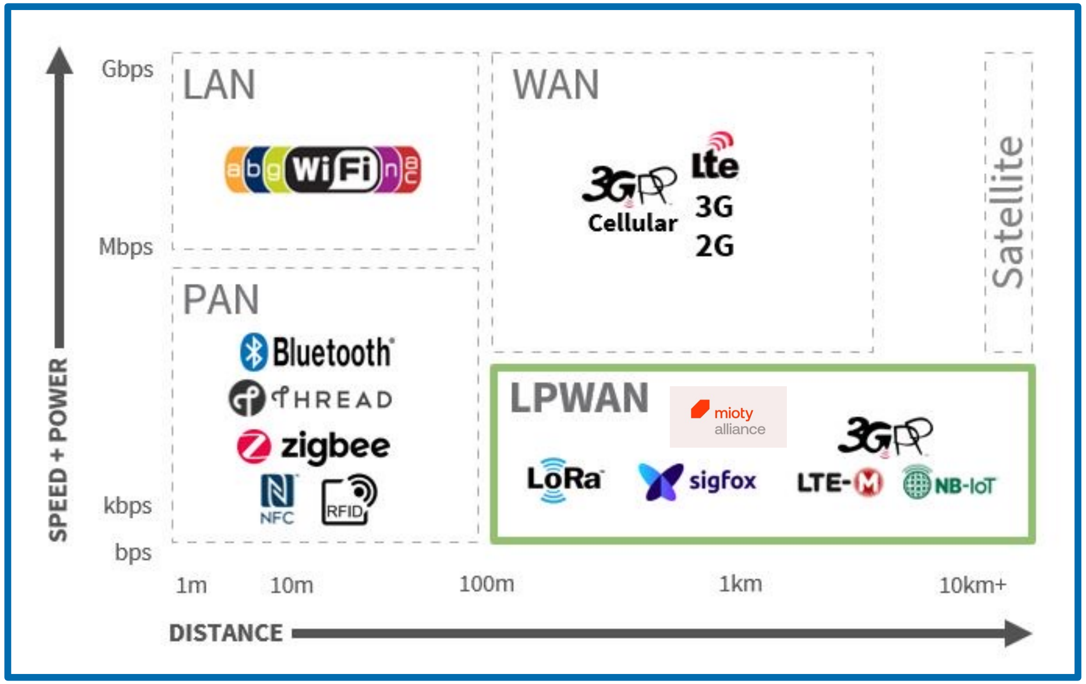
Wireless Sensors Made Simple
for agroecology & sustainable agriculture

LPWAN?

- LPWAN? What is it exactly?

  - ❌ Lightwave Performant in Wide Area Network (WAN)
  - ✅ Low Power WAN
  - ❌ Low Probability for WAN
  - ❌ Light Packets in WAN
  - ❌ Loss-free Protocol for WAN



LPWAN changed everything!

- LPWAN: Low-Power Wide Area Network
- Again, let's take a quick quizz! Check the correct answers…
  - ☒ The revolutionary LPWAN approach
  - ☑ The come-back of LPWAN
  - ☑ The rise of LPWAN

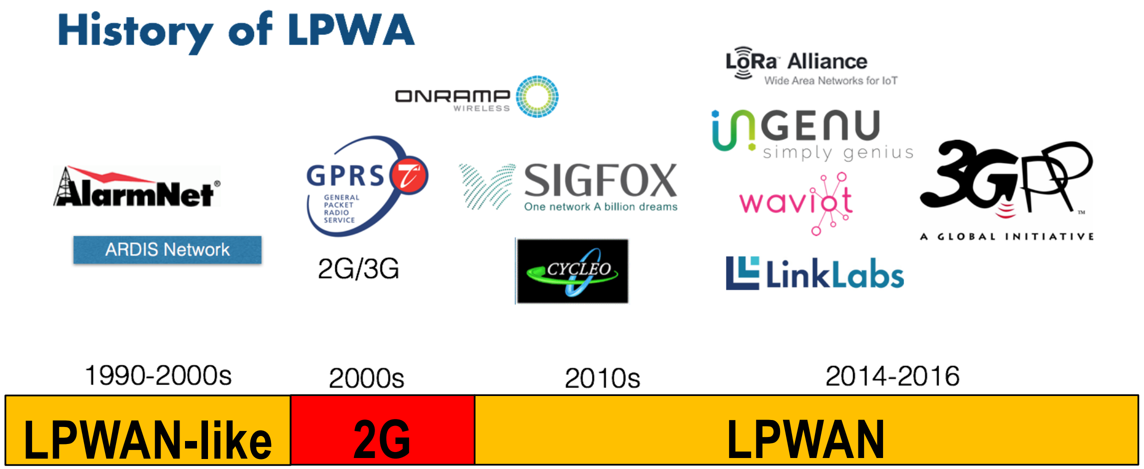
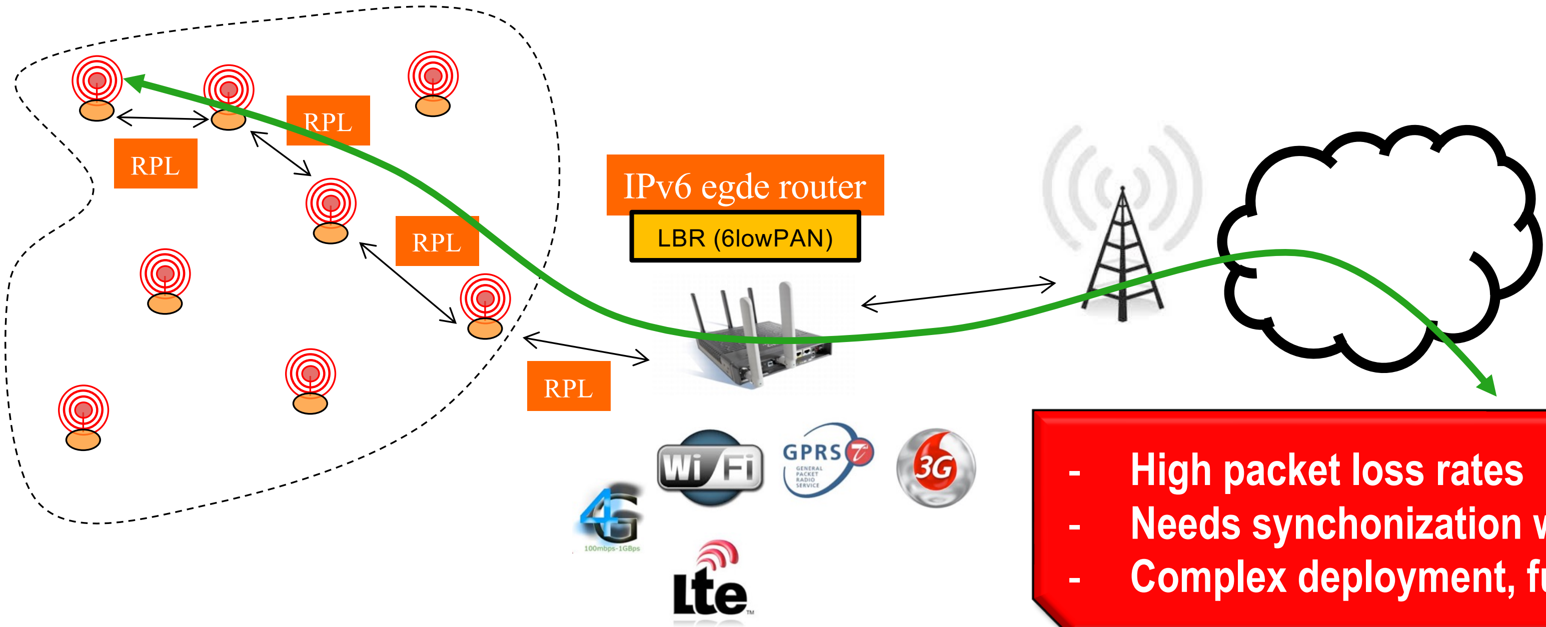


Image credit: https://www.link-labs.com/blog/past-present-future-lpwan

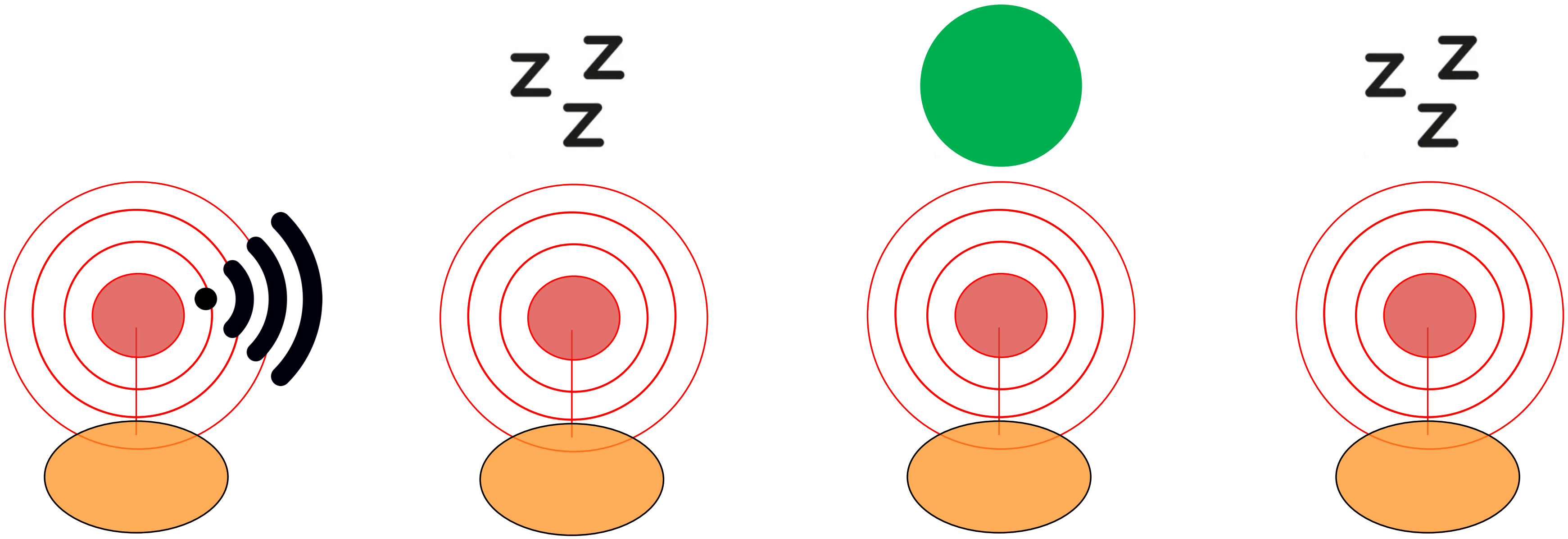
2000-2015: 15 years of multi-hop routing?

- How to use short range radios (e.g. IEEE 802.15.4) for long distance?
- Lot's of scientific contributions!
- The golden age of multi-hop wireless sensor networks!



- High packet loss rates
- Needs synchonization when duty-cycling
- Complex deployment, funneling effect

Managing energy? A nightmare!



Academics vs Industries

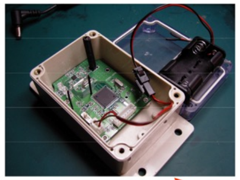
Let's go back to reality!

