SITH: Smart Internet of THings

Fabien Ferrero, Benoît Miramond, Laurent Rodriguez

LEAT, Université Côte d'Azur

SYSTÈMES NUMÉRIQUES POUR L'HUMAIN
ÉCOLE UNIVERSITAIRE DE RECHERCHE

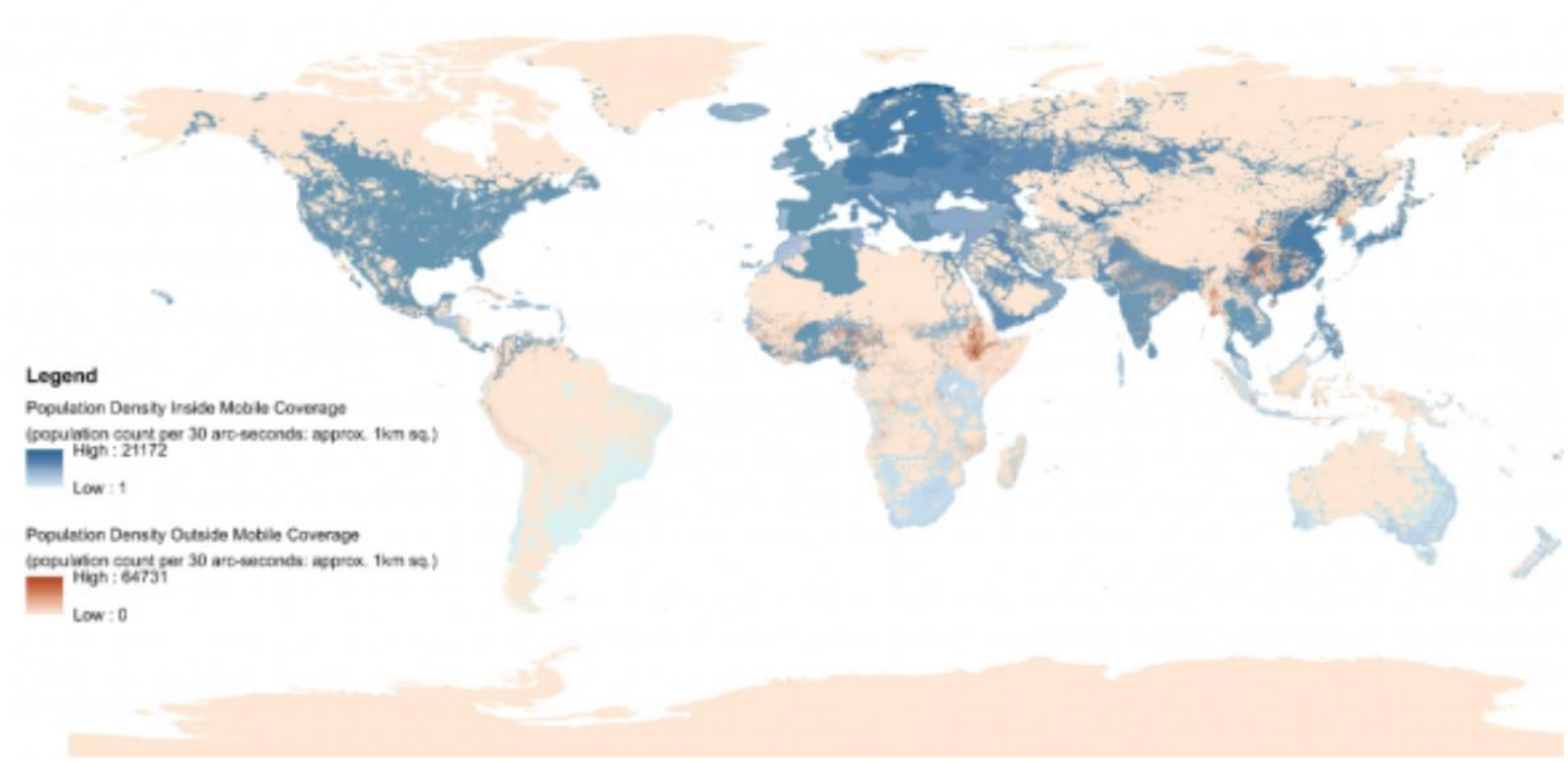
UNIVERSITÉ CÔTE D'AZUR

LEAT
LABORATOIRE D'ELECTRONIQUE ANTENNES ET TELECOMMUNICATIONS

Outline

- **Access to space for IoT**
    - **IoT from space: Opportunity and Challenge**
    - Antenna for Iot from space application
    - Prototype and Measurement
- EDGE AI
- CERN project
- Teaching
- Conclusion and perspectives

