
Sensoren herkennen
roepen en zingen.
Z Z Z
Stiltezone
Veilig thuis!
Hier slaapt Elza (35)
1-VER-244

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l-o-creaTures for sustainable wireless sensing – in ‘a’ G

Jan.12th 2026

Liesbet Van der Perre, Liesbet.vanderperre@kuleuven.be

Special thanks to Jona Cappelle and Gilles Callebaut

AMBIENT-6G & SUSTAIN-6G partners

AMBIENT-6G SUSTAIN 6G

I-o-creaTures for sustainable applications: tailor and study

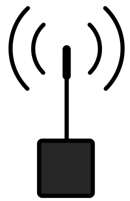
Autonomy & Wireless Technologies: Problem and Solution?

Towards Sustainable Wireless Sensing – in ‘a’ G?

INTERNET *OF*

THINGS

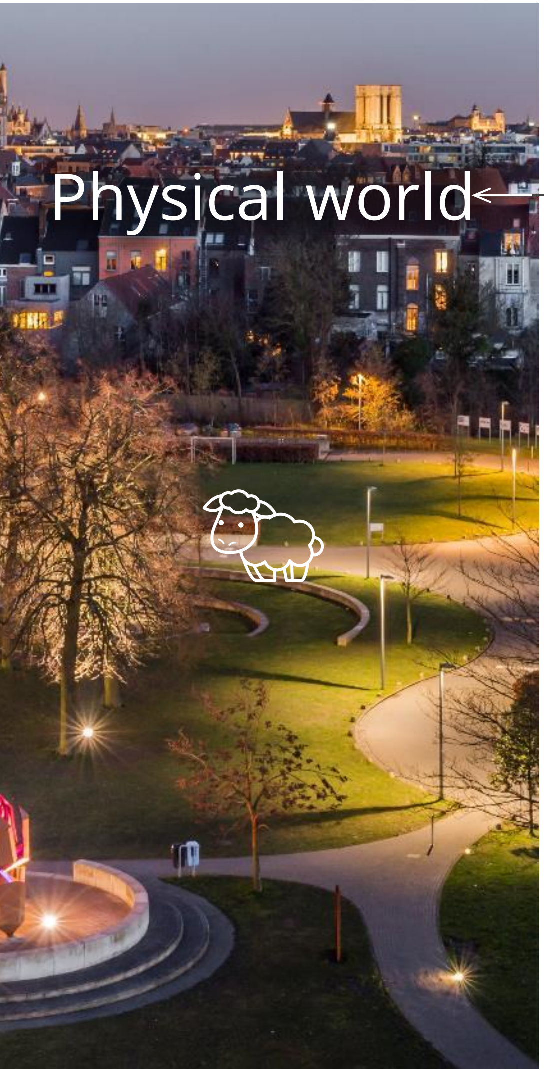
IoT node
Hosting sensors / actuators



Communication

Cloud
Infrastructure

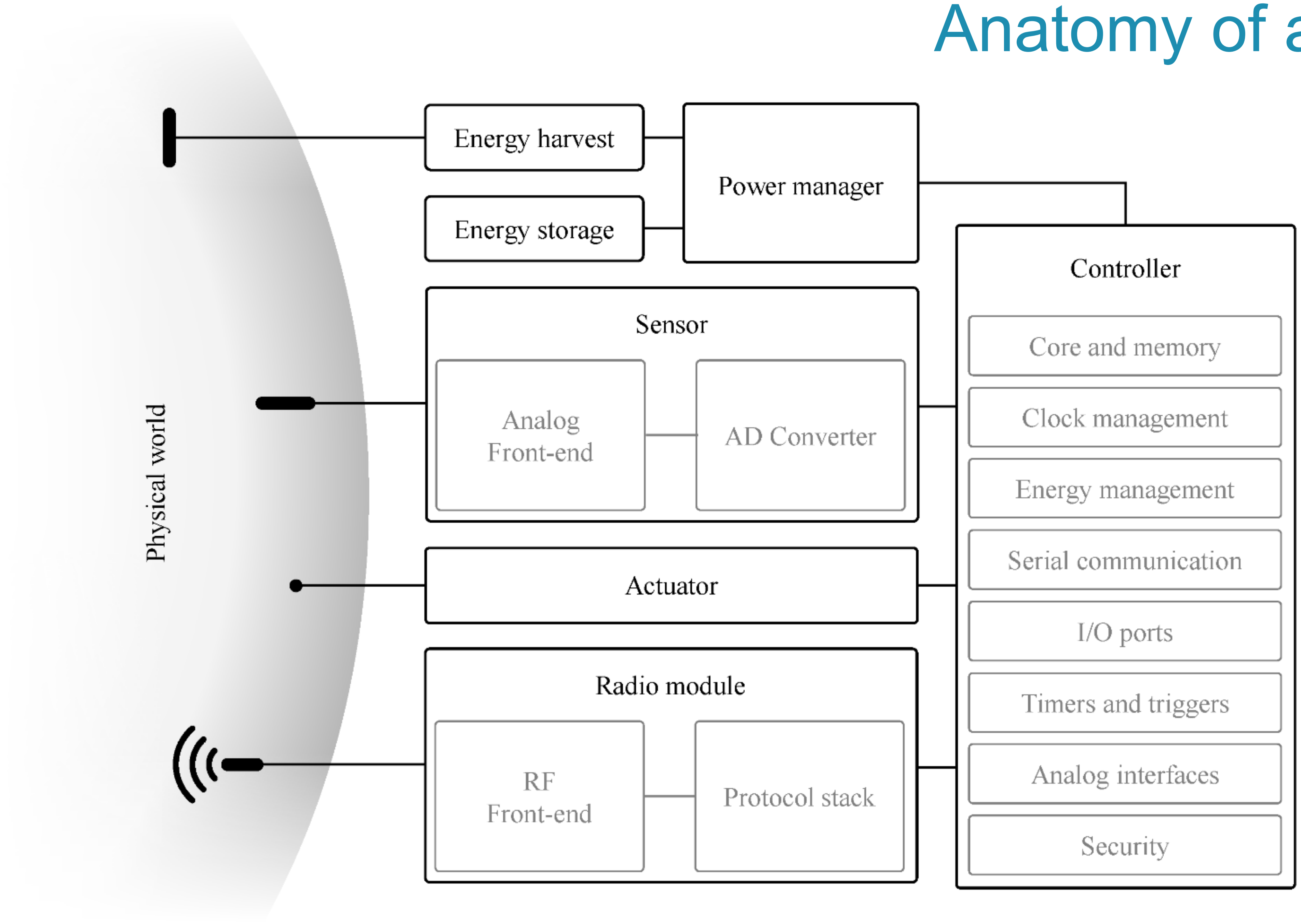
The habitat of the IoT node = physical world



Sensors with interfacing electronics ⟷ Microprocessor with signal processing ⟷ (Wireless) transceiver

Energy and power

Anatomy of an IoT node: functions



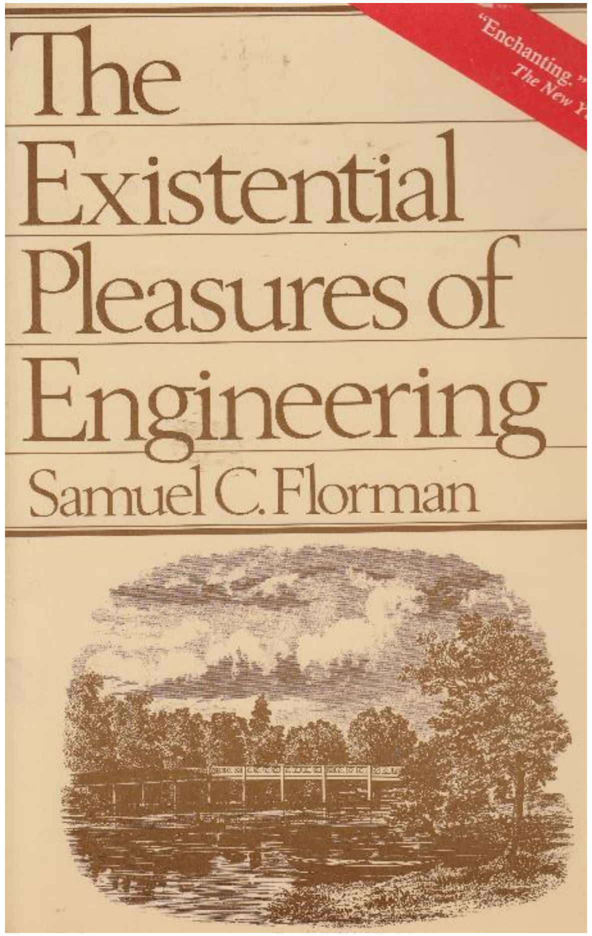
→ creative designs
to tailor for species

IoT design and the existential pleasures of engineering

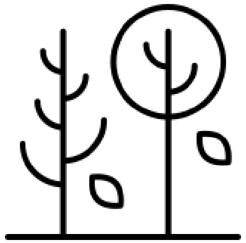
“The art or science of making practical application of the knowledge of pure science’

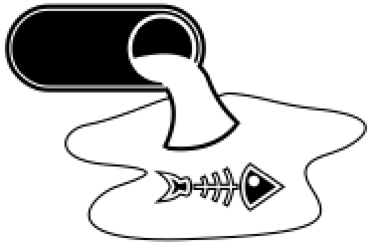
“…they study the sciences and use them to solve problems of practical interest, most typically by the process we call creative design’

..and existential pleasures of engineering education



IoT can help to address ‘hard’ problems in ‘soft‘ themes: connecting for a sustainable future