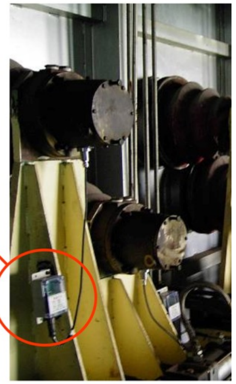
Millions of sensors, self-organizing, self-configuring, with QoS-based multi-path routing, mobility, and …

Complex systems that are collaborating

500 sensors, STATIC deployment, but need to have RELIABILITY, GUARANTEED LATENCY for monitoring and alerting. MUST run for 3 YEARS. No fancy stuff! CAN I HAVE IT?

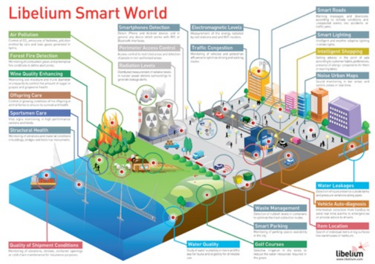
Simple systems that simply send data→telemetry



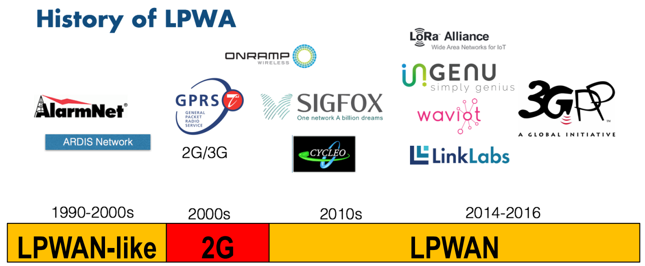


- Placement constraints
- Lifetime constraints

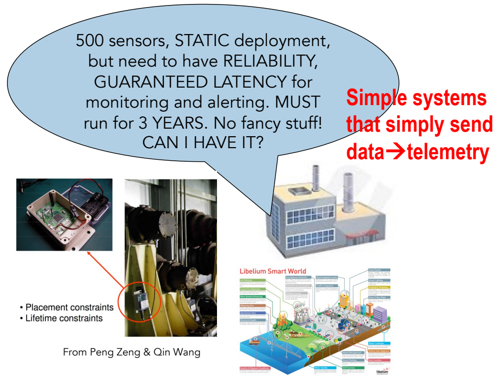
From Peng Zeng & Qin Wang



2010: a new start for LPWAN



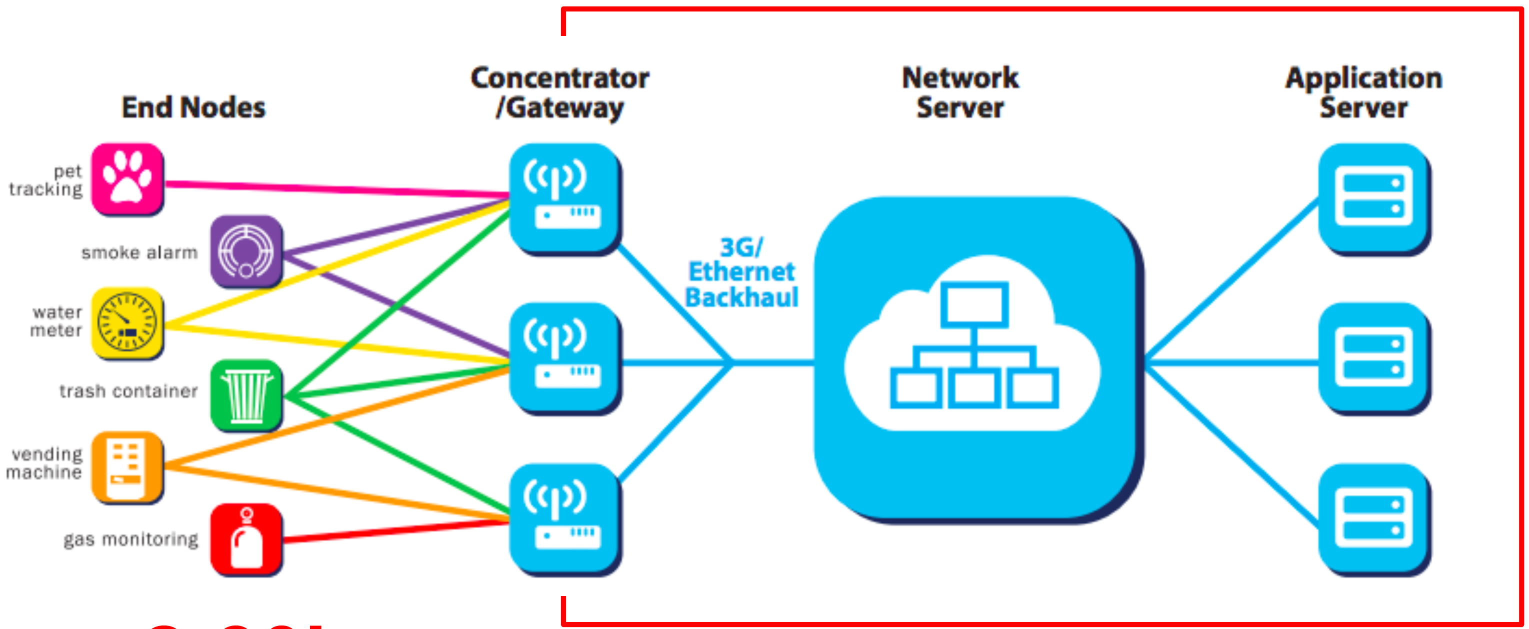
- SigFox (2009) then LoRa (2012, from Cycleo)
- 2 French innovations!
- Unlicensed band (although it is not mandatory)
- Sub-GHz (again, although it is not mandatory)
- Centralized, star topology, gateway-centered
- Low data rate for lower power and, of course, longer range!
- Battery-operated with several years of autonomy
- Several kms can be achieved when transmitting at 14dBm (~25mW)
- ALOHA-based medium access → no medium access control at all!

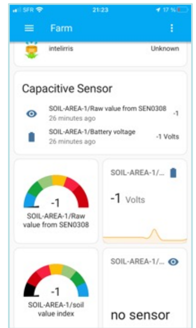


Industries won!

Typical LPWAN networks

- Below, a typical architecture taking graphics from LoRa networks





ThingsBoard

2-30kms

RESCOM, January, 12th, 2016, INRIA Lille

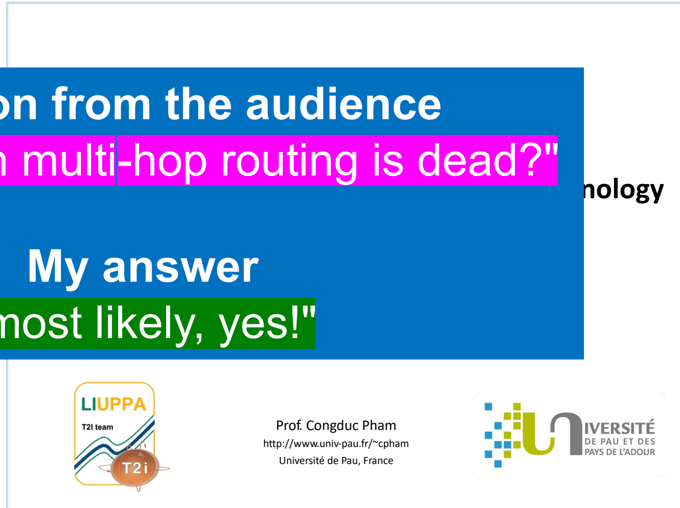
- Talk: "**Low-power, Long-range WAN for IoT: a technology overview**"

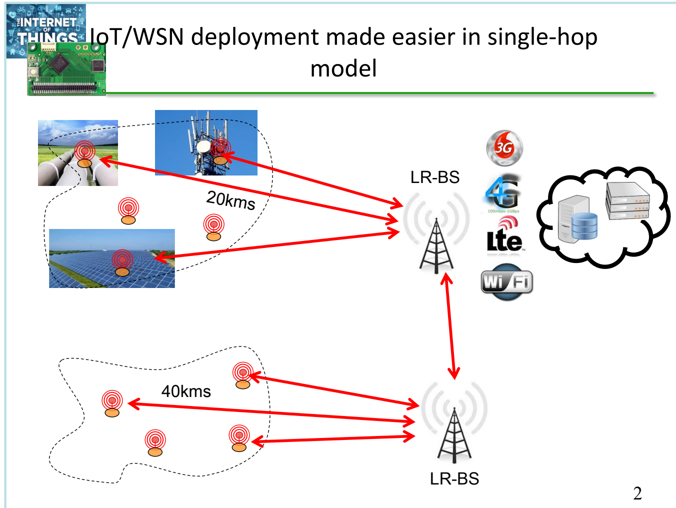
Question from the audience

"Does it mean multi-hop routing is dead?"

My answer

"most likely, yes!"



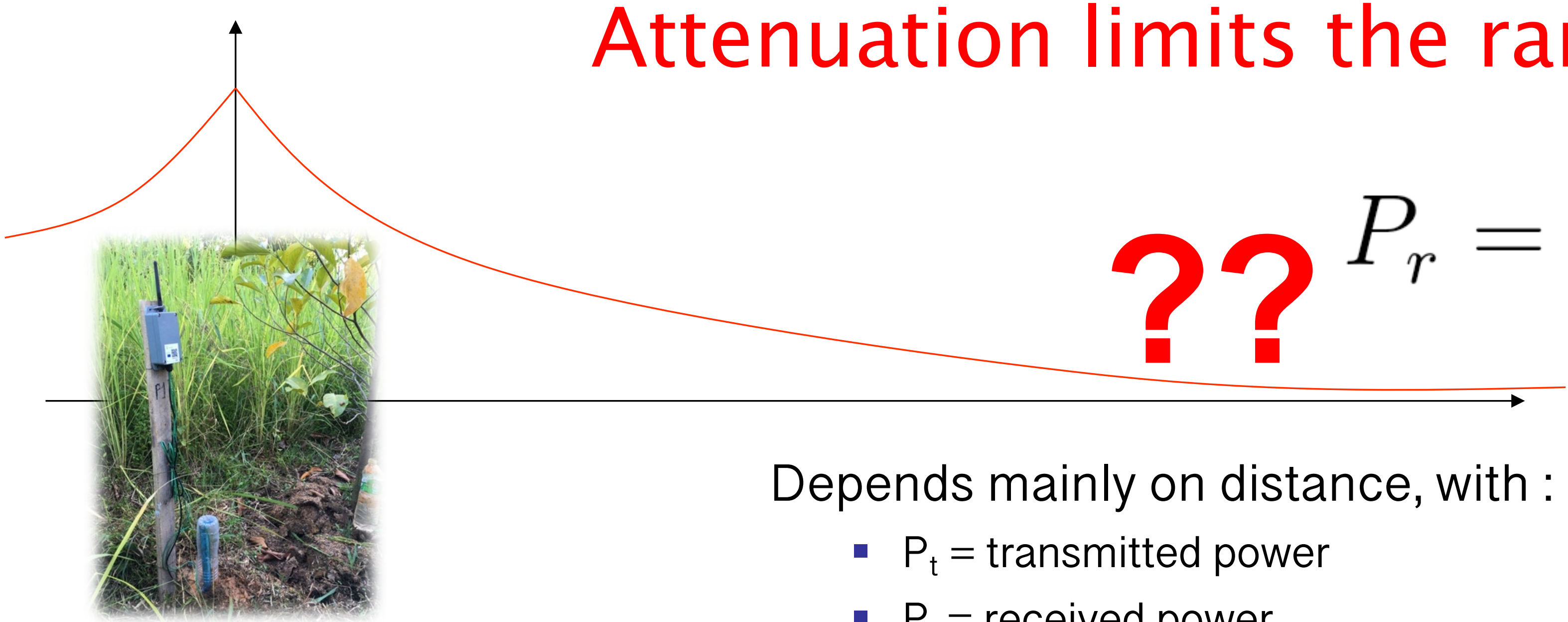


- Contributions on pure multi-hop routing decreased since 2015…
- A shift in research from many foundational theoretical/simulation works to fewer, more practical, deployment-oriented researches

LPWAN big challenge: signal attenuation

X watts

Attenuation limits the range!



$$P_r = \frac{P_t}{d^\alpha}$$

Depends mainly on distance, with :

- P_t = transmitted power
- P_r = received power
- d = distance between antennas
- α from 2 to 4

https://vexlio.com/math-equation-writer/

Attenuation in practice

- For an ideal antenna (theoretic)

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \boxed{\frac{(4\pi f d)^2}{c^2}}$$

Only f and d are variables!