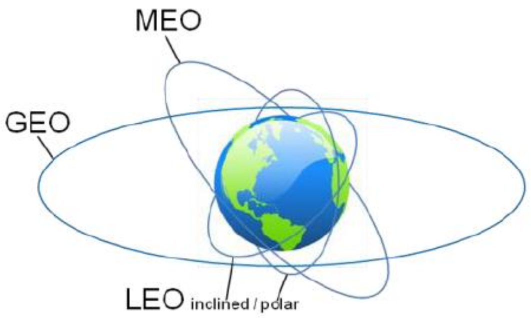
Mobile phone coverage

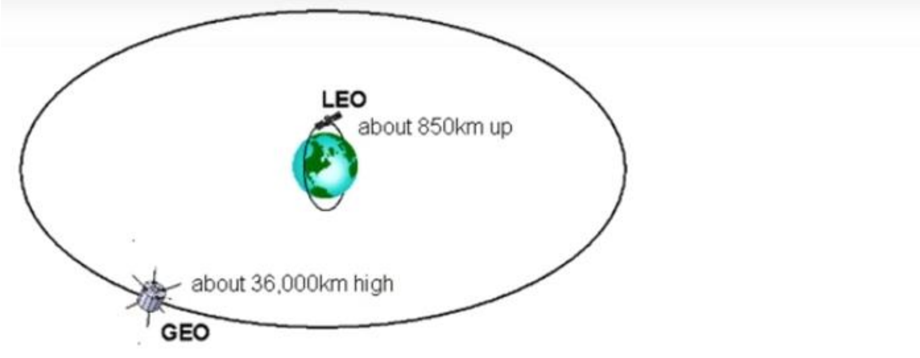


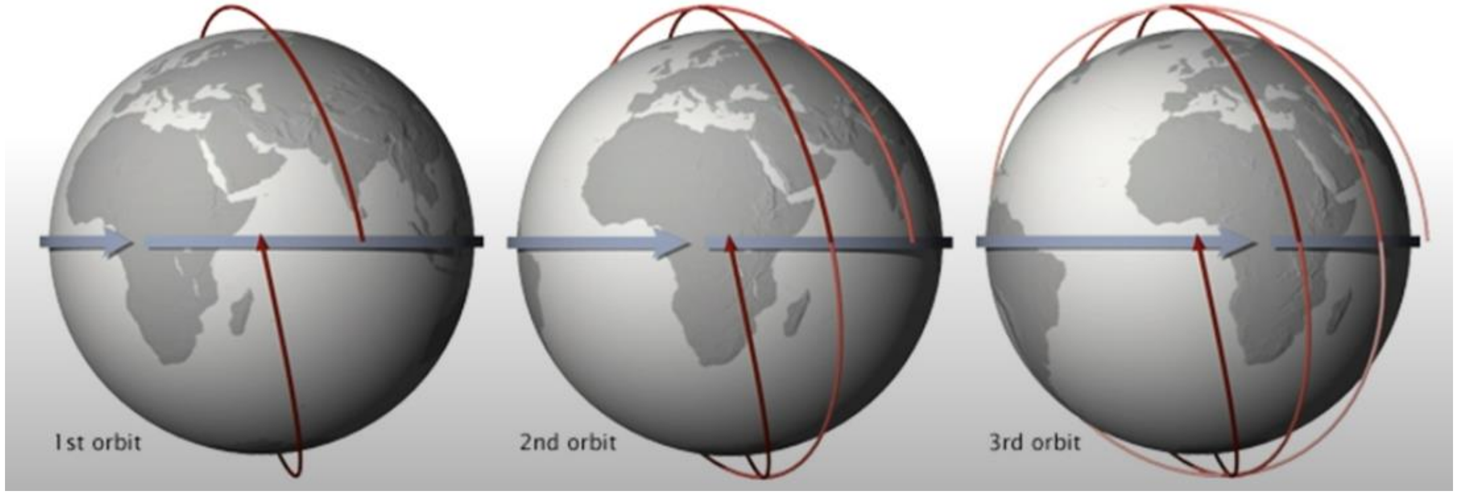
EPAR's 2014 Review of Mobile Coverage (terrestrial networks)

IoT from space with LEO satellite

Low Earth Orbite reduce communication distance







IoT from space with LEO satellite : uplink

How does the Lacuna technology work?

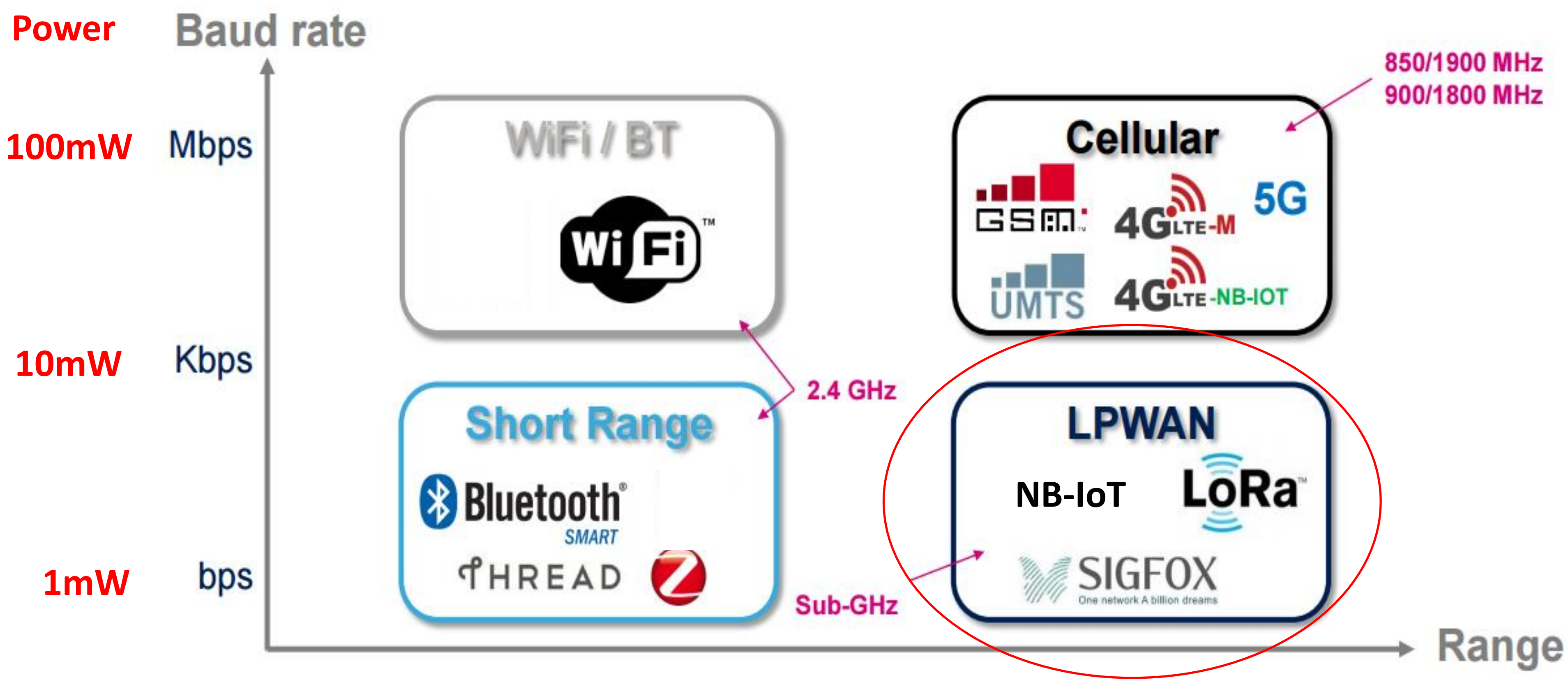
1. Battery powered devices direct to satellite – no gateway required
2. Satellites in low earth orbit collect and store received messages
3. Messages are relayed to ground station when satellite goes overhead
4. Data relayed to *The Lacuna Network* for distribution
5. Distributed to Lacuna Space customers or other operators as appropriate