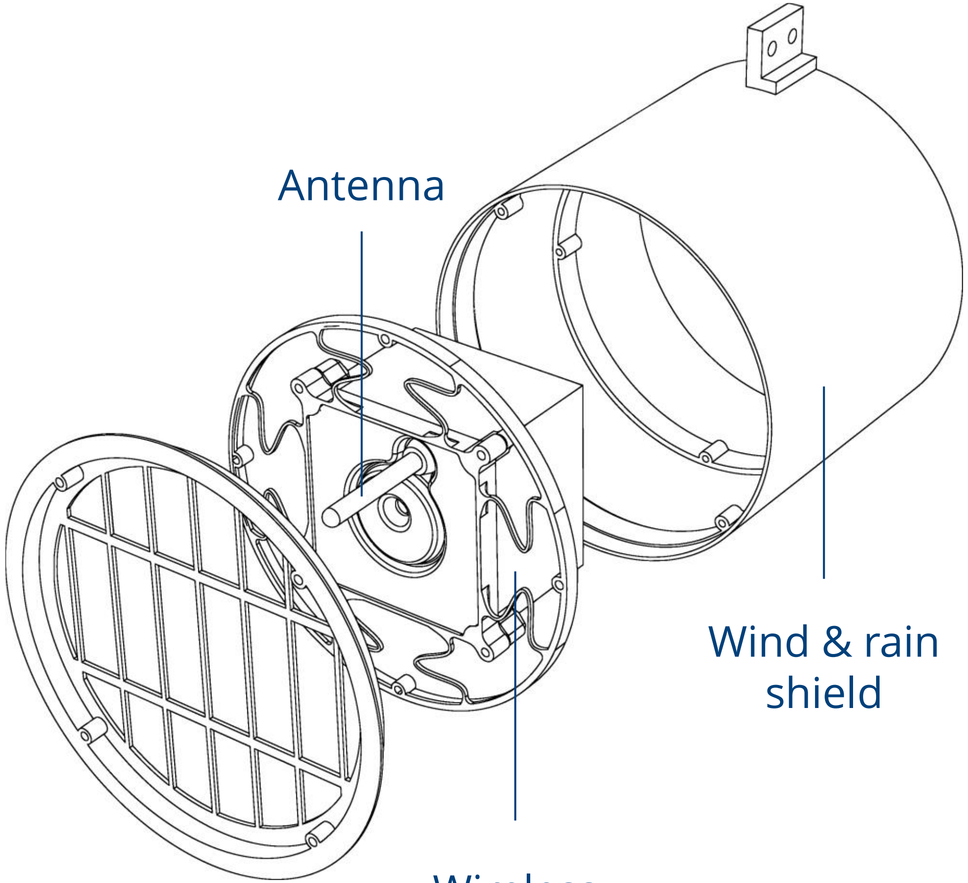




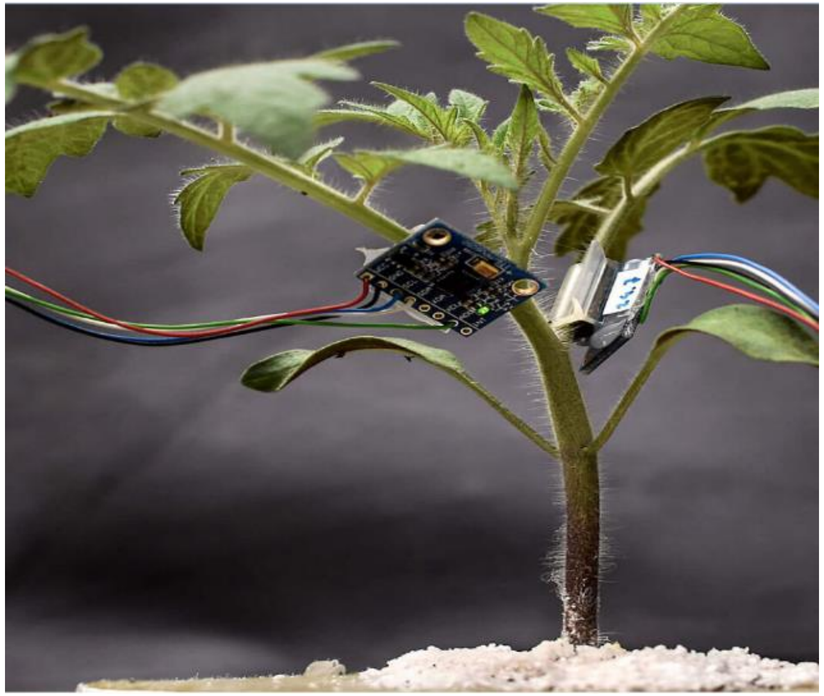
‘smart dust’ vision:

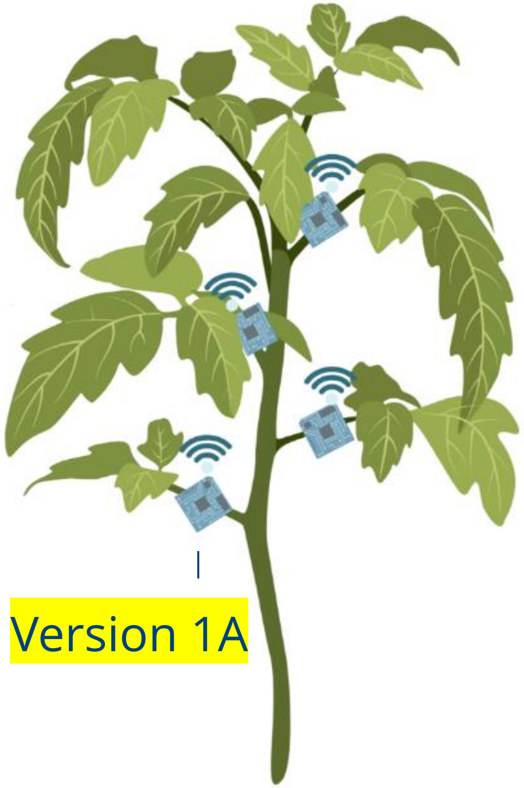
Sensors or devices few millimeters in size, and can share information over a wireless network.

IOASE: CREATING SILENCE

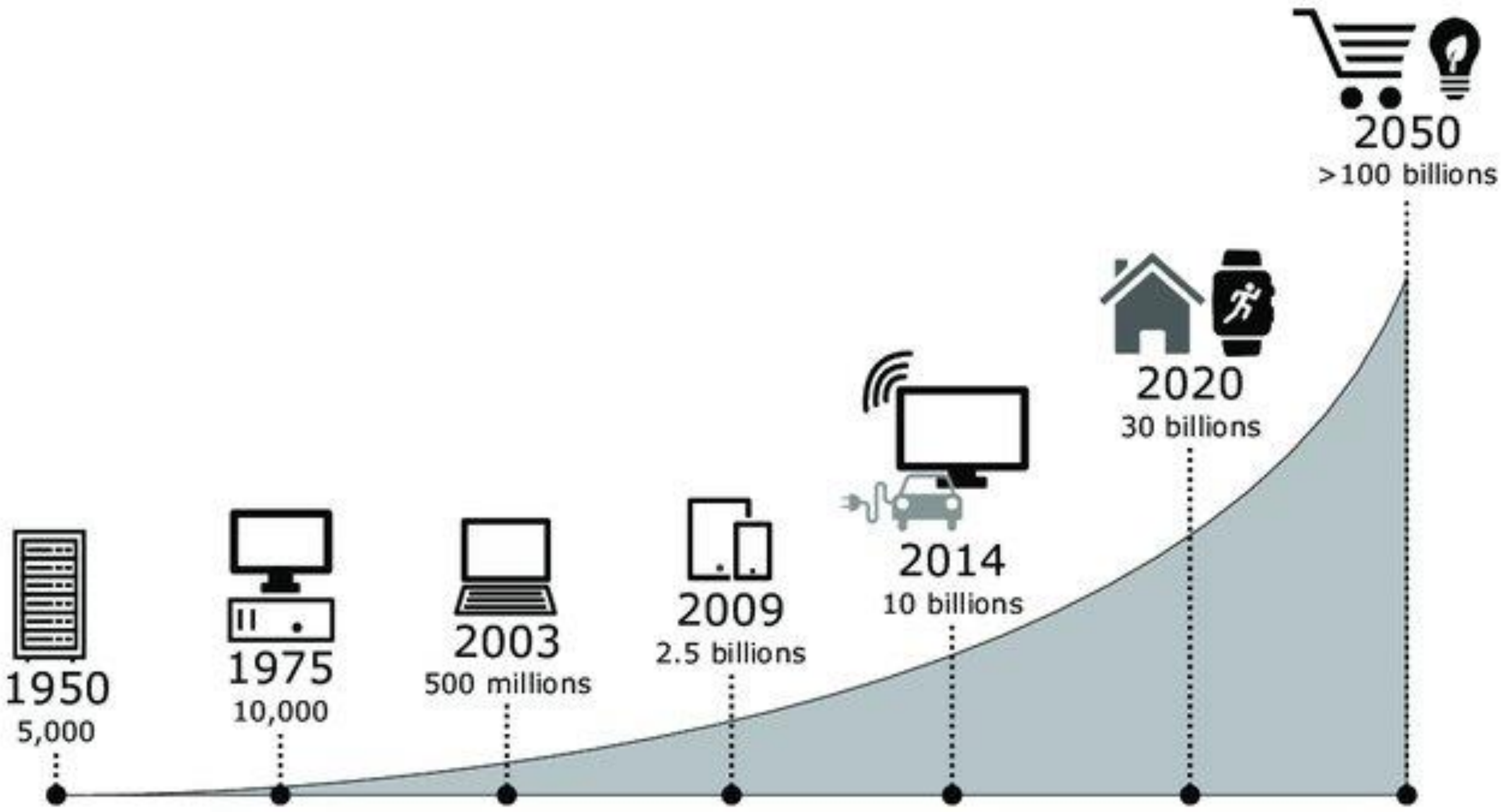


Plant movement sensor: (ultra) constraint design





The risk: from smart dust to sleep to toxic dust?



© Capra, M. et Al. (2019). Edge Computing: A Survey On the Hardware Requirements in the Internet of Things World. Future Internet. 11. 100. 10.3390/fi11040100.

The story of the elephant in the room - could be the story of IoT for sustainability?

Moreau, N. et Al.

Could Unsustainable Electronics Support Sustainability?