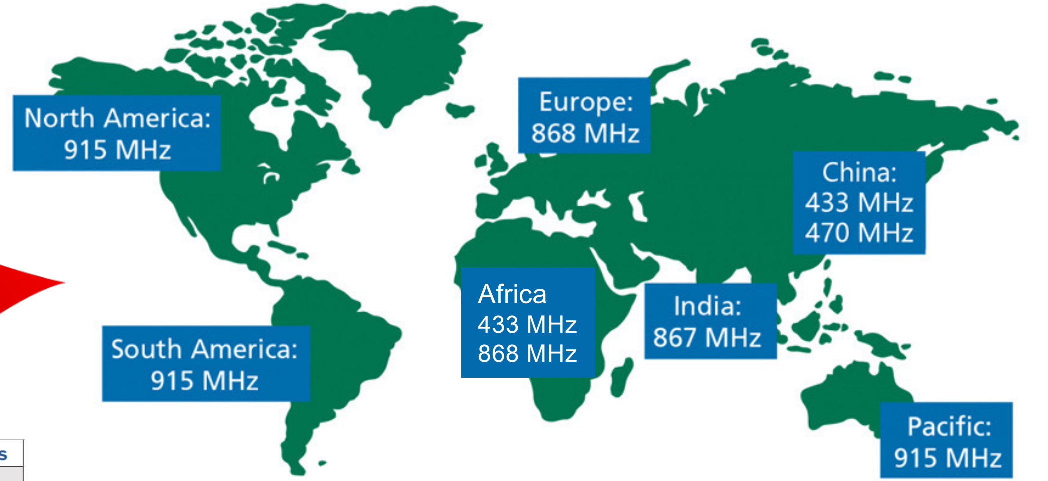
- P_t = transmitted power
- P_r = received power
- P_t / P_r is high when P_r is small → high attenuation
- d = distance between antennas
- c = light speed in space 3.10^8 m/s
- λ= wave length of the signal=c/f
- Higher frequencies f means higher attenuation!

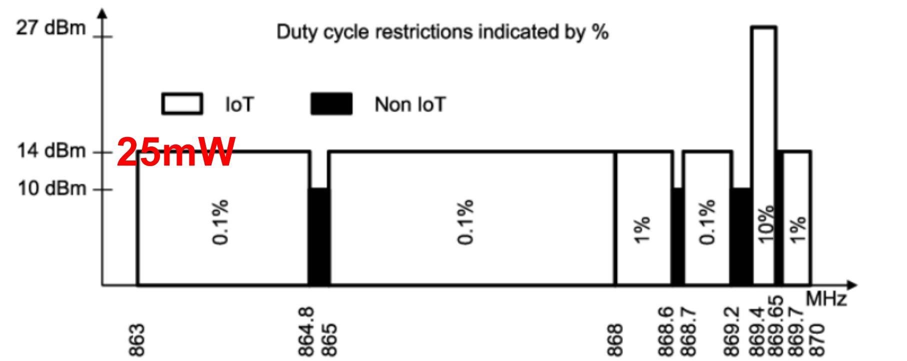
Lower frequency, lower attenuation

THERE IS A LOT MORE BASS NO? CAN HARDLY HEAR THE VOICE!

LPWAN most used frequencies in ISM

ISM Band Frequencies
6.765 - 6.795 MHz
13.553 - 13.567 MHz
26.957 - 27.283 MHz
40.66 - 40.70 MHz
83.996 - 84.004 MHz
167.992 - 168.008 MHz
433.05 - 434.79 MHz
886 - 906 MHz
2.400 - 2.500 MHz
5.725 - 5.875 MHz
24.0 - 24.25 GHz
61.0 - 61.5 GHz
122 - 123 GHz
244 - 246 GHz





Source : https://www.semanticscholar.org/paper/Coverage-and-Capacity-Analysis-of-Sigfox%2C-LoRa%2C-and-Vejlgaard-Lauridsen/

Attenuation, values in watts

- Free Space Path Loss model

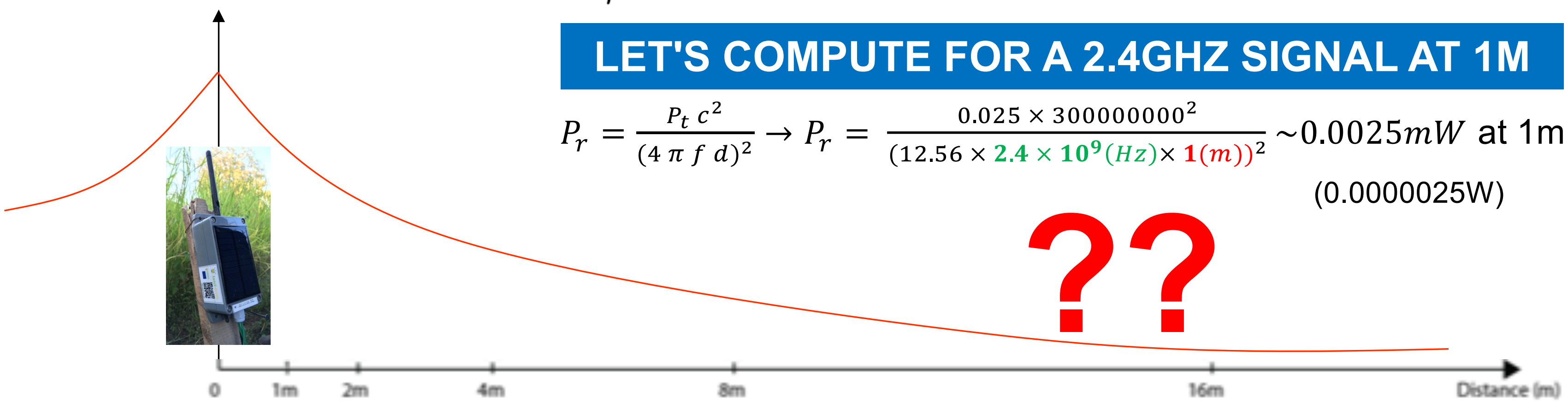
$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

LET'S COMPUTE FOR A 2.4GHZ SIGNAL AT 1M

$$P_r = \frac{P_t\, c^2}{(4\,\pi\, f\, d)^2} \rightarrow P_r = \frac{0.025 \times 300000000^2}{(12.56 \times 2.4 \times 10^9 (Hz) \times 1 (m))^2} \sim 0.0025mW \text{ at 1m}$$

(0.0000025W)

25mW



0.0025mW
x10,000 smaller!

0.00062mW
x39,810 smaller!

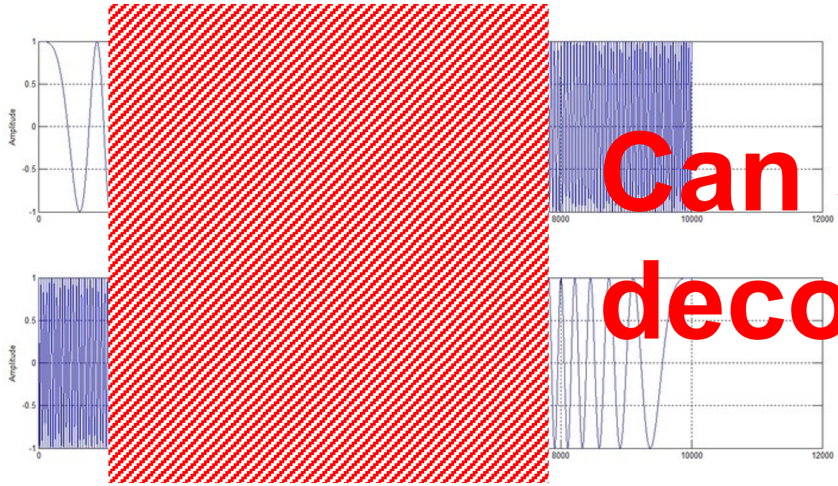
0.0000099526mW
x2,511,886 smaller!

How can we increase range?

- Increase TX power and/or improve RX sensitivity
- RX sensitivity (decoding capability~robustness) can be increased when transmitting slower – like speaking slower!
- → LPWAN have low data rates
- Ex: LoRa technology. Spreading Factor defines how long is a symbol. Longer duration ➠ more robustness

up chirp → Binary 0

down chirp → Binary 1



Can still decode!

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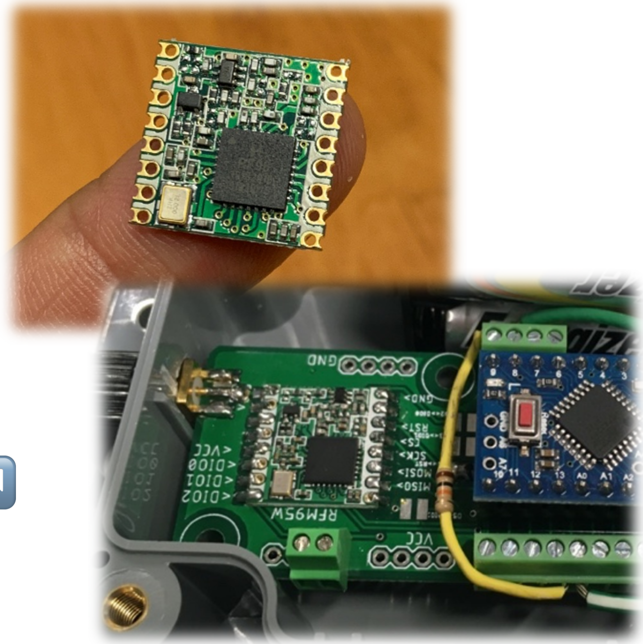
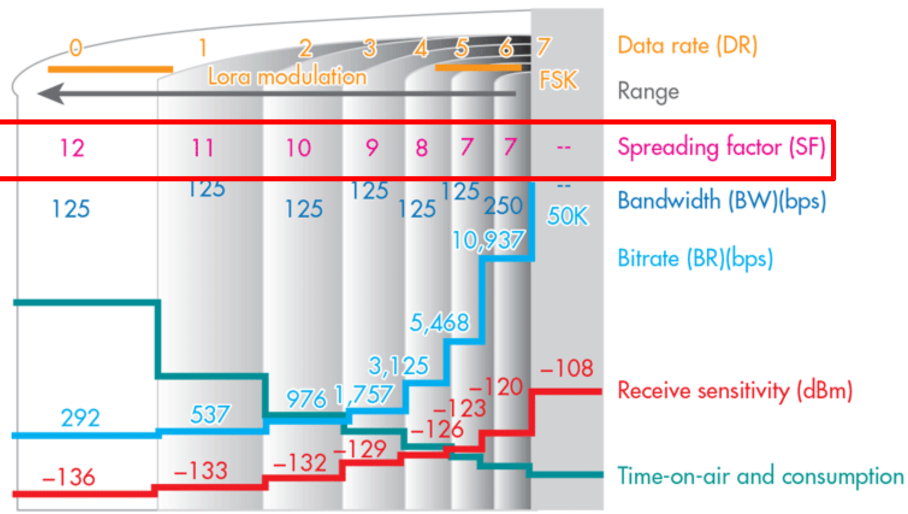
The price to pay!