Use ISM bands : 868 or 920MHz

Outline

- **Access to space for IoT**
  - IoT from space: Opportunity and Challenge
  - **Antenna for Iot from space application**
  - Prototype and Measurement
- EDGE AI
- CERN project
- Teaching
- Conclusion and perspectives

LP-WAN technologies opportunities



Siths' UCA BoardRFT dev board

- The target is a **RFT-AI Dev. Kit** board equipped with a **STM32L476RGT6 Microcontroller.** This MCU is based on **the ARM Cortex M4 architecture** and runs at a frequency of **80 MHz. The board provides 1 MB Flash and 128 KB SRAM.**
  - **LoRa SX1262 Module with CP antenna**
  - Quectel L96 M33 GPS module
  - Accelerometers
  - Gyroscope
  - Magnetometer
  - 9 Axis Sensor TDK InvenSense ICM-20948 - Digital,
  - PDM Microphone MEMS (Silicon) Omnidirectional SPH06
  - Air Quality Sensor - Sensirion AG SGP30-2.5K
  - Optical Sensor Ambient - Lite-On Inc. LTR-303ALS-01

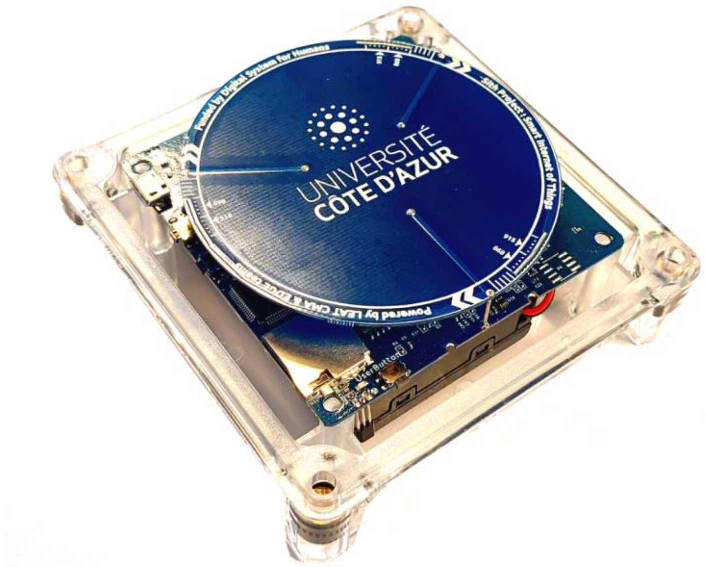
Outline

- **Access to space for IoT**
  - IoT from space: Opportunity and Challenge
  - Antenna for Iot from space application
  - **Prototype and Measurement**
- EDGE AI
- CERN project
- Teaching
- Conclusion and perspectives

Sith Development Kit

Based on LS-200 Reference Schematic :

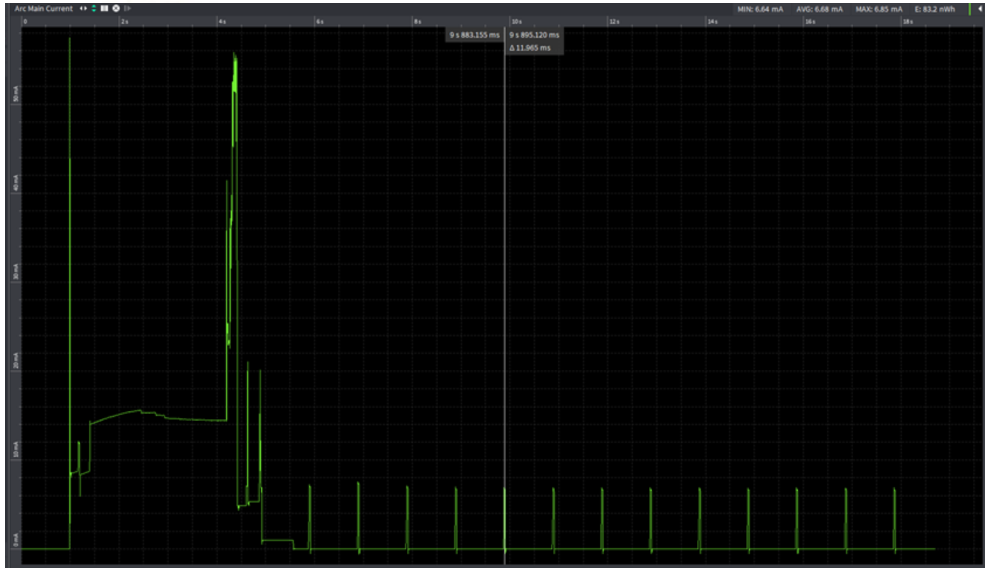
- 868/923 RHCP antenna
- SX1262
- STM32L476 (1Mb flash)
- Ublox M8Q GPS
- Sensors : Accelerometer, Air quality, ..
- Hall sensor