Sustainability 2021, 13, 6541. https://doi.org/10.3390/ su131265

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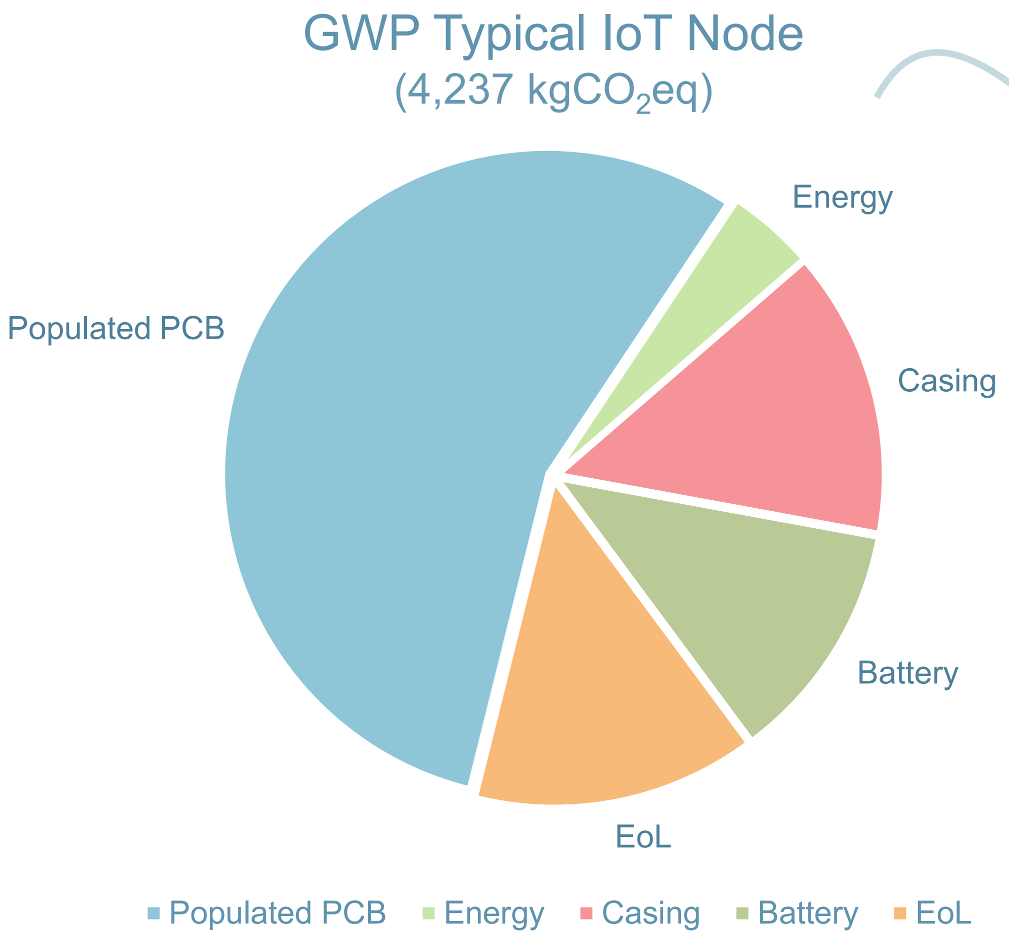
IoT node| Life Cycle Assessment (LCA)



Energy small impact

10 years operation,
mixed grid

Method used
ReCiPe 2016 v1,1 Midpoint (H)

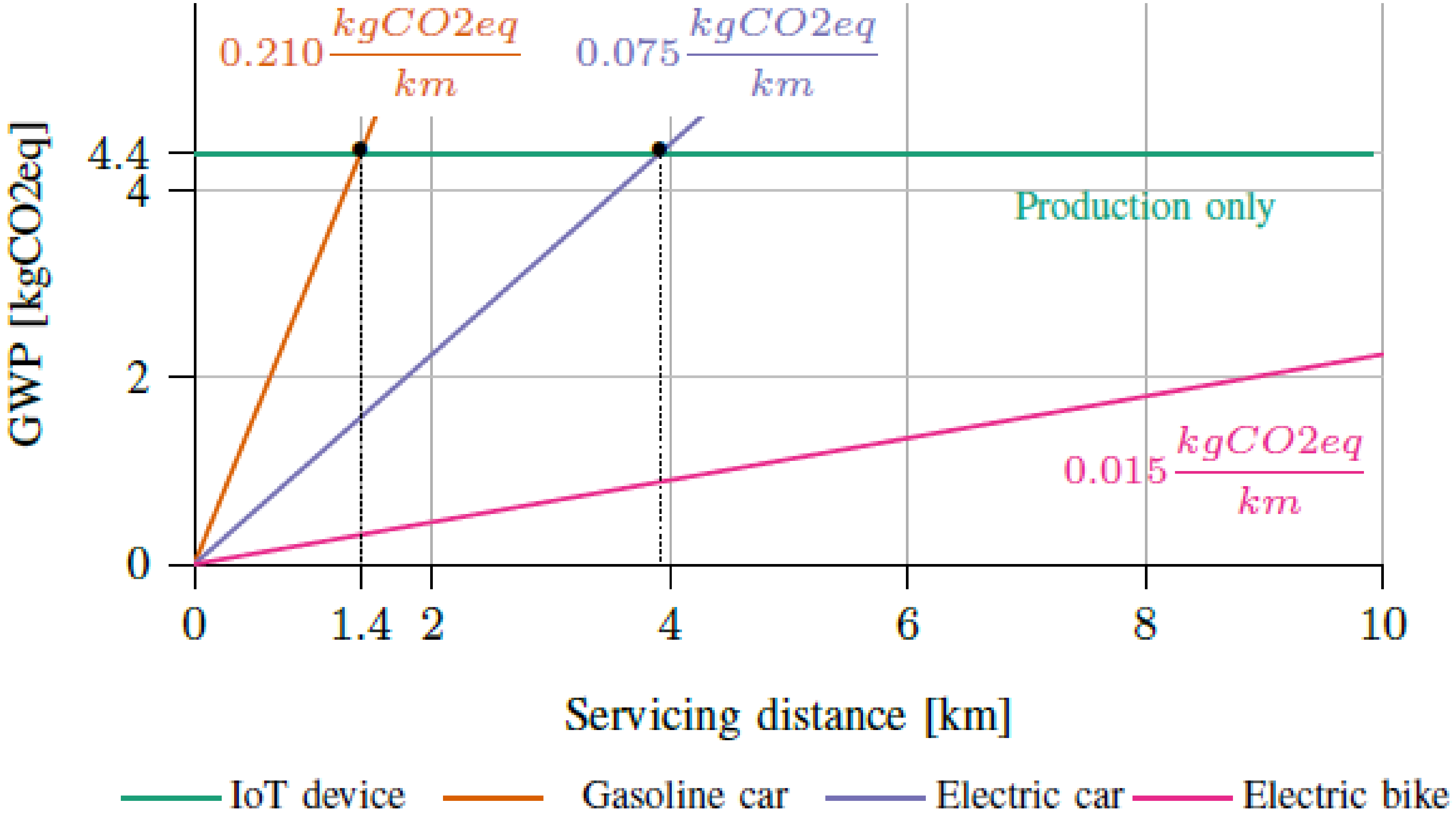
LCA | Insights – Critical thinking

Energy consumption small compared to total GWP

PCBs & ICs very big impact

Battery is toxic and finite

Impact comparison smart meter case:
IoT device versus annual manual intervention



Smart lighting case demonstrates quantitative assessment is essential.

Indoors

Study for WiFi-connected ‘Philips Hue’

‘Smart’ bulb always connected: + 3.5kWh/year
(not counting potential network-side penalty)

Net positive for 10W lamp:
only when ≥ 1 hour extra off/day

Outdoors

Study for NB-IoT connected streetlamps

Lamps consumption 80 -250W

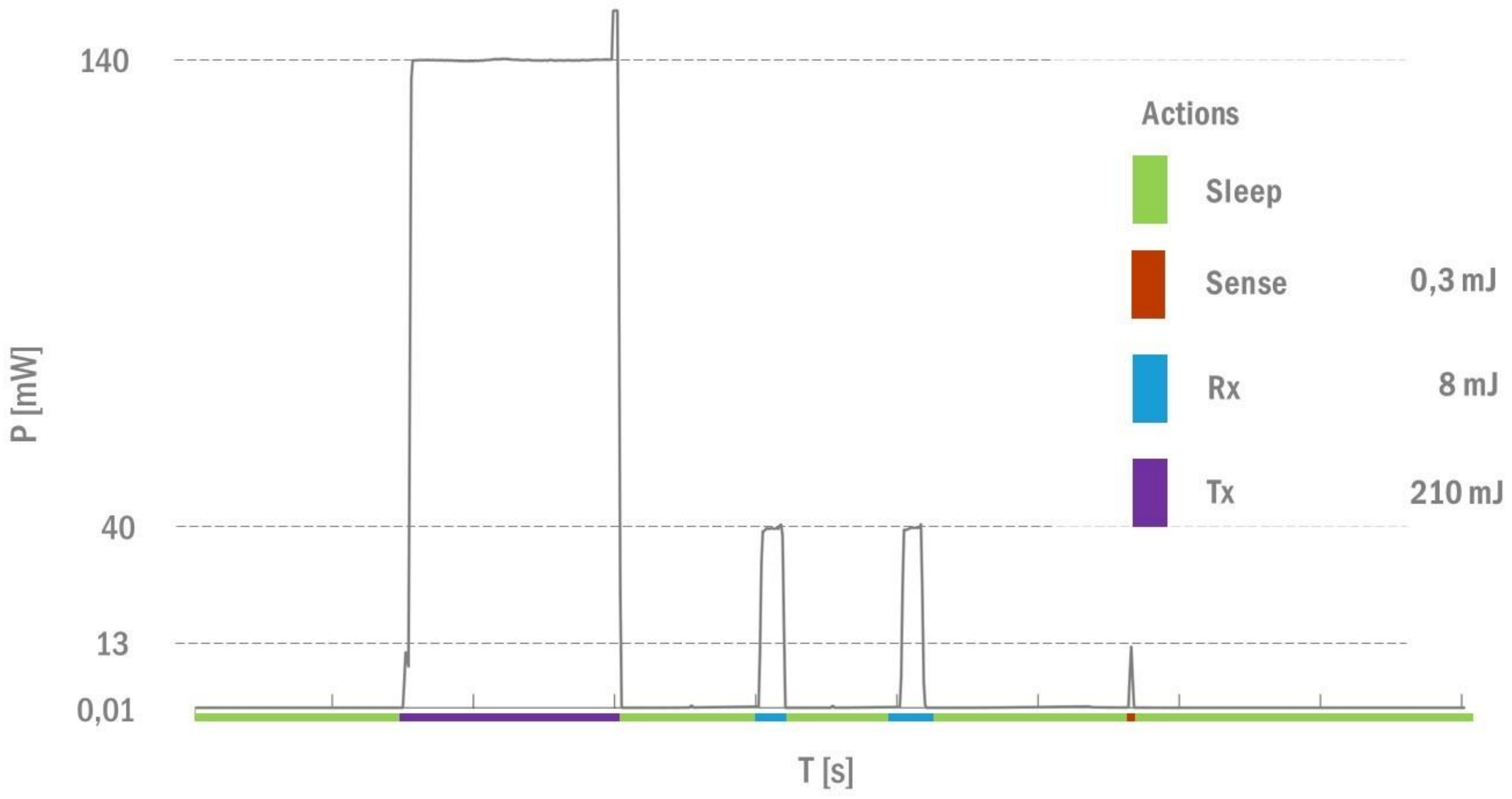
- ➔ Overall energy saving
- ➔ Also, benefits wildlife and people’s sleep quality