HopeRF RFM series



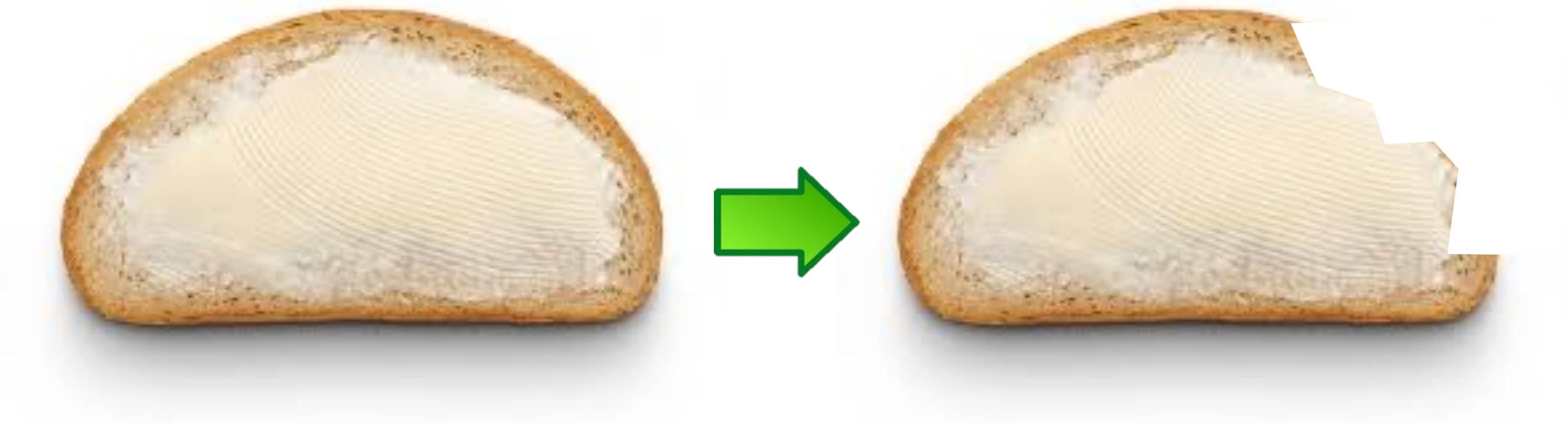
- **The price to pay for LPWAN**
- LoRa radio has very low throughput
  200bps – 37500bps
  0.2kbps – 37.5kbps
- Spreading Factor ↗ Sensitivity ↗ time-on-air ↗



WiFi 802.11n: 450 000 000 bps (450Mbps)
WiFi 802.11g: 54 000 000 bps (54Mbps)
Bluetooth3&4: 25 000 000 bps (25Mbps)
Bluetooth BLE: 2 000 000 bps (2Mbps)
3G/4G : 20Mbps-200Mbps
LoRa : 200bps – 37500bps (0.0002 –0.0375Mbps)
3G/LoRa ratio: 20,000,000bps/200bps = 100000!

DISTRIBUTE to be more robust!

The buttered toast analogy



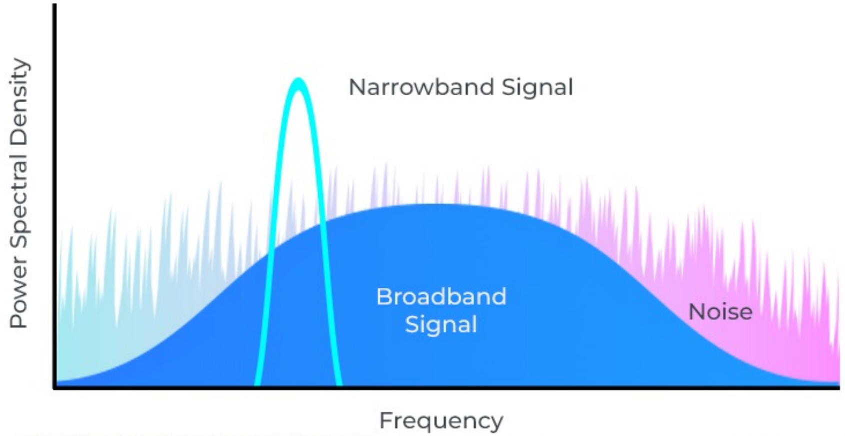
- Assuming you could get back ALL your butter, how much butter did you loose?
- This is the idea behind **spread spectrum** techniques: the more you "spread", the more it is robust to interferences

Another solution: BE INVISIBLE!

- **Ultra-narrow band** (UNB) of about only 100Hz (e.g. SigFox) SIGFOX
- High frequency diversity from one message to another
- Narrowband reduces noise and increases transmission quality
- **But decoding is much more complex…**

More than 1000 times smaller!

	LoRa	SIGFOX
Frequency band	868/915 MHz	868/915 MHz
Physical layer	CSS - Chirp Spread Spectrum	UNB – Ultra Narrow Band
Spreading factor	$2^7 - 2^{12}$	NA
Channel bandwidth	125 kHz to 500 kHz	100 Hz (UL) 600 Hz (DL)
UL (upload) data rate	29-50 kbps	100 bps
DL (download) data rate	27-50 Kbps	600 bps
Efficiency (bit/s/Hz)	0.12	0.05
Doppler sensitivity	Up to 40 ppm	Unconstrained
Max Tx power	EU: +14 dBm US:+23 dBm	EU: +14 dBm US:+23 dBm
Max link budget	156 dB	156 dB



Sigfox Ultra Narrow Band

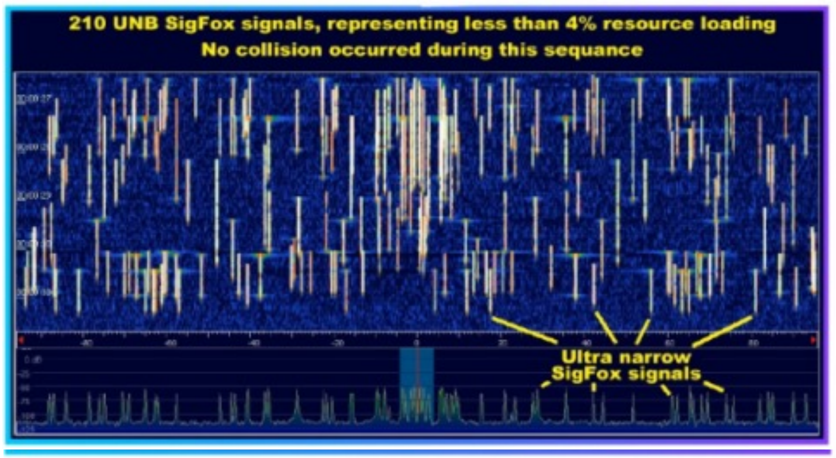


Image credit: Spakfun and https://www.linuxembedded.fr/2020/03/introduction-a-sigfox

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Where to search?

- The well known "needle in a haystack" problem
- You need to have some clue
  - Top?
  - Bottom?
  - Left?
  - Right?
  - Middle?
  - …
- Or be able to look everywhere … at the same time!

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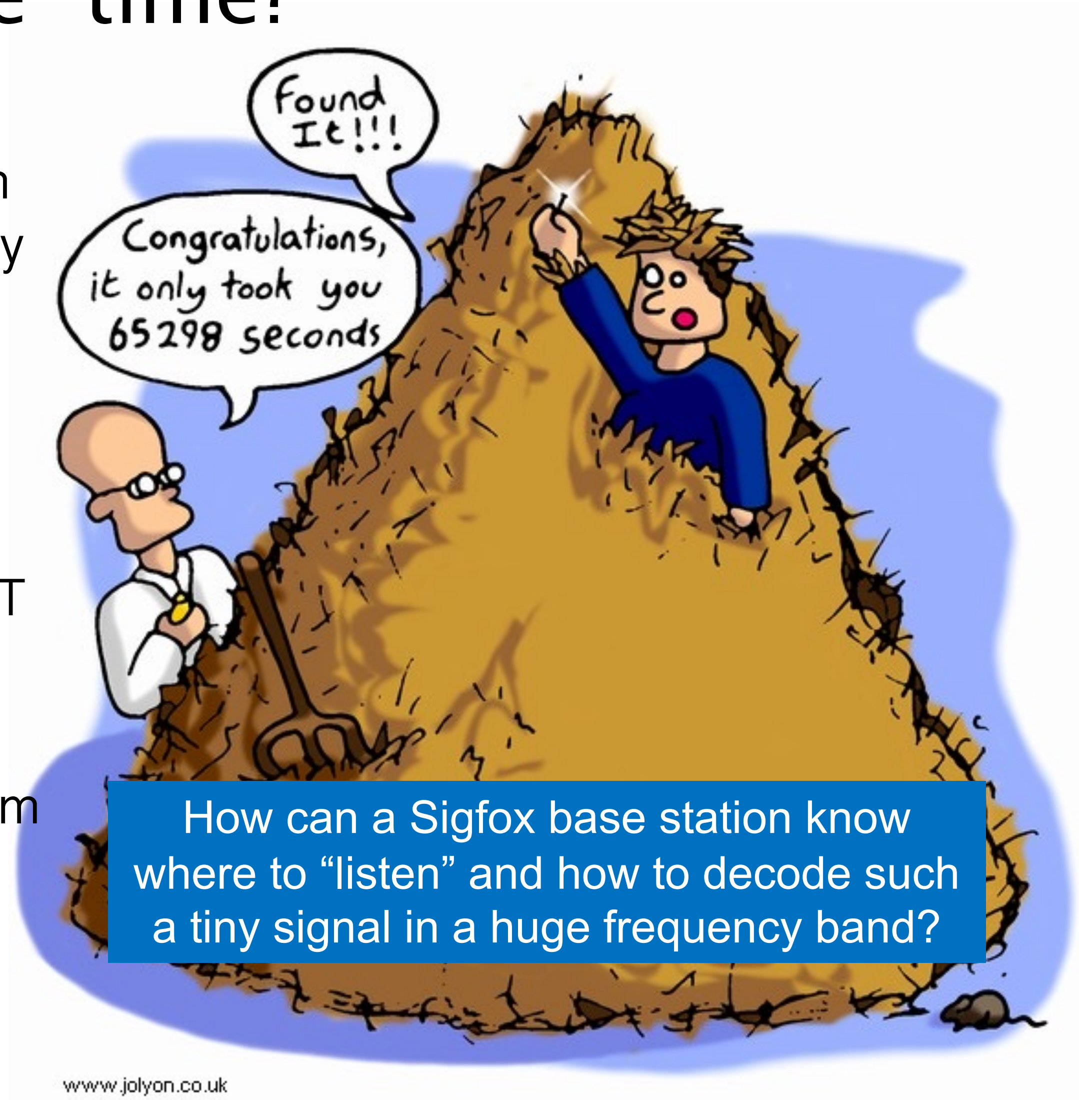
Find in a "reasonable" time?

- Sigfox base stations operate with very wideband receivers (typically tens of kHz to several MHz).
- **Continuously monitor the whole usable ISM band → need high-end & costly hardware!**
- Detect “energy spikes” using FFT + envelope detection
- Appears as a thin peak in the base station’s frequency spectrum
- Identifies candidate signals & applies Sigfox demodulation



How can a Sigfox base station know where to “listen” and how to decode such a tiny signal in a huge frequency band?