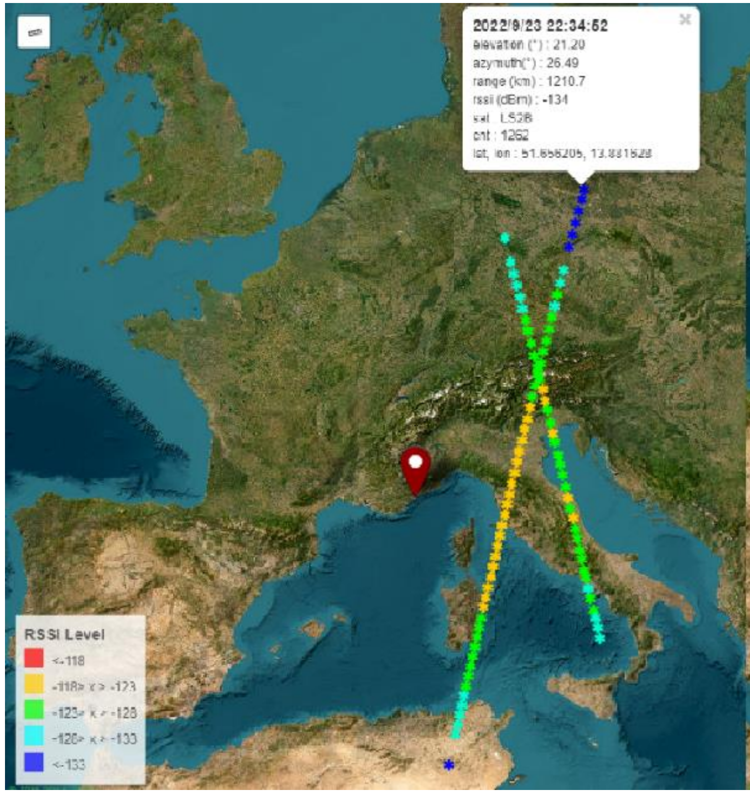
Sleep power : 20uA

Relay mode : 60uA

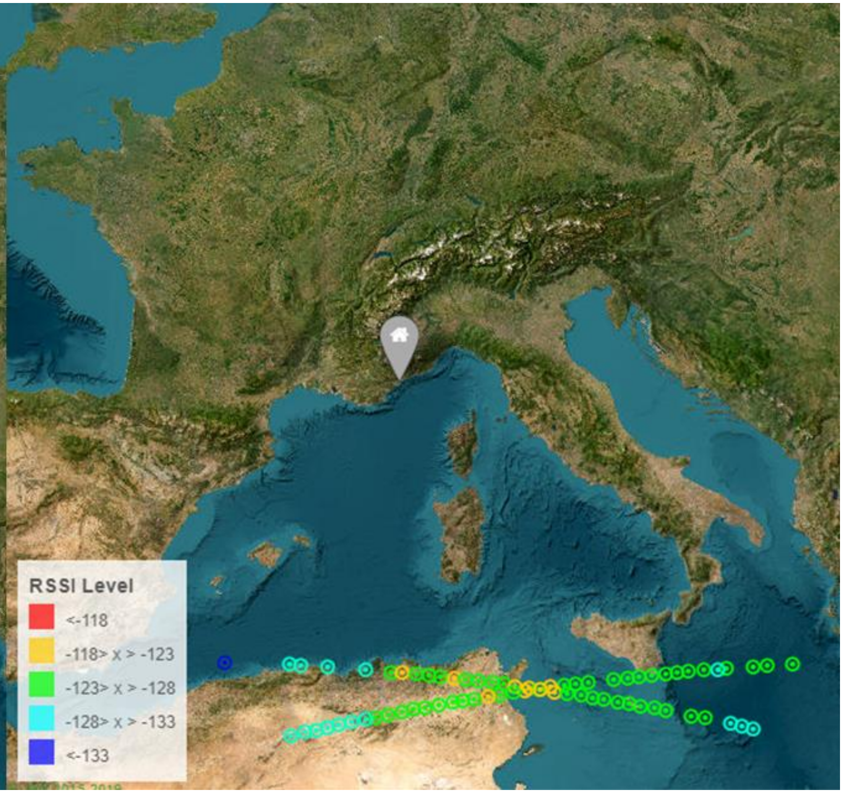
Several years of autonomy with a single battery



In the Field first results



LS2D (polar orbit)



LS2C (37° inclination orbit)

Communication down to 20° of elevation

Siths' UCA BoardRFT dev board

- The developed board, doted with the designed antenna becomes the first IoT object communicating with space through LPWAN
- Data throughput in the order of tens of bits per second

=> Need for AI on the edge for complexes applications

Outline

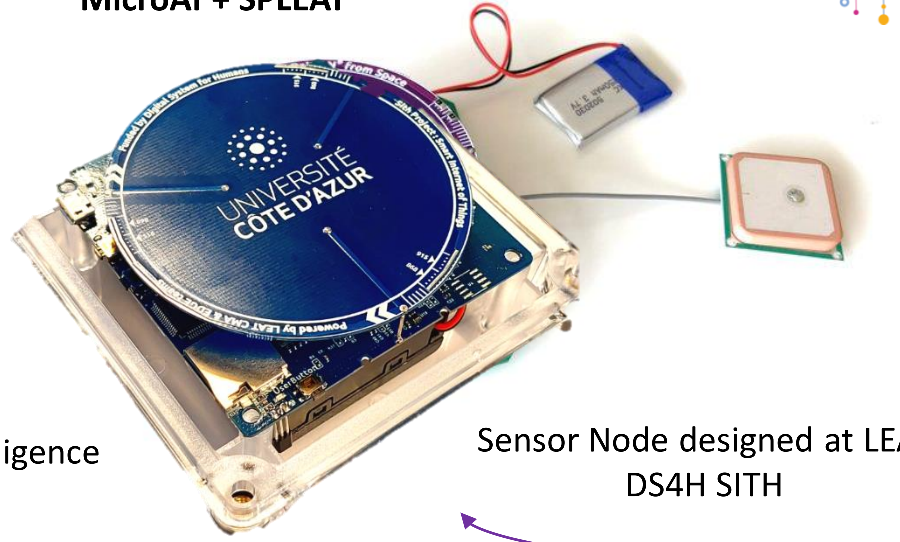
- Access to space for IoT
- **EDGE AI**
  - **Applications and constrains**
  - Prototype and Measurement
- CERN project
- Teaching
- Conclusion and perspectives