I-o-creaTures for sustainable applications: tailor and study

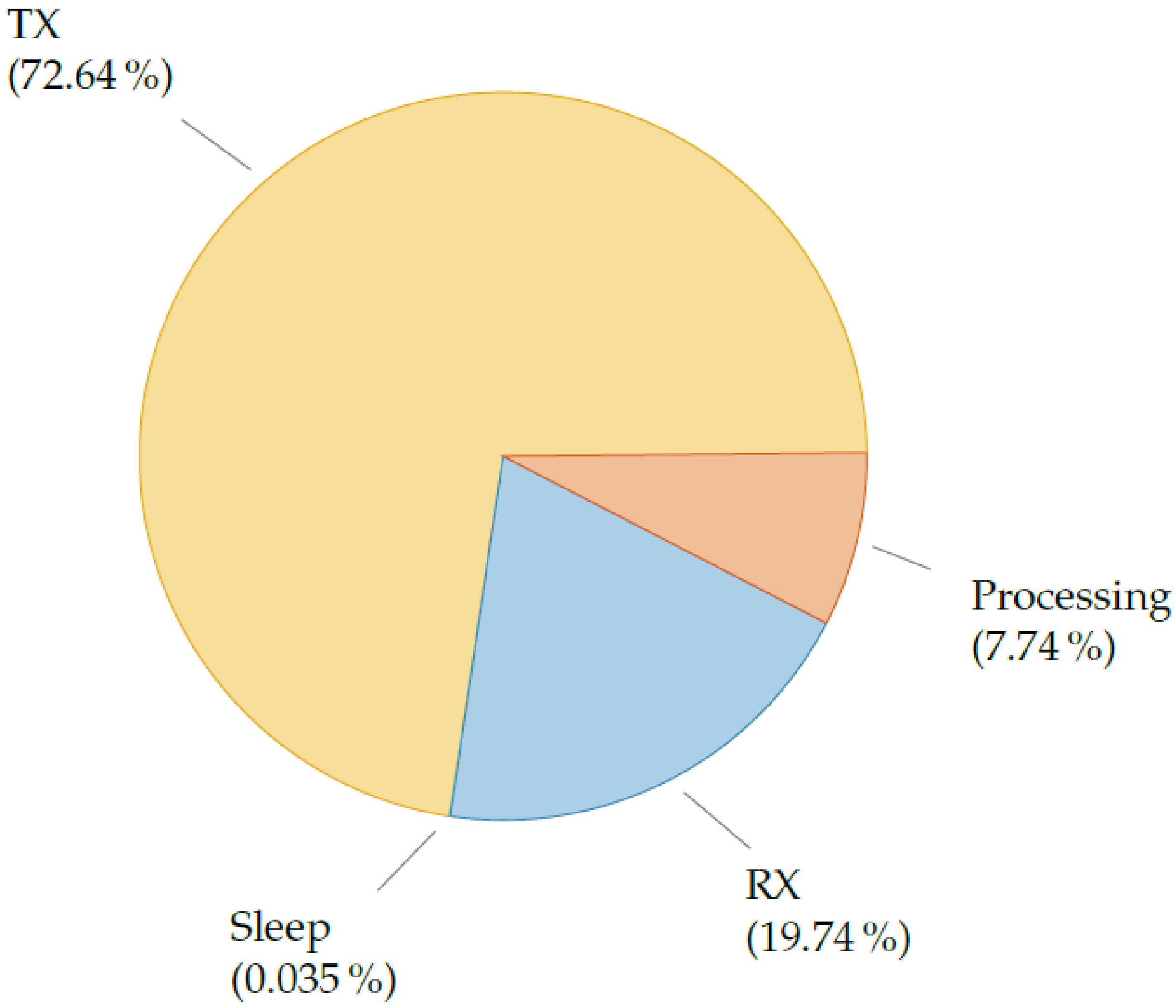
Autonomy & Wireless Technologies: Problem and Solution?

Towards Sustainable Wireless Sensing – in ‘a’ G?

Power/energy consumption of an IoT node: who's to blame?



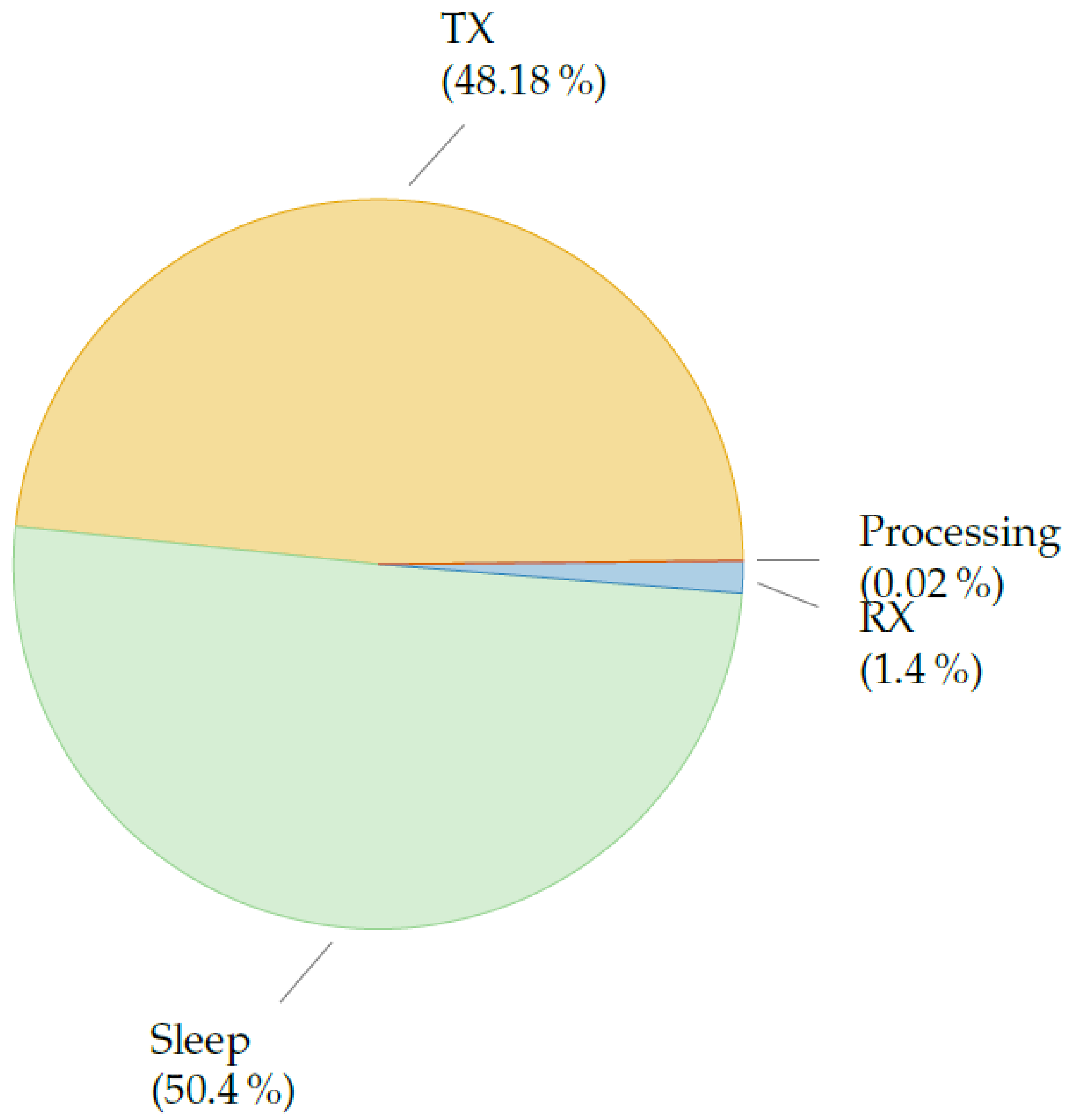
Representative case: **power** consumption in remote IoT node