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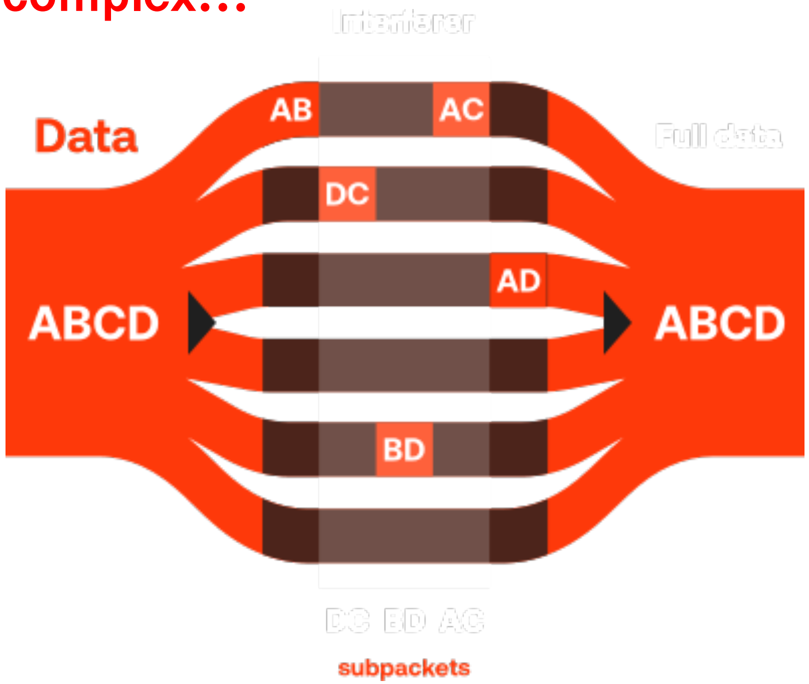
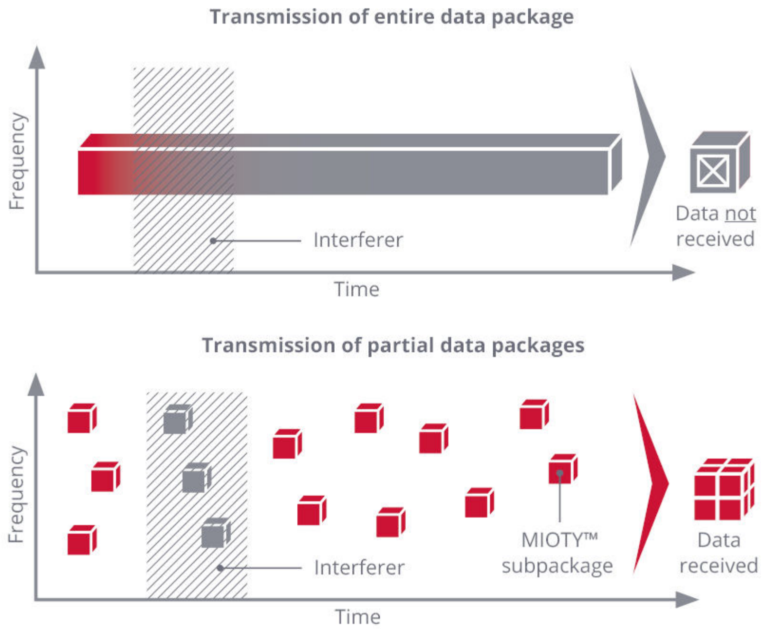
Even smarter! Distribute AND be invisible!

- A new comer: mioty technology based on Telegram-Splitting-UNB
- **Again, decoding is much more complex…**

mioty alliance



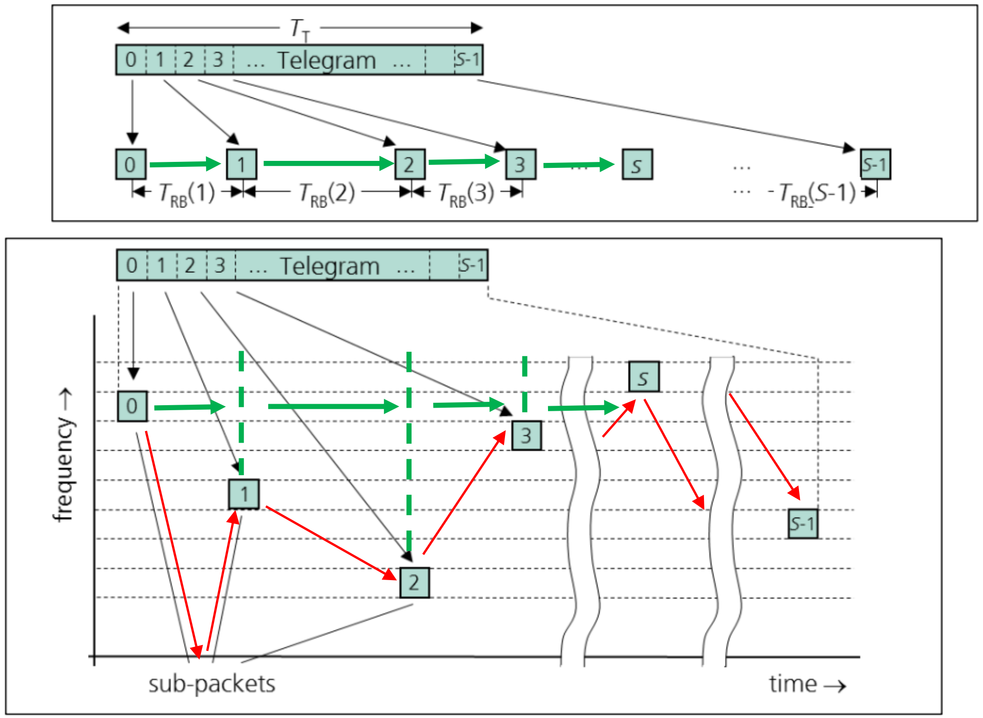


Prof. Congduc Pham http://www.univ-pau.fr/~cpham

Telegram-Splitting

- Developed by Fraunhofer IIS – now an ETSI standard
- **Randomness everywhere**! Random time intervals & frequency carriers

- Packet (telegram) split into a minimum of 24 burst (core frame)
- Each burst is sent on a different frequency (up to 34)
- Each burst is separated from the others by a certain time
- Each burst includes 1/3 of sync data (but no identification)
- Information is triplicated to support collision
- Creates time and frequency diversity with redundancy



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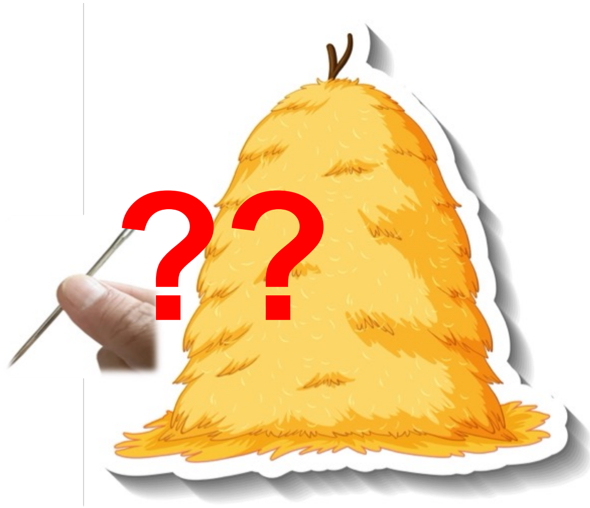
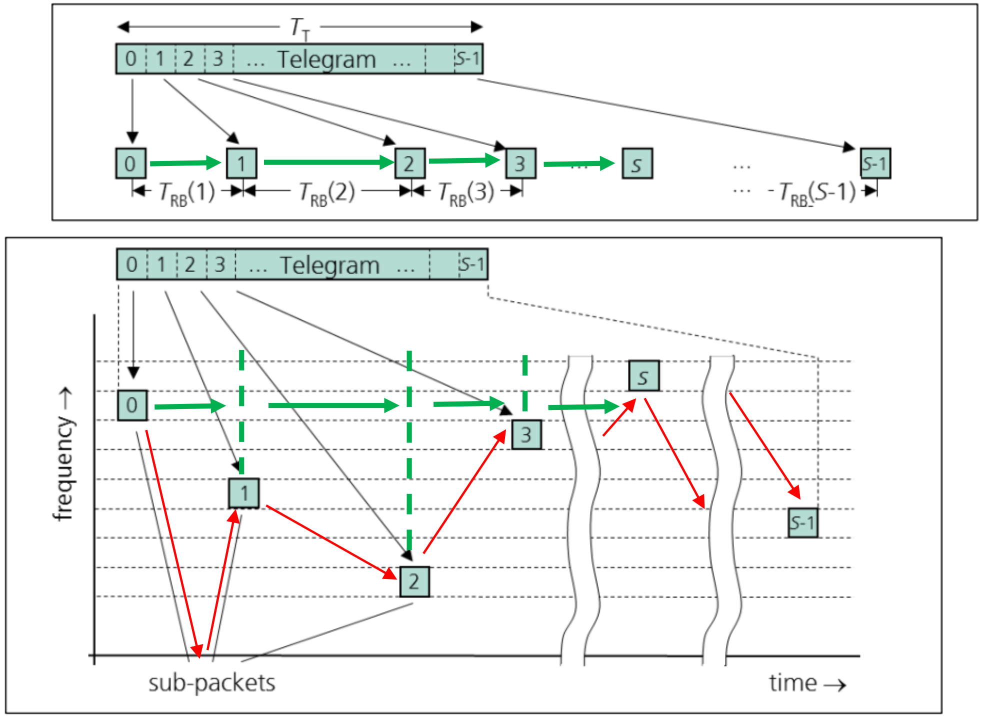
Needle in a haystack?

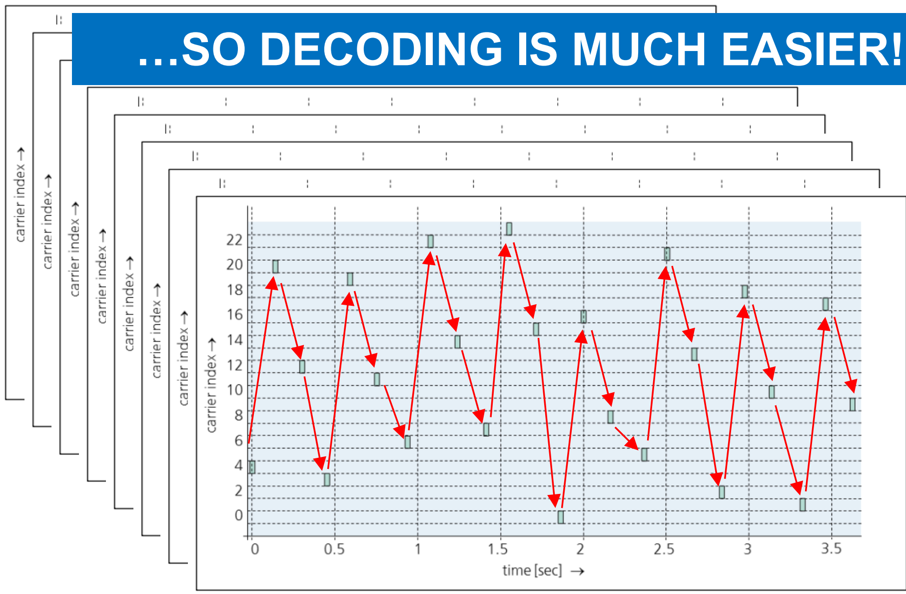


- mioty uses TS-UNB, so do we have the "needle in a haystack" issue?
- mioty uses time and frequency diversity



BUT USES 8 PRE-DEFINED PATTERNS

...SO DECODING IS MUCH EASIER!