Example of distributed AI with Satellite IoT

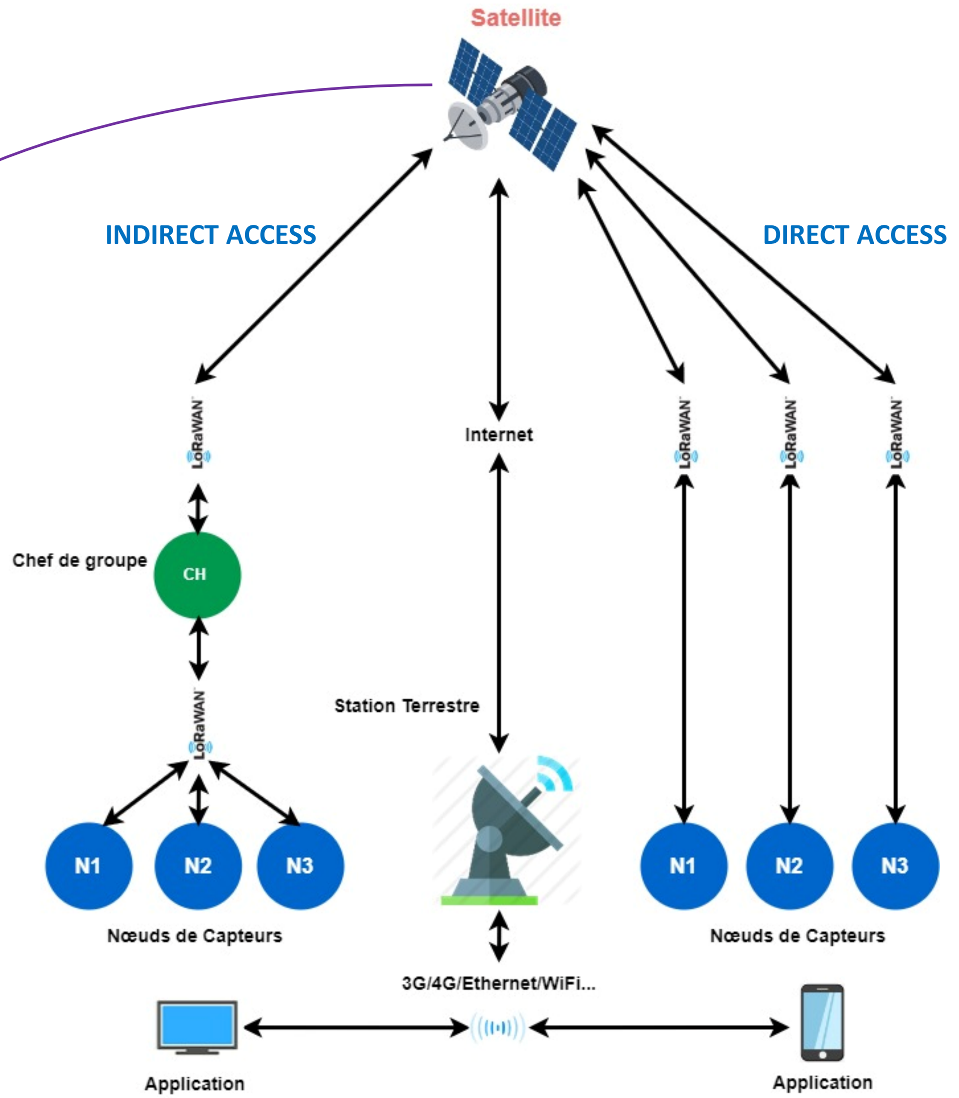
Ground sensors connected to a satellite.
End nodes embed sensors, MCU, battery and LoRA connectivity.
Each node embeds EdgeAI and has to be autonomous in energy.

MicroAI + SPLEAT

Satellite LoRa Gateway
Embedded AI



Sensor Node designed at LEAT
DS4H SITH



Ns: Nodes
CH: Cluster Head
AI: Artificial Intelligence

I. Abdoulaye, L. Rodriguez, C. Beleudy, B. Miramond, Embedded Artificial Neural Network for Data Prediction in Efficient Wireless Sensors Networks, ASPAI 2022

Smart sensors

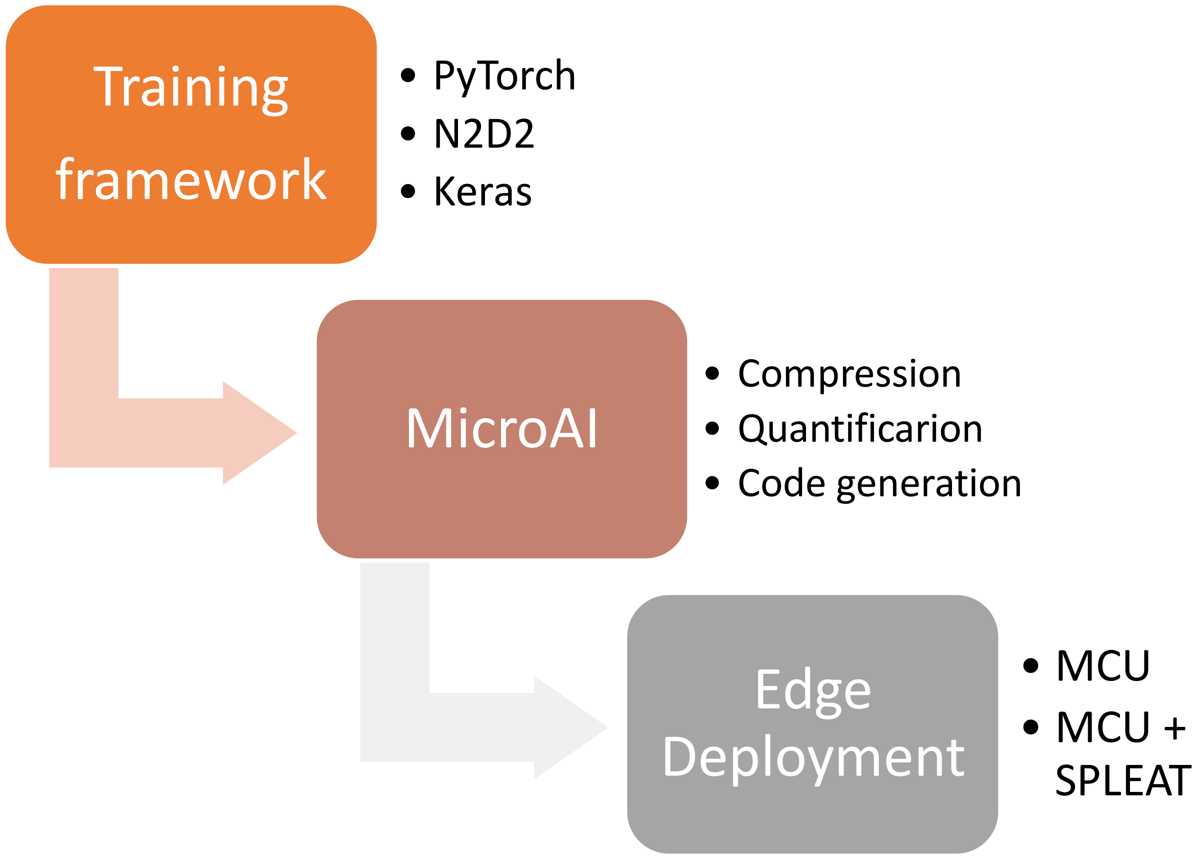
- Edge AI offers the possibility to embed near-sensor processing
- **By bringing AI closer to the sensor, the goal is:**
  - **To reduce the amount of data to communicate**
  - **To lower the global energy consumption of the digital infrastructure**
  - **To reduce latency for decising making (close or open loop)**
- It includes
  - Near-sensor classification + Data fusion
  - Distributed AI in order to enable self-organization of WSN