Listen very carefully

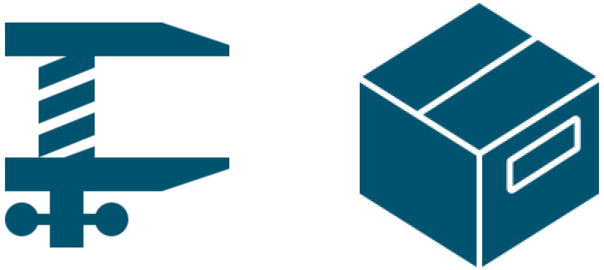
Sleep as much as possible

Representative case: **energy** consumption remote IoT node



Think before you talk

Sleep quietly



1. Reduce and package the data

2. Improve listening skills

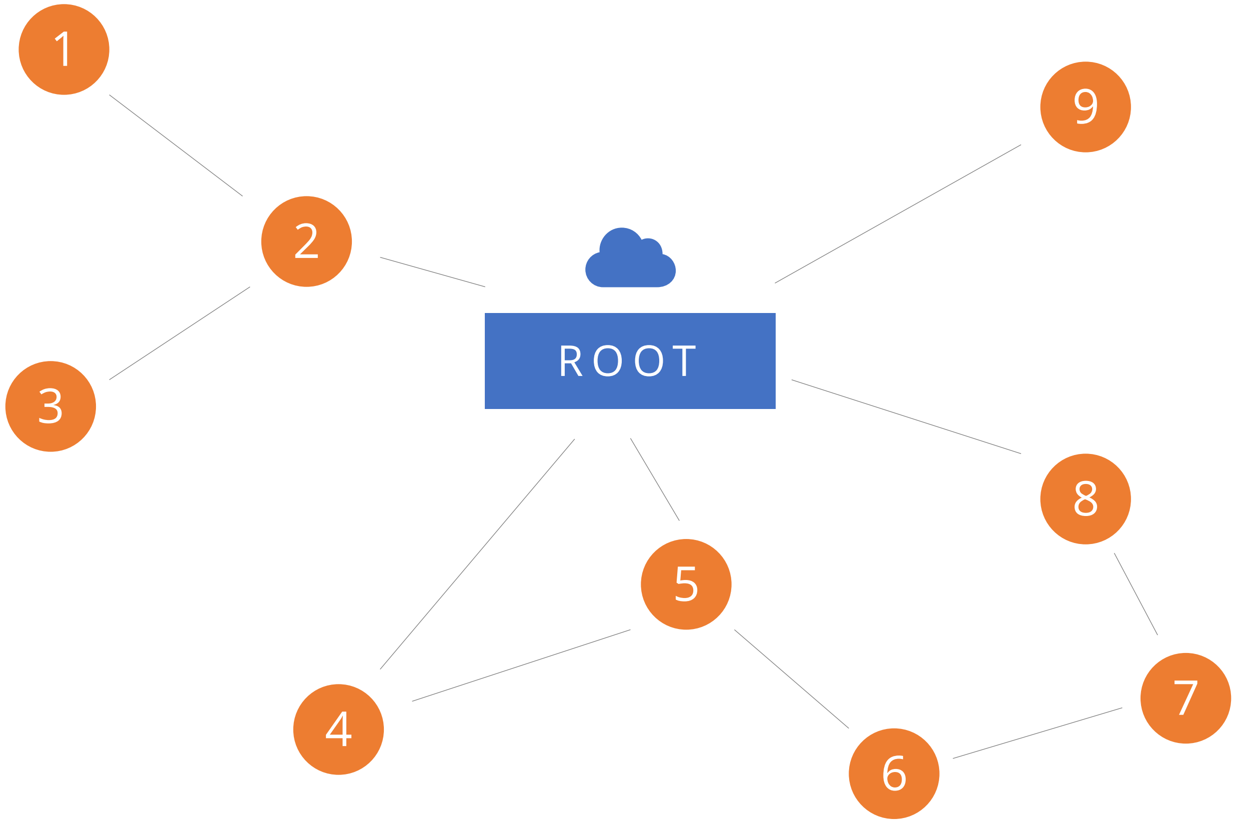
Receive with large arrays

Establish multi-hop transmission

Reception with large arrays (massive MIMO) listen very carefully – reduce IoT node Tx power

G. Callebaut, S. Willhammar, A. P. Guevara, A. J. Johansson, L. Van Der Perre and F. Tufvesson, "Experimental Exploration of Unlicensed Sub-GHz Massive MIMO for Massive Internet-of-Things," in *IEEE Open Journal of the Communications Society*, vol. 2, pp. 2195-2204, 2021

Mesh networking & message accumulation



Focus on energy ⚡
- Channel Activity Detection (CAD) usage
- Centralized routed mechanism
- Accumulation/append on each node

Leenders, G.; Callebaut, G.; Ottoy, G.; Van der Perre, L.; De Strycker, L. An Energy-Efficient LoRa Multi-Hop Protocol through Preamble Sampling for Remote Sensing. *Sensors* **2023**, *23*, 4994.

I-o-creaTures need to be fed to keep them alive

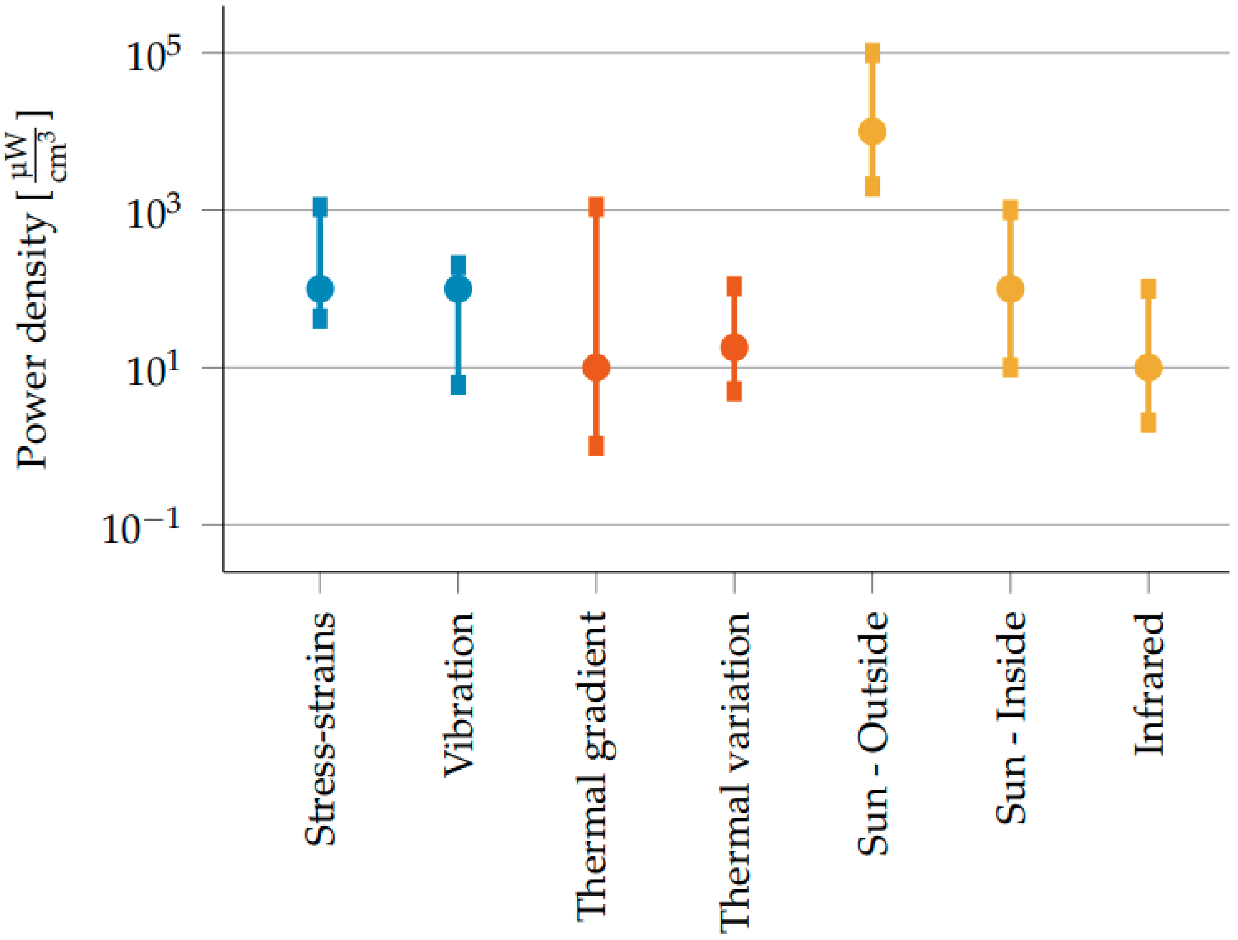
they take energy
from the environment

or you need to
feed them energy

→ ‘The art of Design’ and operation co-optimization/iteration:
find/select components, calculate, duty cycle, dimension, …

Surviving on harvested energy: options and challenges

Mechanical - Thermal - Radiant

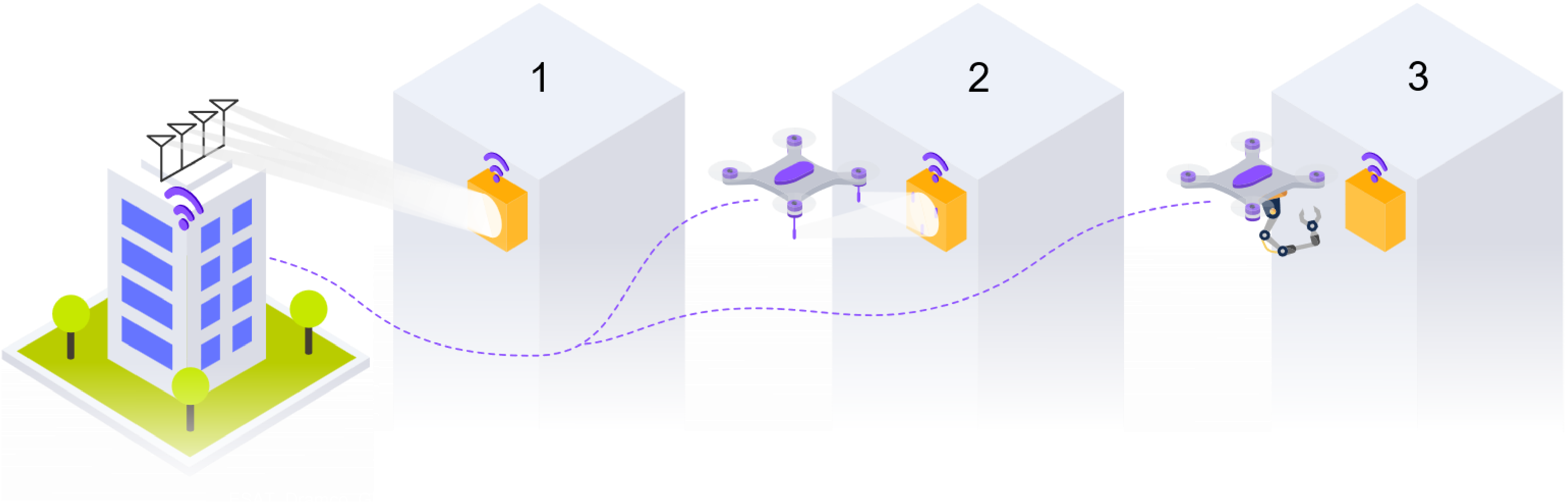


How to survive in dark windless environments?