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LoRa, Sigfox, mioty: common point?

- LoRa: Spread Spectrum
- Sigfox: Ultra-Narrow-Band
- mioty: Ultra-Narrow-Band + Telegram Splitting

WHY ALL THESE HASSLES?

BECAUSE THEY USE UNLICENSED BANDS!

AND SO?

ANYBODY CAN USE THESE BANDS, NEED TO BE MORE ROBUST & SMARTER!

WHAT IF LICENSED BAND?

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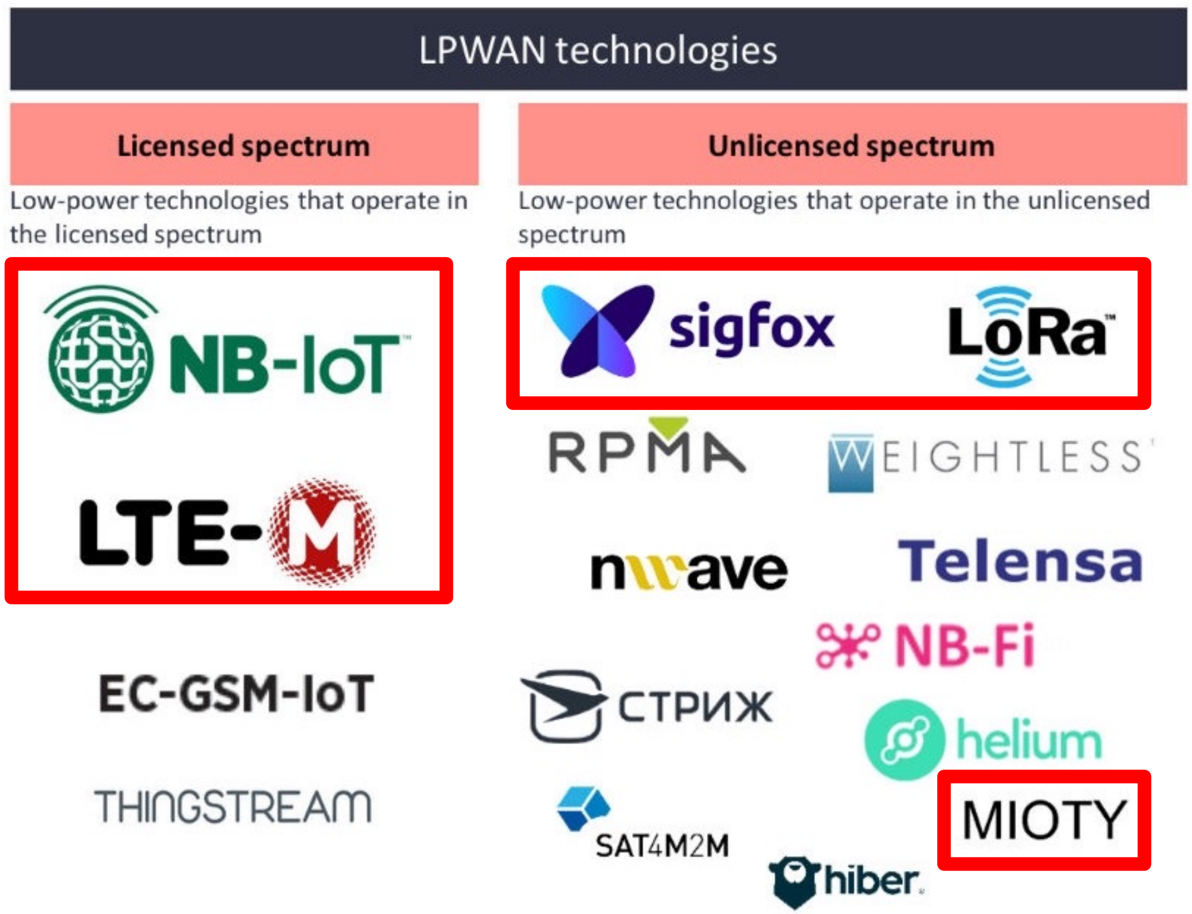
The LPWAN actors

Historically, LTE (4G) technology

Included in 5G Massive IoT family (mMTC)



Source: IoT Analytics LPWAN Market Report 2018 - 2023

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NB-IoT & LTE-M solutions

- They both come from **mobile cellular** technologies
- They operate in **licensed bands** assigned to operators
  - → Quality-of-Service needs (somehow) to be provided
- They use **scheduled** channel access
  - → Devices cannot transmit whenever they want
  - → Base station assigns radio resources and transmission times
  - → When, how long, and on which subcarriers (e.g. frequency)

LTE-M is optimized for mobile, higher-data, low-latency IoT with support for voice and handover→ ~lightweight 4G for IoT

NB-IoT is optimized for massive, deep-coverage, low-power, low-data, static IoT → specifically designed for IoT

What your mother never told you…

- Despites all these smart mechanisms, obtaining several kms range at low power is still very challenging!

HIGH OVERHEAD, LOW TRANSFER EFFICIENCY!

REDUNDANCY & REPETITION FOR ROBUSTNESS

LORAWAN RECOMMENDS 2-3 REPETITIONS, SIGFOX USES 3

MIOTY'S OVERHEAD IS USUALLY 300-500%

NB-IoT CAN HAVE FROM 2 TO 128 REPETITIONS (DEEP)

LTE-M CAN HAVE 2, 4 OR 8 REPETITIONS

2025: the 4 (3?) that counts!

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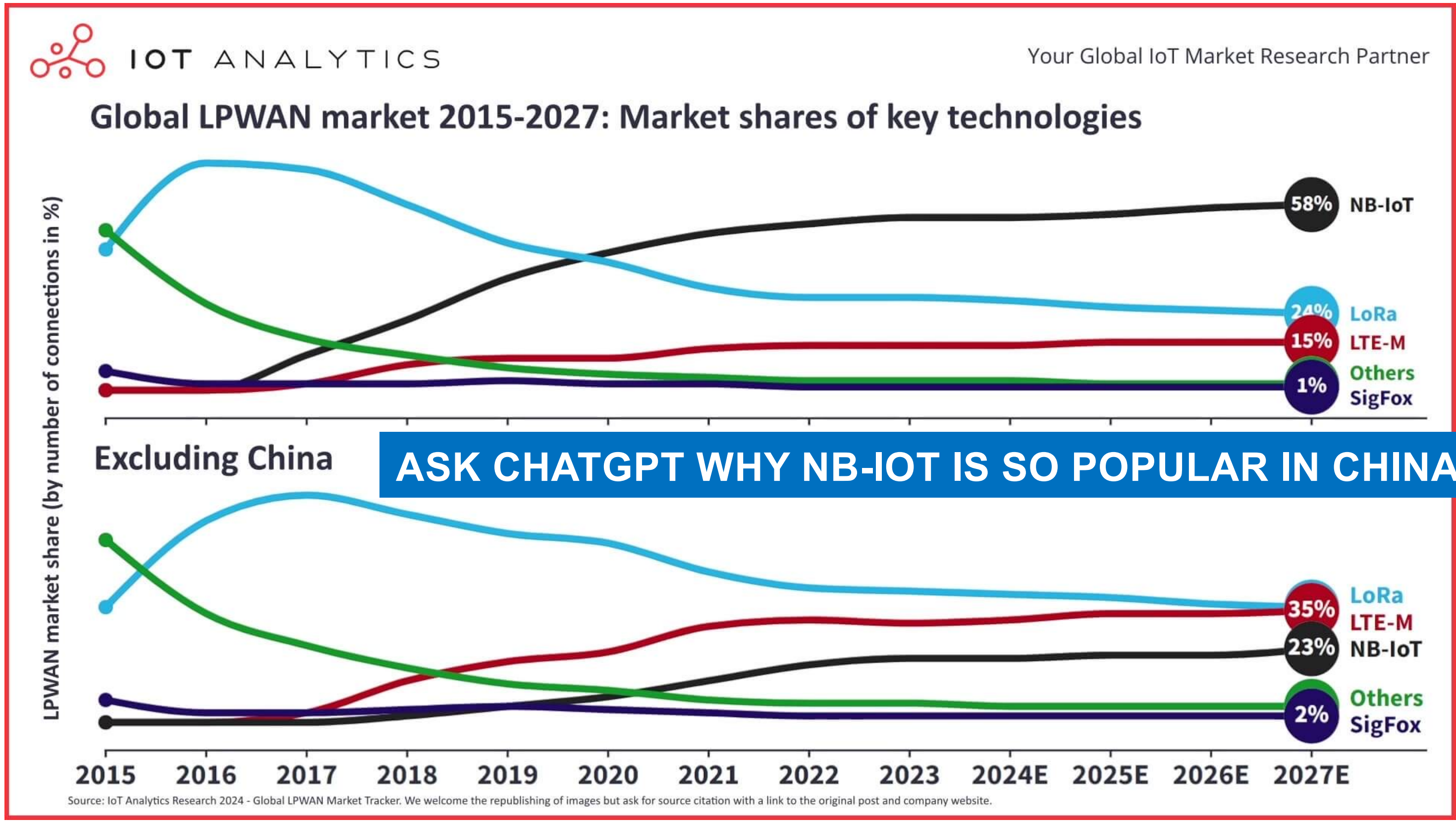
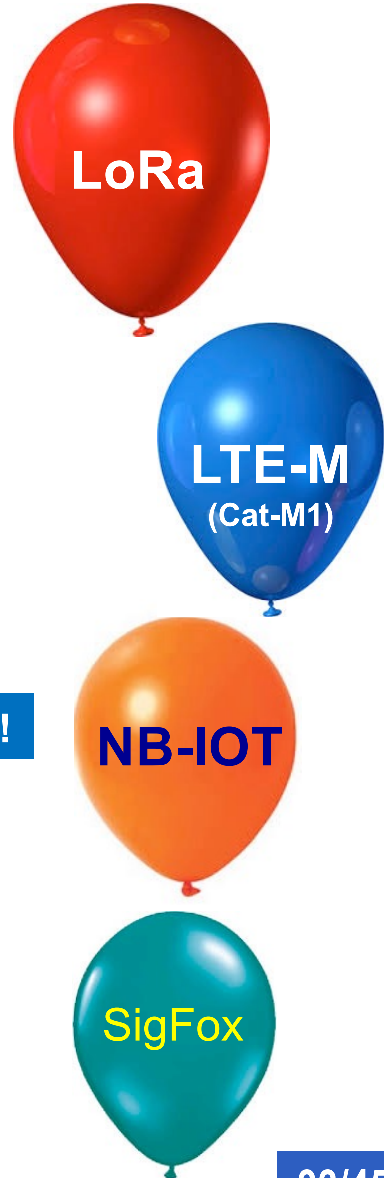


ASK CHATGPT WHY NB-IOT IS SO POPULAR IN CHINA!



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Go for standard or not?

- Opening an interesting question!

Technology	Open Standard?	PHY	Operator Required?	Private Network?
LoRaWAN	✓ Yes	LoRa = proprietary	✗ No	✓ Yes
mioty	✓ Yes	✓ Standard	✗ No	✓ Yes
Sigfox	✗ No	Proprietary	✓ Yes	✗ No (few exceptions)
NB-IoT	✓ Yes (3GPP)	Standard	✓ Yes	✗ No
LTE-M	✓ Yes (3GPP)	Standard	✓ Yes	✗ No

THE MAIN NEED IS INTEROPERABILITY!

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How to decide?