Siths’ UCA BoardRFT dev board

- The target is a **RFT-AI Dev. Kit** board equipped with a **STM32L476RGT6 Microcontroller.** This MCU is based on **the ARM Cortex M4 architecture** and runs at a frequency of **80 MHz. The board provides 1 MB Flash and 128 KB SRAM.**
  - **LoRa SX1262 Module with CP antenna**
  - Quectel L96 M33 GPS module
  - Accelerometers
  - Gyroscope
  - Magnetometer
  - 9 Axis Sensor TDK InvenSense ICM-20948 - Digital,
  - PDM Microphone MEMS (Silicon) Omnidirectional SPH06
  - Air Quality Sensor - Sensirion AG SGP30-2.5K
  - Optical Sensor Ambient - Lite-On Inc. LTR-303ALS-01

The LEAT codesign flow for Edge AI

- Complete Solution: *from Training to Edge*
- Training of networks (frameworks PyTorch, Keras, N2D2)
- Embedded preparation of ANN with MicroAI
  - Quantification des SNN
  - Automatic code generation
  - Open-source: https://bitbucket.org/edge-team-leat/microai_public



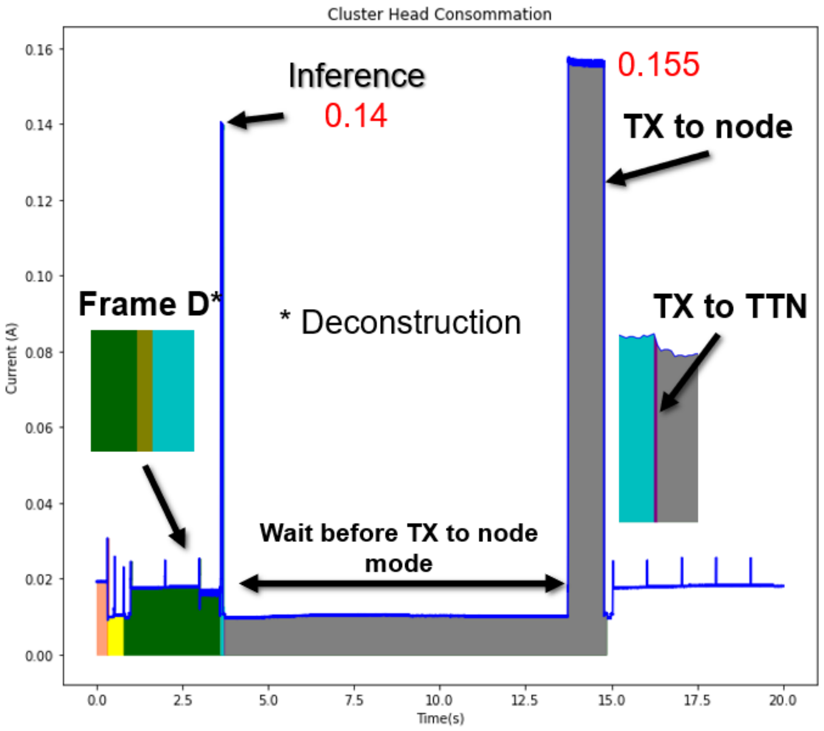
Quantization and deployment of deep neural networks on microcontrollers, PE Novac, GB Hacene, A Pegatoquet, B Miramond, V Gripon, Sensors 21 (9), 2984, 2021
SPLEAT: SPiking Low-power Event-based ArchiTecture for in-orbit processing of satellite imagery,, N. Abderrahmane B. Miramond, IJCNN 2022