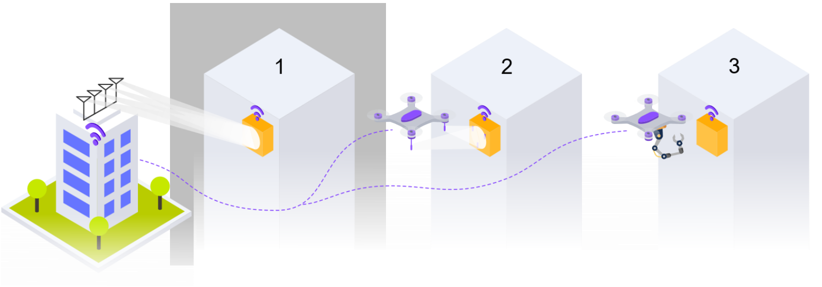
Low power density

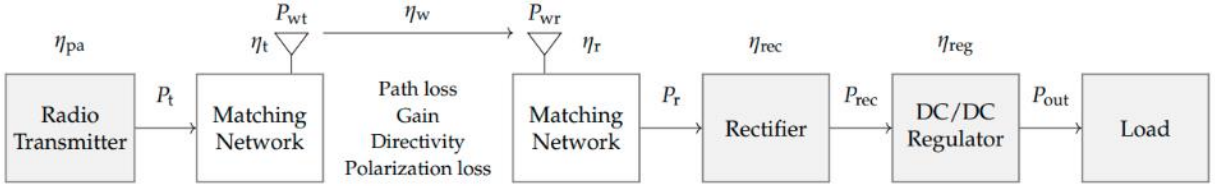
Need for extra circuitry and transducers

Charging remote IoT nodes:
energy surfing on RF waves or boarding a drone



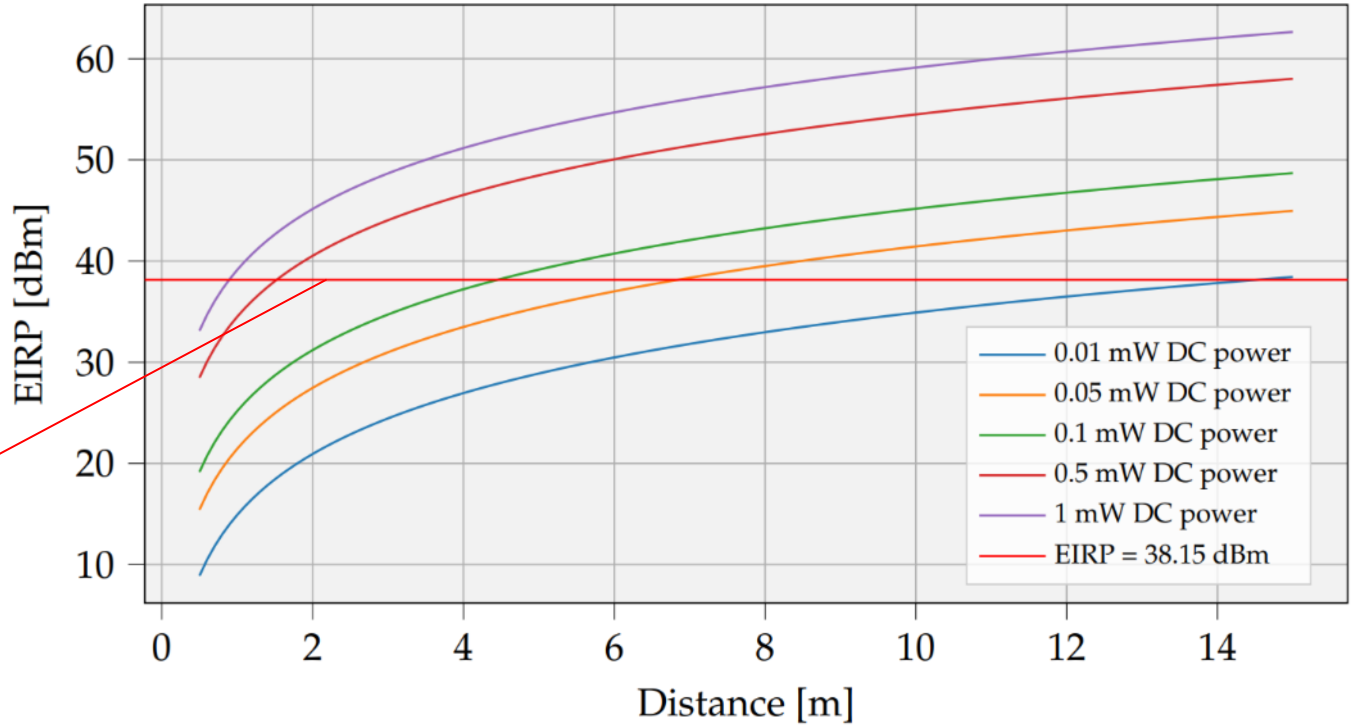
Uncoupled Wireless Power Transfer → RFPT





SISO

Energy harvester
↓
Evaluation board AEM40940



EIRP is limited by standards
E.g., ETSI EN 302 208

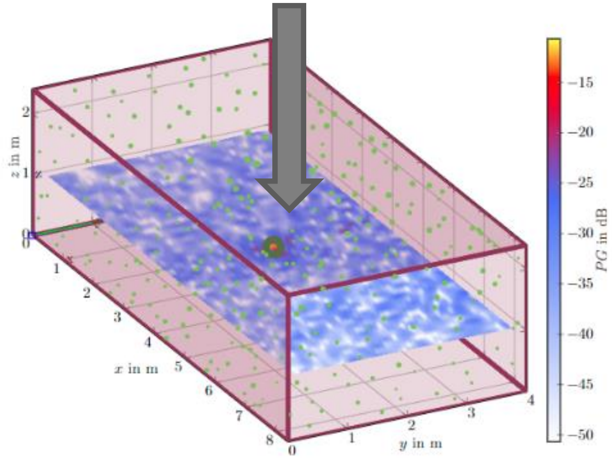
With 38.15 dBm equals to 6.5 W of radiated power

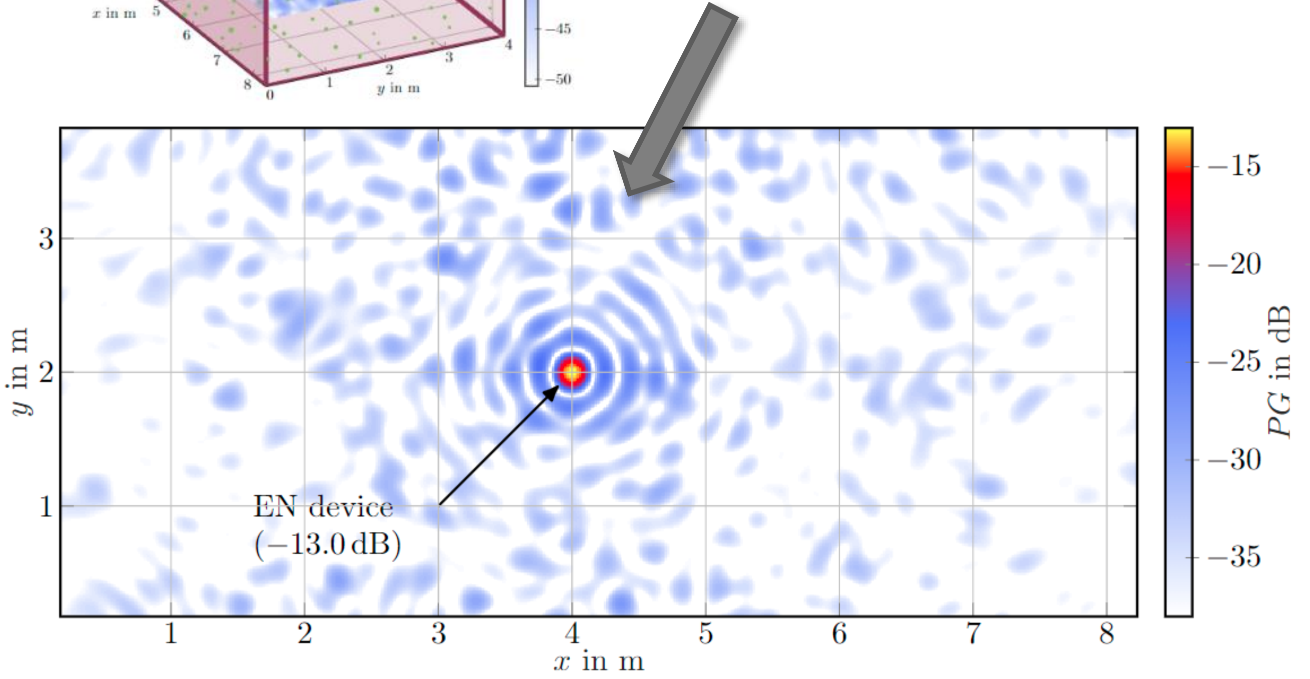
Distributed RFPT with large arrays: efficiency boost!

Simulation-based assessment in REINDEER project

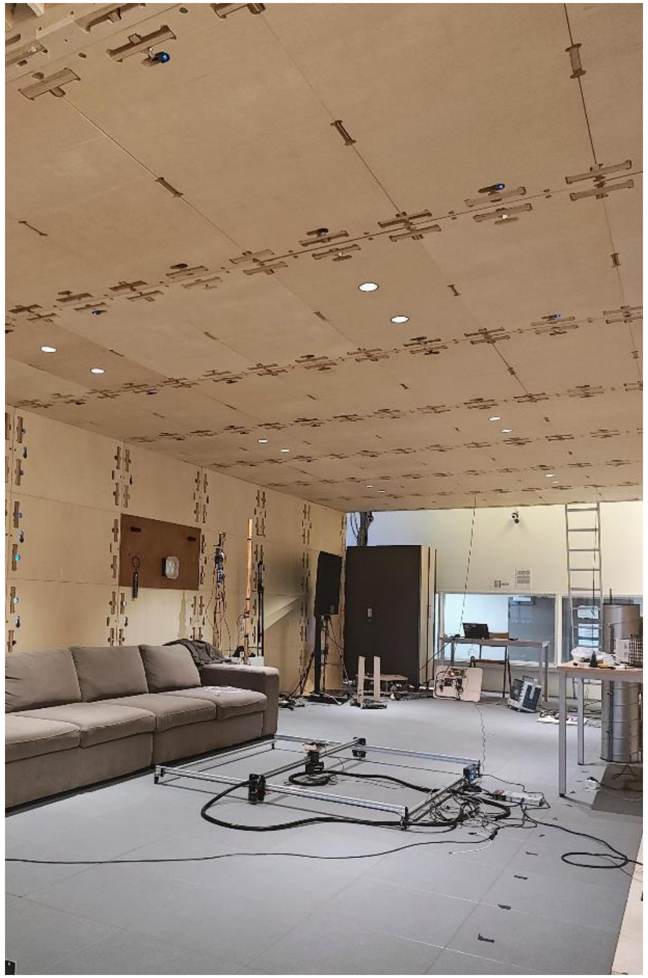
Techtile testbed Ghent
Dimensions 8.4 x 2.4 x 4 m
280 TX antenna's