SILICON LABS
CONNECTED INTELLIGENCE

LPWAN Landscape

Standards vs. Proprietary Solutions

THIBAUT COLIN

- 9 years at Silicon Labs
- R&D Manager
- Working on Wi-SUN
- Member of the SubGig and Proprietary Organization

Journées LPWAN 2025
Rennes

Standards-Based LPWAN Solutions

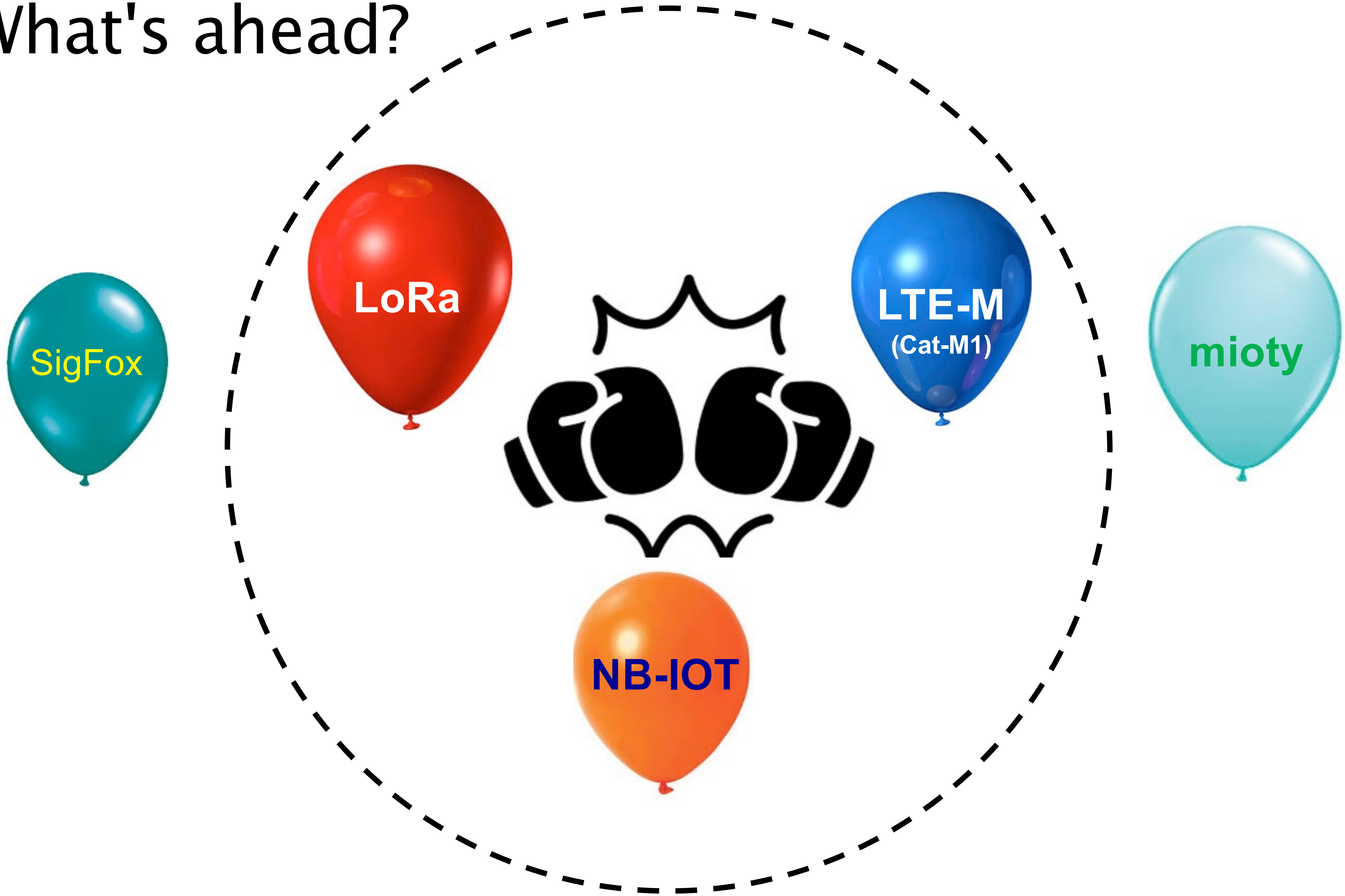
- **Ecosystem**
  - Open and flexible
  - Collaborative, favor interoperability
- **Innovation**
  - Distributed across multiple participants
- **Inertia**
  - High: it often takes time to drive changes
  - Guarantees a certain stability
- **Efficiency**
  - Based on compromises: depending on the network, it can be either an advantage or a drawback

Proprietary LPWAN Solutions

- **Ecosystem**
  - Integration is seamless across the vendor's products.
  - Ease of use and time to market
  - Closed
- **Innovation**
  - Controlled and centralized
  - Can be more versatile
  - Harder for the end user to influence decisions
- **Inertia**
  - Low or high: Depends on the customer / provider relationship
- **Efficiency**
  - Vertical optimization: Can be tailored to the targeted applications


2025, billions of IoT devices are deployed worldwide !

What's ahead?



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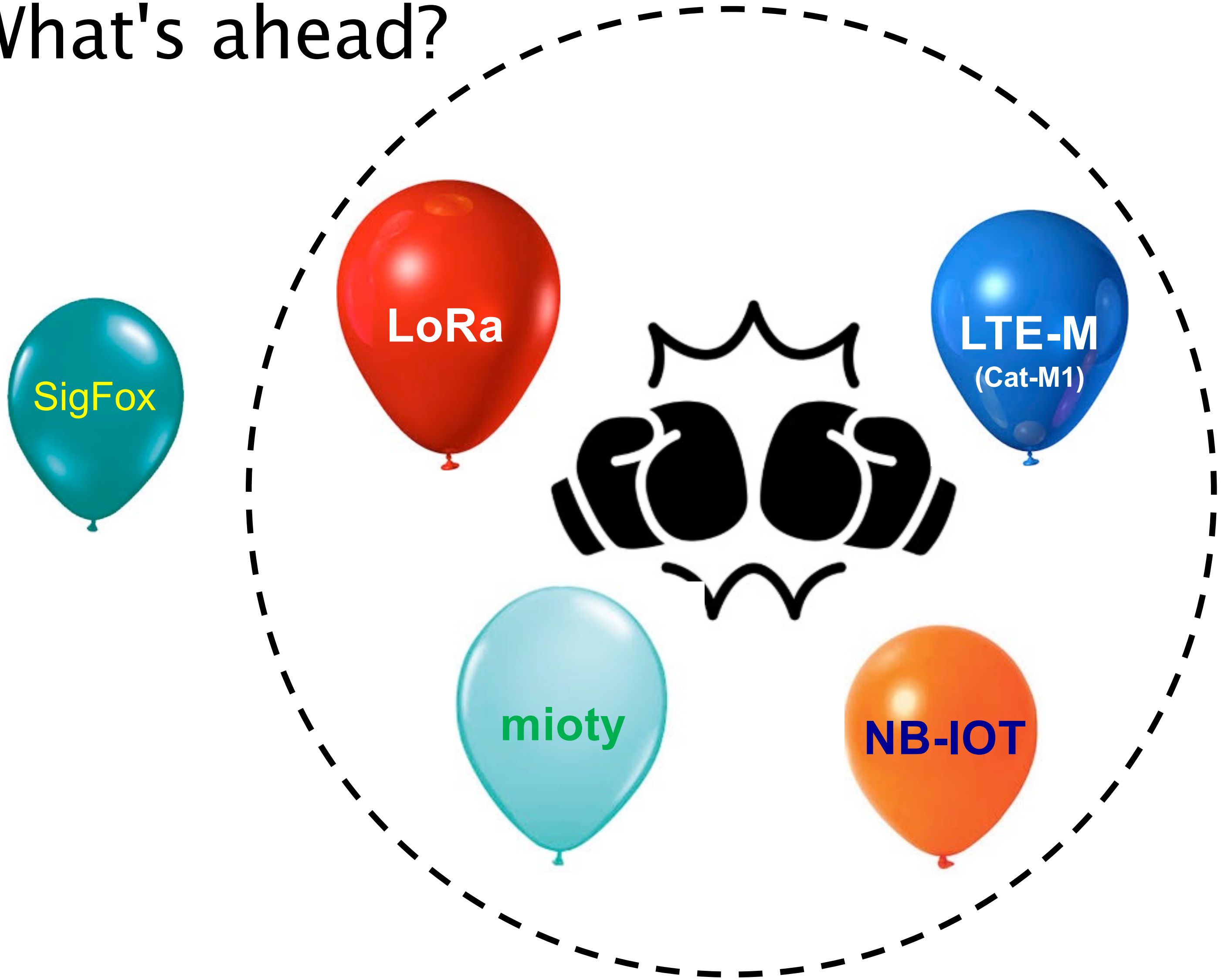

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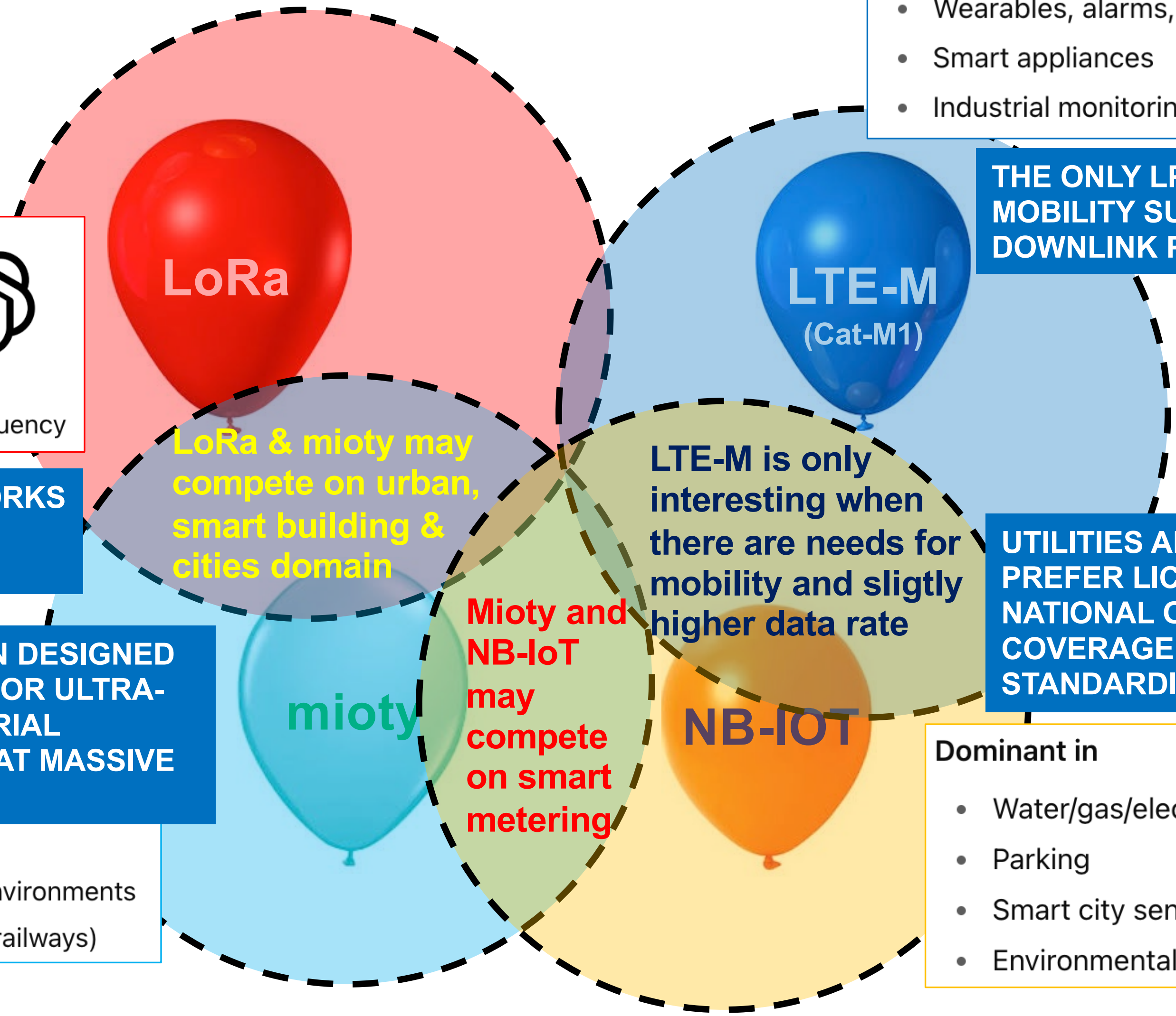
What's ahead?