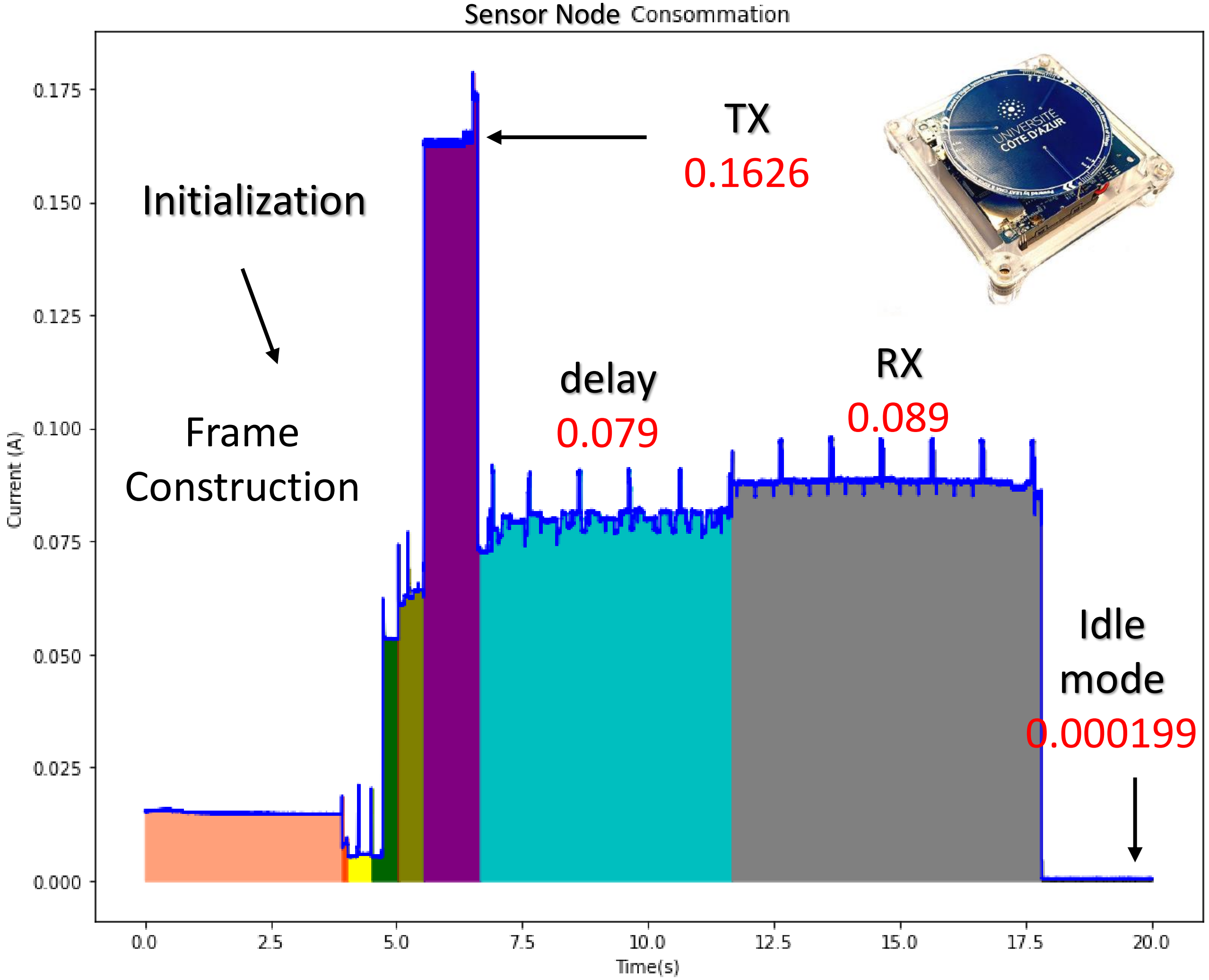
Outline

- Access to space for IoT
- **EDGE AI**
  - Applications and constrains
  - **Prototype and Measurement**
- CERN project
- Teaching
- Conclusion and perspectives

Evaluation and Discussion of Embedded Inference

Energy consumption evolution



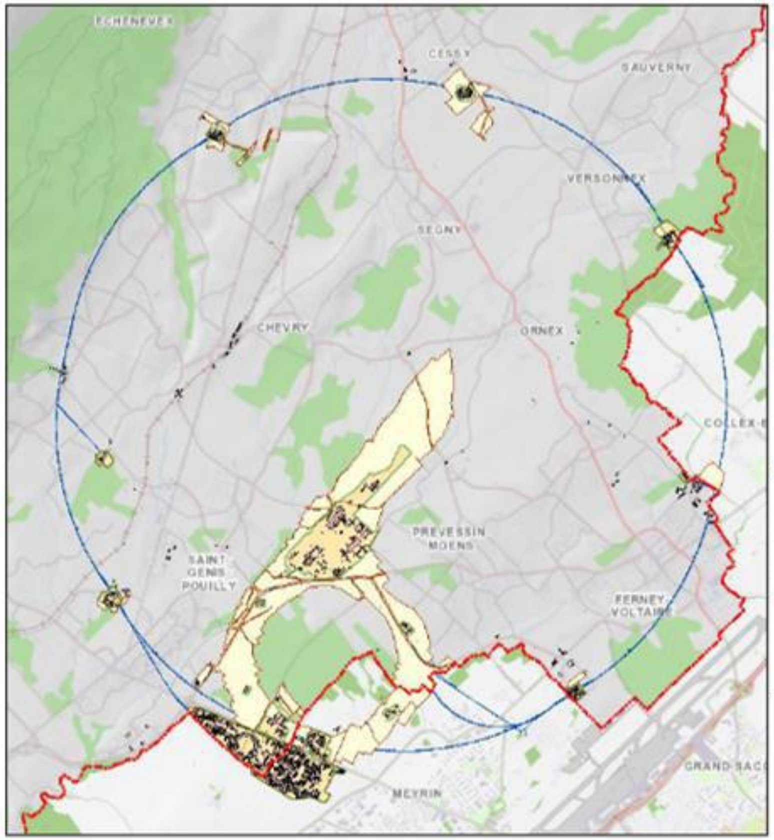


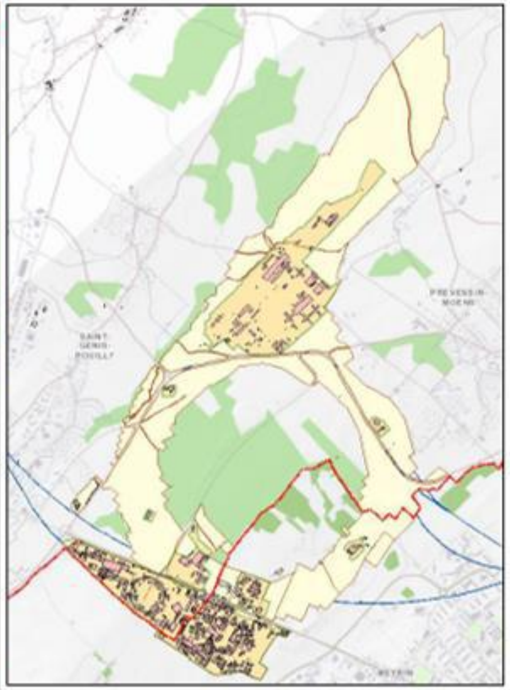
Outline

- Access to space for IoT
- EDGE AI
- **CERN project**
- Teaching
- Conclusion and perspectives