Power spot (4, 2, 1)
PG = -13.0 dB

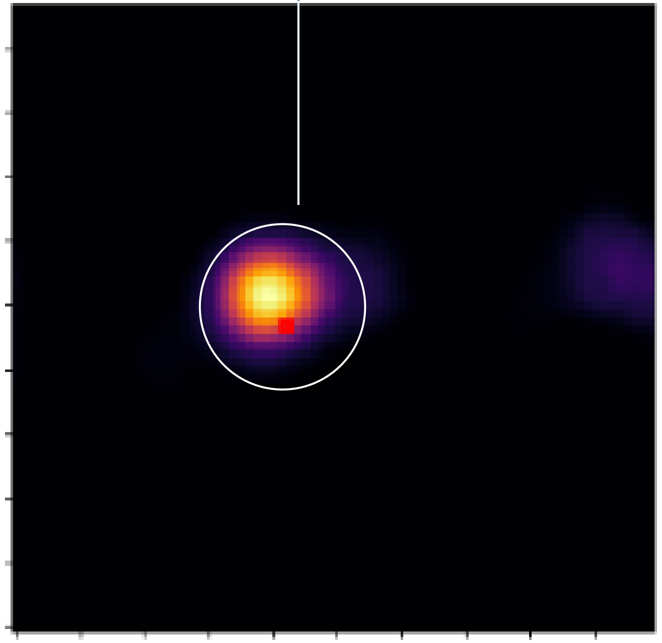




Validation with 280 antennas

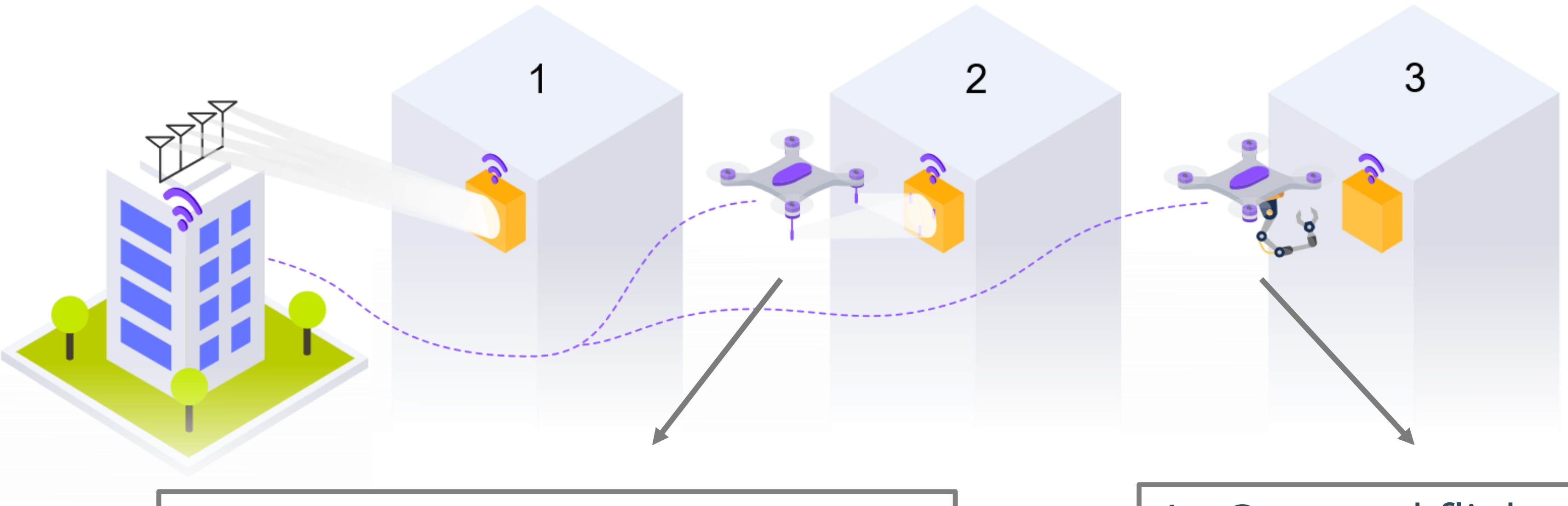


Focal region



https://vimeo.com/showcase/reindeer-results-video-showcase?video=1038523769

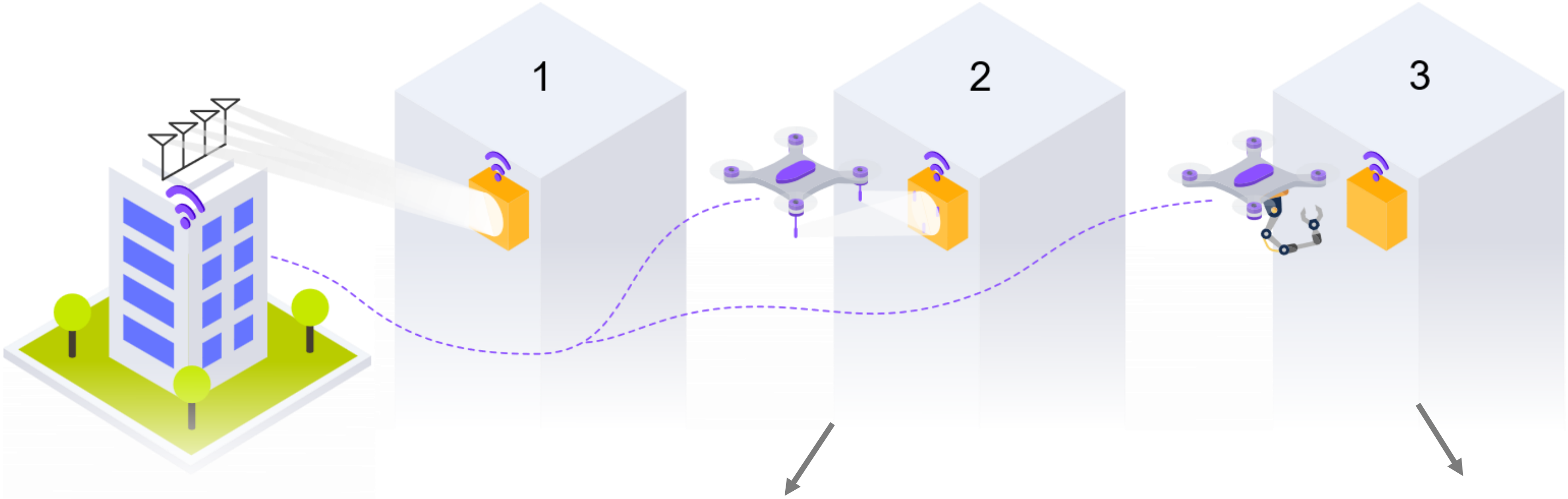
UAV-based service: Operating principle and recharging concept



1. Outward flight
   to IoT node
2. Charge IoT battery
   with energy from UAV battery
3. Return flight
   to charge station