Dominant in

- Agriculture
- Municipal or campus networks
- Smart buildings
- Logistics sensors with low message frequency

EASY TO DEPLOY, PRIVATE NETWORKS LOW COST, AND FLEXIBILITY THAT OPERATORS CANNOT MATCH

Dominant in

- Trackers (logistics, pets, assets)
- Wearables, alarms, emergency devices
- Smart appliances
- Industrial monitoring requiring more data

THE ONLY LPWAN WITH REAL MOBILITY SUPPORT AND DOWNLINK PERFORMANCE

THE ONLY LPWAN DESIGNED FROM DAY ONE FOR ULTRA-ROBUST INDUSTRIAL ENVIRONMENTS AT MASSIVE SCALE

Dominant in

- Oil & gas
- Mining
- Industry 4.0
- High-noise or high-interference environments
- Large-area monitoring (pipelines, railways)

UTILITIES AND GOVERNMENTS PREFER LICENSED SPECTRUM, NATIONAL OPERATOR COVERAGE, AND LONG-TERM STANDARDIZATION

Dominant in

- Water/gas/electricity smart metering
- Parking
- Smart city sensors
- Environmental monitoring

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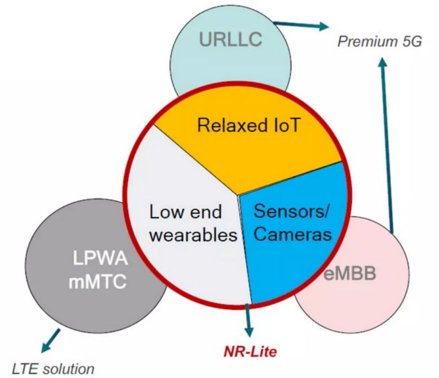
Anything new at sight?

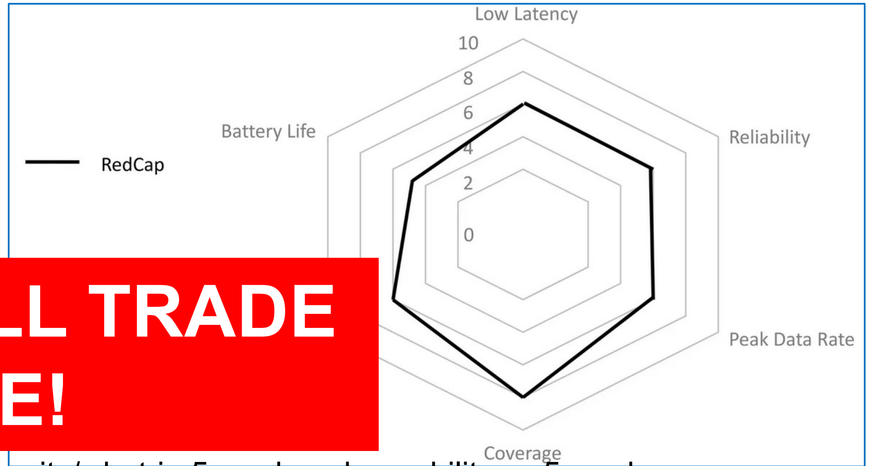
LET'S SEE…

- 5G RedCap – A little quizz?

  - ✗ 5G Red Cap covers all needs!
  - ✗ 5G Remote Edge Device – Connected Appliance Protocol
  - ✗ 5G Radio Early Data – Channel Access Procedure
  - ✓ 5G Reduced Capability
  - ✗ 5G Robust Embedded Demodulator – Cognitive Adaptive PHY
  - ✗ 5G Redundant Encoded Datagram – Channel-Agile Partitioning



WHO WILL BE THE USERS…



FORESEEN TO REPLACE LTE-M

DANGER: JACK OF ALL TRADE IS A MASTER OF NONE!

Figures from https://www.everythingrf.com/community/what-is-5g-reduced-capability-or-5g-redcap

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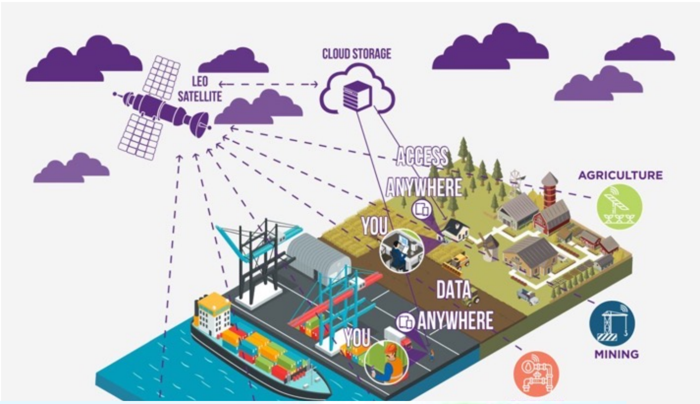
Going beyond terrestrial network!

With no obstacle, we can reach a satellite!

https://www.everythingrf.com/community/what-is-satellite-iot-connectivity



https://www.smartsight.in/industry-insights/iot-for-wildlife-conservation-and-environmental-monitoring/

EchoStar XXI satellite

Formely TerreStar 2, launched in 2017

Geostationary satellite, S-band 2GHz

Huge transponder of 18 meters!

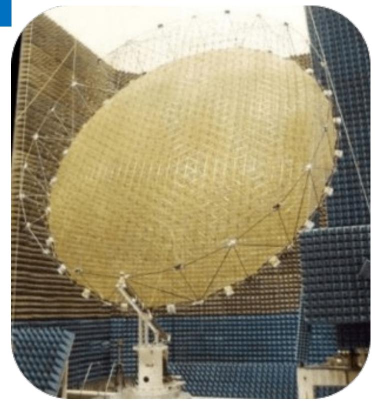
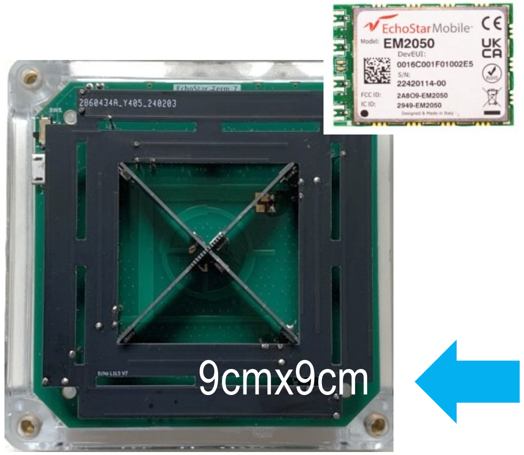
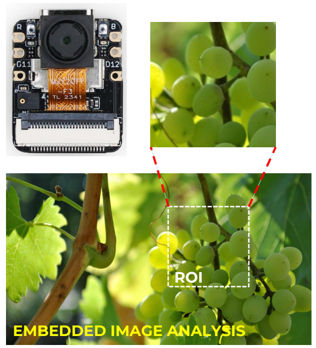


Image credit: EchoStar





Low-cost satellite IoT

F. Ferrero & M. T. Nguyen

LEAT laboratory, University of Nice, France

https://github.com/nguyenmanhthao996tn/LEAT-EchoStar-Terminal-BSP

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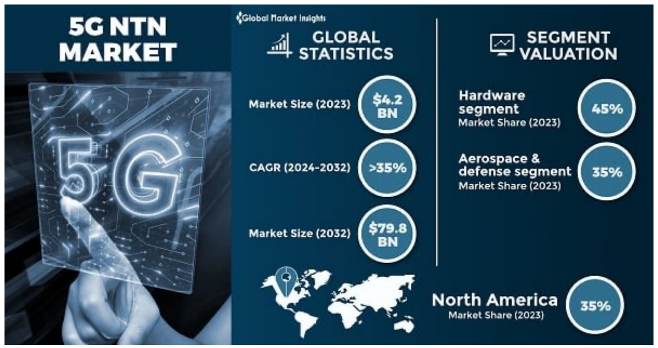
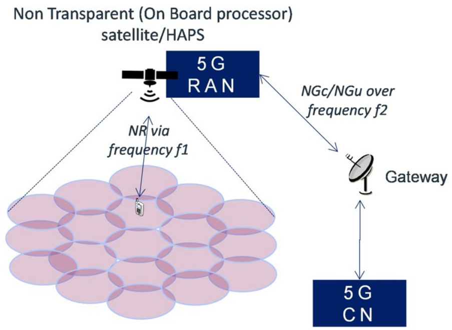
IoT connectivity battle going to space!

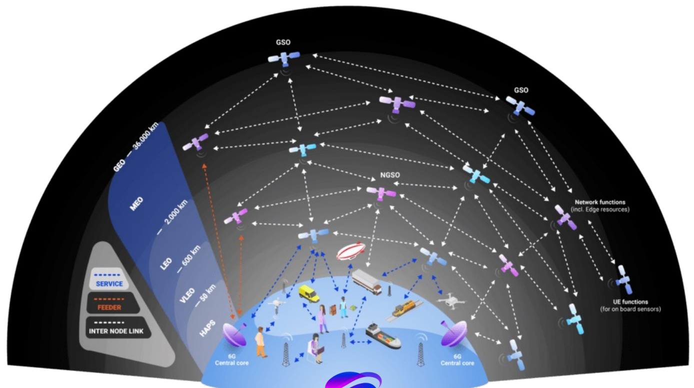
- Non-Terrestrial Networks (NTN) & Direct-to-Satellite (DtS) IoT
- DtS version of LoRa PHY for more robustness → Semtech LR-FHSS
- mioty can easily be extended to DtS communications
- NB-IoT for DtS is challenging but possible

BUT TRADITIONAL CELLULAR ACTORS WANT THEIR SHARE!

- Cellular Network standards such as 5G NTN and future 6G with **native** NTN support







6GNTN

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What about research?

- PHY & MAC Layer Optimization
- Energy optimization
- Interference mitigation
- Massive network scalability
- Security & privacy
- AI/ML-driven adaptive networking
- Geolocation & mobility enhancement
- Industrial robustness
- Multi-technology integration with 5G

MY MAIN INTERESTS

How to reduce congestion?

How to support very dense scenarios?

Coexistence of technologies in the ISM bands

Spectrum sharing strategies

Conclusions

- **LPWANs are here to stay!**
- Technology maturation is already here!
- From application perspective, it is great!
- From research perspective, well…**we can study, evaluate, propose**…
- … but will be marginal change to "standards" (see Ethernet, WiFi, …)
- Innovative applications with more open technologies
  - Collaboration between devices in P2P & mesh
  - Hybrid and continuity of access: multi-radio, terrestrial, non-terrestrial, …
- **Ad-hoc** deployments with **application-specific mechanisms** in **agriculture, agroecology, environment, wildlife, …**

STILL EXCITING RESEARCH BEFORE I RETIRE!