1. Outward flight
   to IoT node (incl. charged battery)
2. Swapping IoT battery
3. Return flight
   to charge station

Energy assessment: component contributions



? UAV energy consumption model → Travel path & distance

IoT battery size

Power transfer – rate, time, efficiency

? UAV energy consumption model → Travel path & distance

Payload

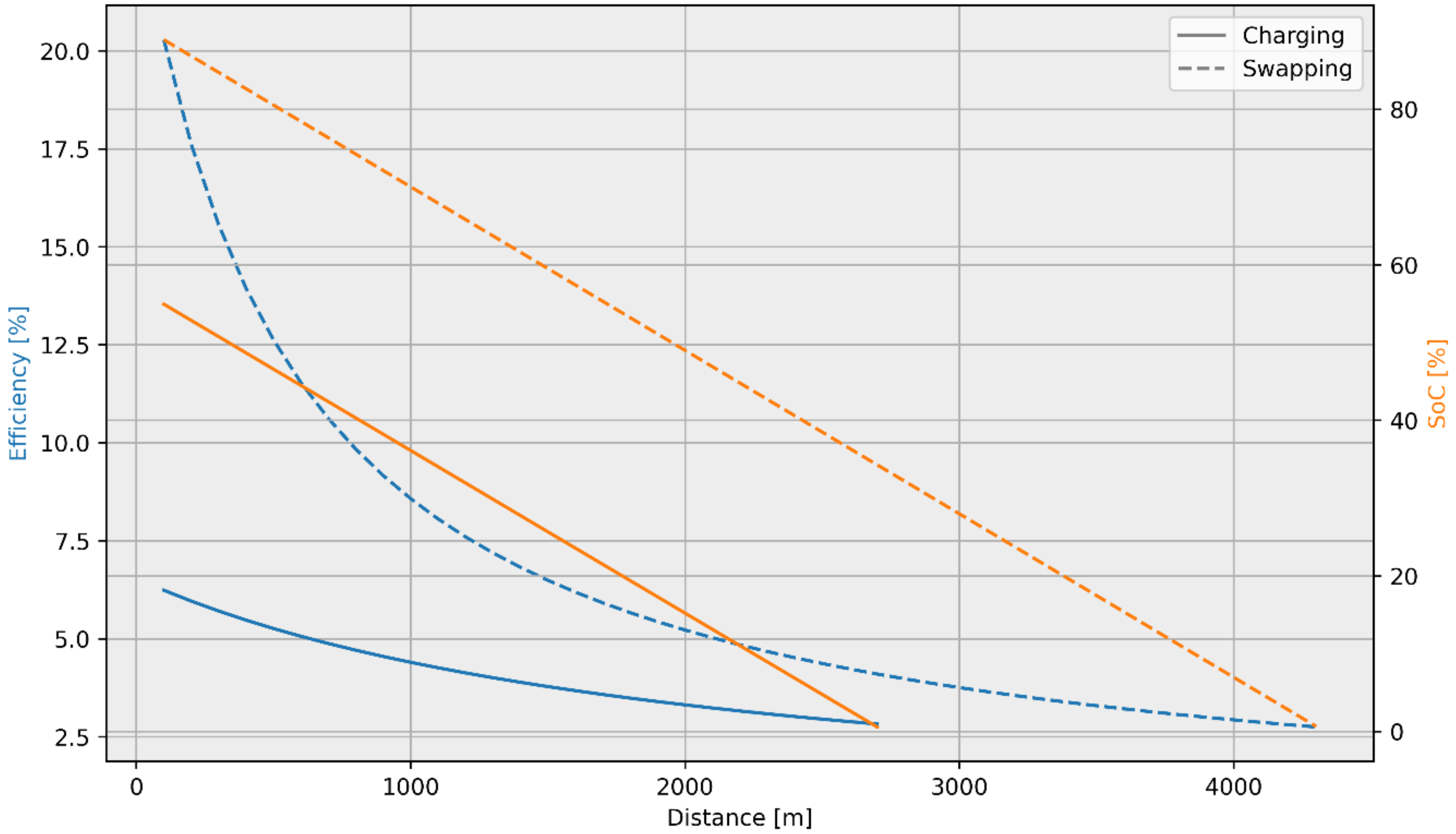
Swapping time

Overall efficiency comparison

$$\eta_{charge} = \frac{E_{delivered}}{E_{uav,consumed}}$$

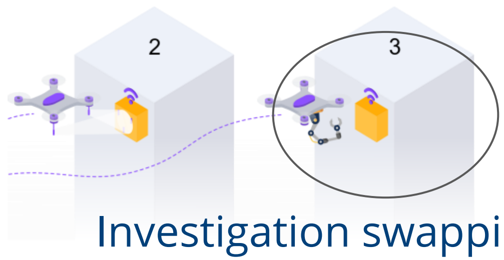
$$\eta_{swap} = \frac{E_{delivered}}{E_{uav,consumed} + E_{delivered}}$$

Same assumptions used



Wireless charging requires more energy than swapping

Swapping more efficient



Investigation swapping mechanism

I-o-creaTures for sustainable applications: tailor and study

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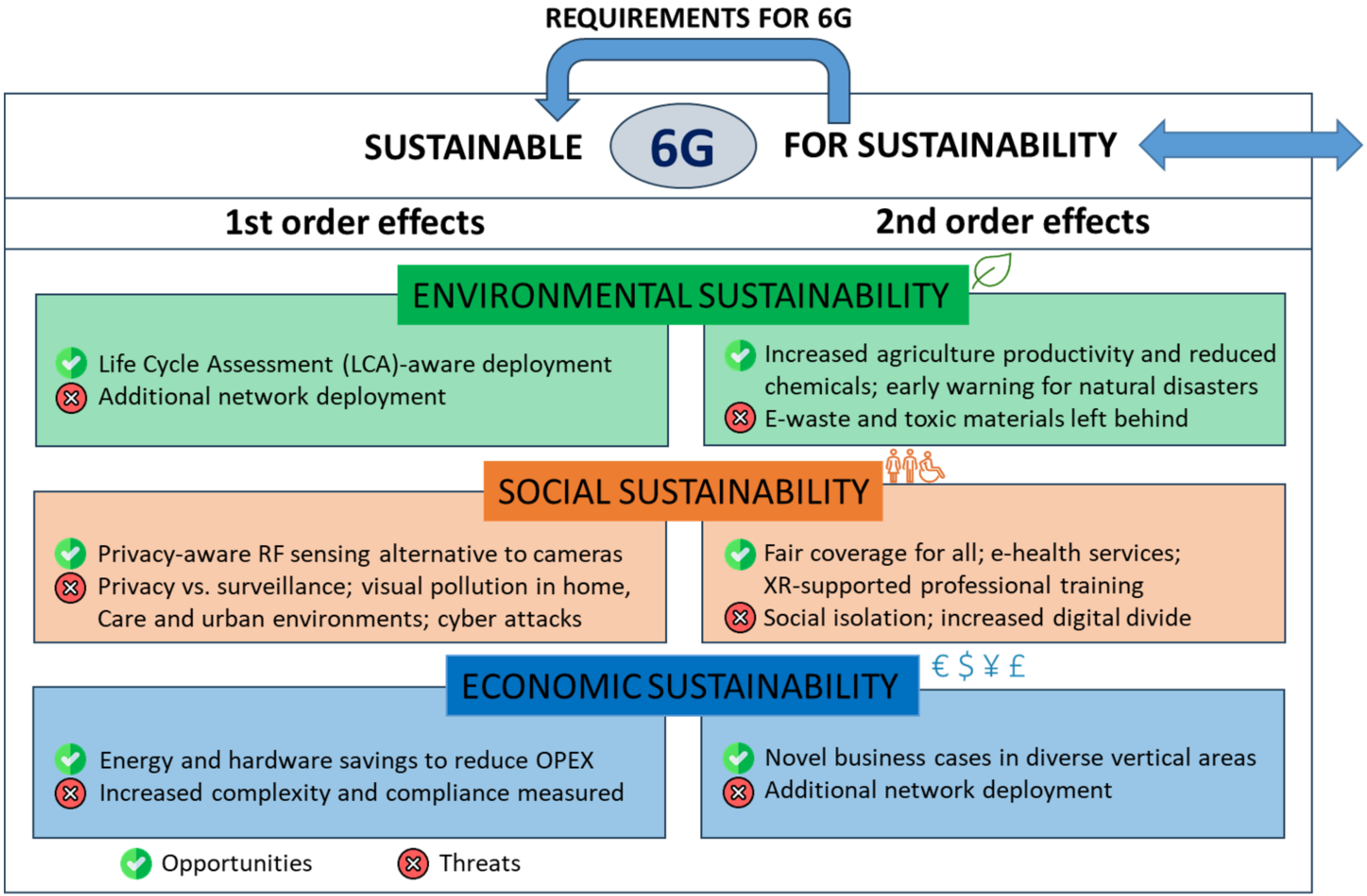


SUSTAIN 6G

Merluzzi, M., Bouchet, O., Balador, A., Callebaut, G., Gavras, A., Van der Perre, L., ... & Schmelz, L. C. (2026). Towards Sustainable 6G: A Holistic View of Trade-offs and Enablers. *arXiv preprint arXiv:2601.04817*. Accepted for publiaction in IEEE comm magazine

Example of verticals, corresponding KVIs & KPIs

Agriculture	
KVIs	KPIs
Water waste reduction; production efficiency	ubiquitous coverage; low latency for autonomous machines

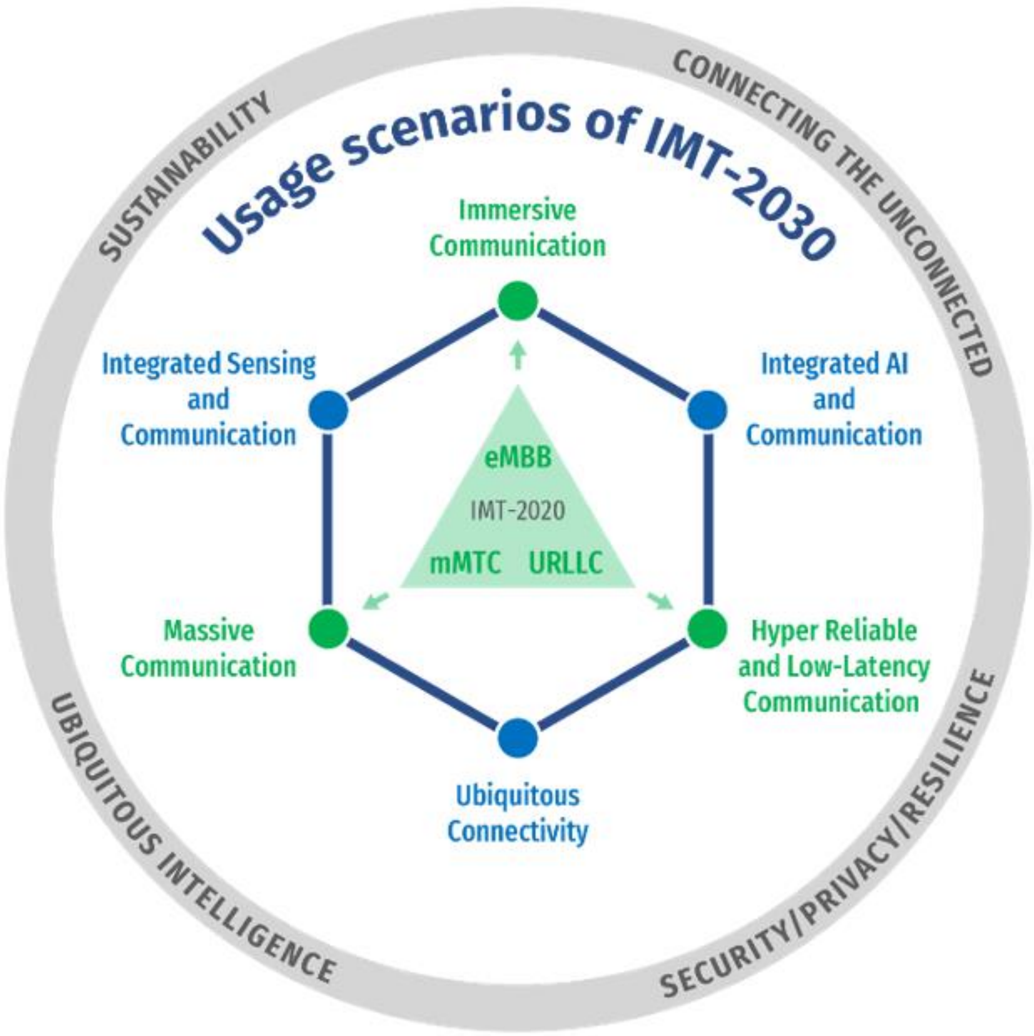
Energy	
KVIs	KPIs
system reliability; production gain; Renewable transition	moderate to high data rate for smart grids; ultra-low latency for real-time grid control

Telemedicine	
KVIs	KPIs
per patient expenditure reduction; number of treatments	high data rates for remote surgery and diagnostics; security and privacy

What are wireless connectivity requirements for representative vertical use cases?

1. Data rate, (low) latency: nothing 4G/5G can't do?
2. Coverage: why not (a case to be) provided by 4G/5G?
3. Enabling ultra-low energy at node side: could it be done

Could 6G be the answer – to everything at once?



I-o-creaTures for sustainable sensing: don’t jump to conclusions!

1. Check what the application needs - which ‘G’ could do (better).
2. Mind the wireless communication to give IoT nodes a long life.
3. Don’t forget to recover the nodes and take care of batteries.