CERN biodiversity project

SURFACE TOTALE DU DOMAINE DU CERN: 626 Ha





Domaine clôturé

- Meyrin (79 Ha)
- Prévessin (83 Ha)
- Point LHC
- Points SPS

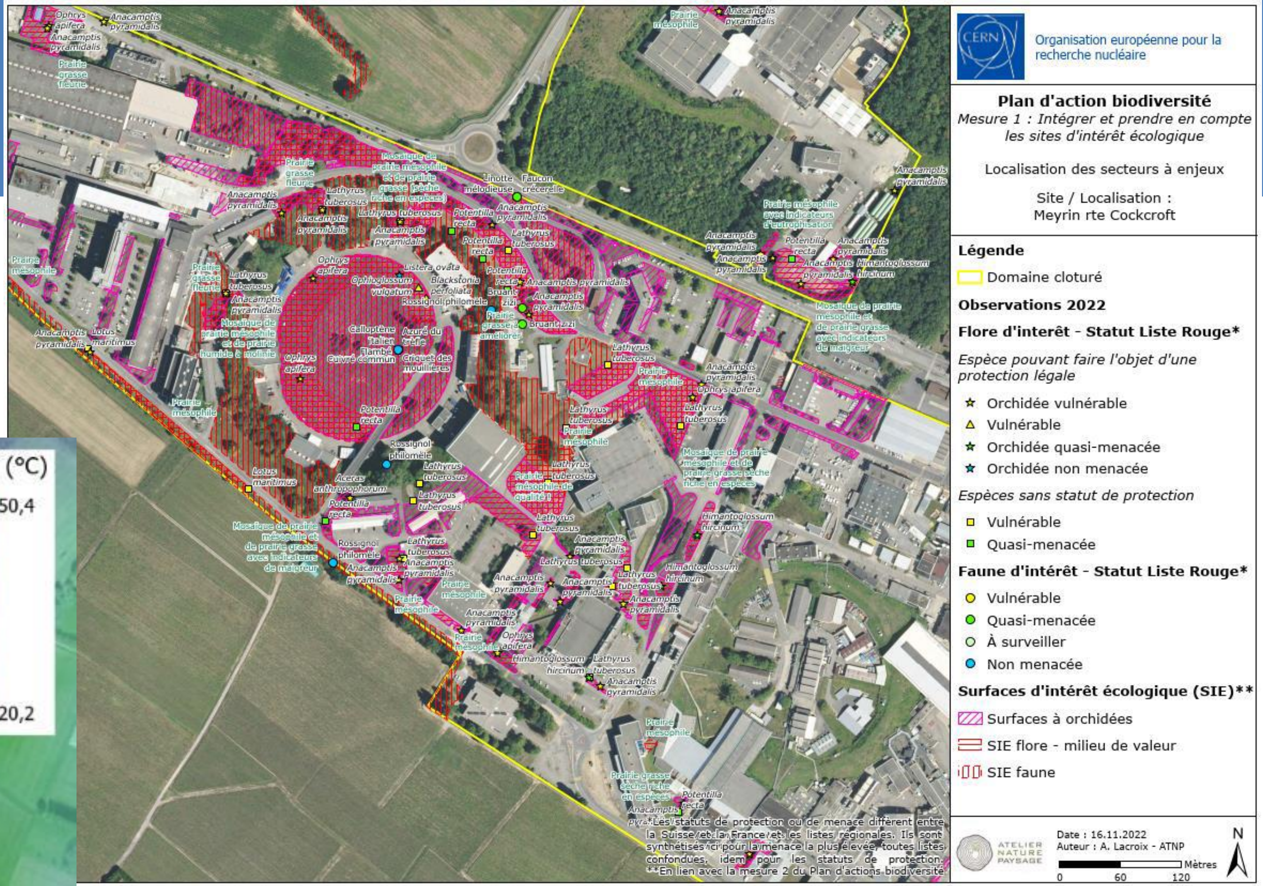
- Surface totale: 211 Ha
- Surface espaces verts:101 Ha
- Surfaces voiries/parkings: 57 Ha
- Surface bâti: 39 Ha

Domaine non clôturé

Bois, Forêts 136 Ha
Champs 258 Ha
Surface totale: 415 Ha

Présenté par Sabrina Schadegg, HSE/ENV-EP

CERN biodiversity project



Présenté par Sabrina Schadegg, HSE/ENV-EP

CERN biodiversity project

- **Objectives:**
  - Deploy 200 sensors:
    - Monitoring of environmental data (air quality, temperature, etc.)
    - Detection and listing of bird species present on the site
  - Criteria:
    - Lifetime of the sensors (at least one year of autonomy)
    - Pattern recognition (environmental events, bird songs, etc.)
- **Benefits:**
  - To have a **better knowledge of the environmental parameters** to allow actions to improve the site in a concern of **eco-responsibility** and **sustainability (reforestation, fields, work on the buildings - roofs, etc.).**
  - Lead future developments of the site in the respect of the environmental criteria

Outline

- Access to space for IoT
- EDGE AI
- CERN project
- **Teaching**
- Conclusion and perspectives

Enseignements

The electronic boards funded by the SITH project enable the implementation of many concepts for various teaching modules such as embedded AI and IoT.

- Master EIT-Digital option Systèmes Autonomes (IA Embarquée)
- 4th and 5th year in computer science and electronics at Polytech Nice Sophia (Embedded AI)
- ITII 5th year (Embedded AI and communicating objects)
-

~ 120 Students

Etudiants du Master EIT-Digital déployant un modèle d'intelligence artificielle pour la reconnaissance d'activité humaine sur les cartes du projet SITH dans le cadre d'un cours sur l'IA embarquée

Outline

- Access to space for IoT
- EDGE AI
- CERN project
- Teaching
- **Conclusion and perspectives**

Conclusion

- First card to enable **IoT communication to space with AI capability**
- Enable **collaboration between LEAT's IoT and Edge AI team**
  - Synthesize our respective skills within the same platform
- Opening **national and international collaboration** (INPHYNI, CERN, HCMC University Vietnam, DaNang University Vietnam)
- Evolution:
  - **Energy autonomy**: energy harvesting (solar) + super capa
  - **Increase supported standards** (BLE, Wifi, S-band – geostationary communication)
  - **Modularity** (daughter card – MCU, Sensors, etc.)

Laboratory of Electronics Antennas and Telecommunications

LABORATOIRE D'ELECTRONIQUE ANTENNES ET TELECOMMUNICATIONS

fabien.ferrero@univ-cotedazur.fr
benoit.miramond@univ-cotedazur.fr
laurent.Rodriguez@univ-cotedazur.fr

LABORATOIRE D'ELECTRONIQUE ANTENNES ET TELECOMMUNICATIONS

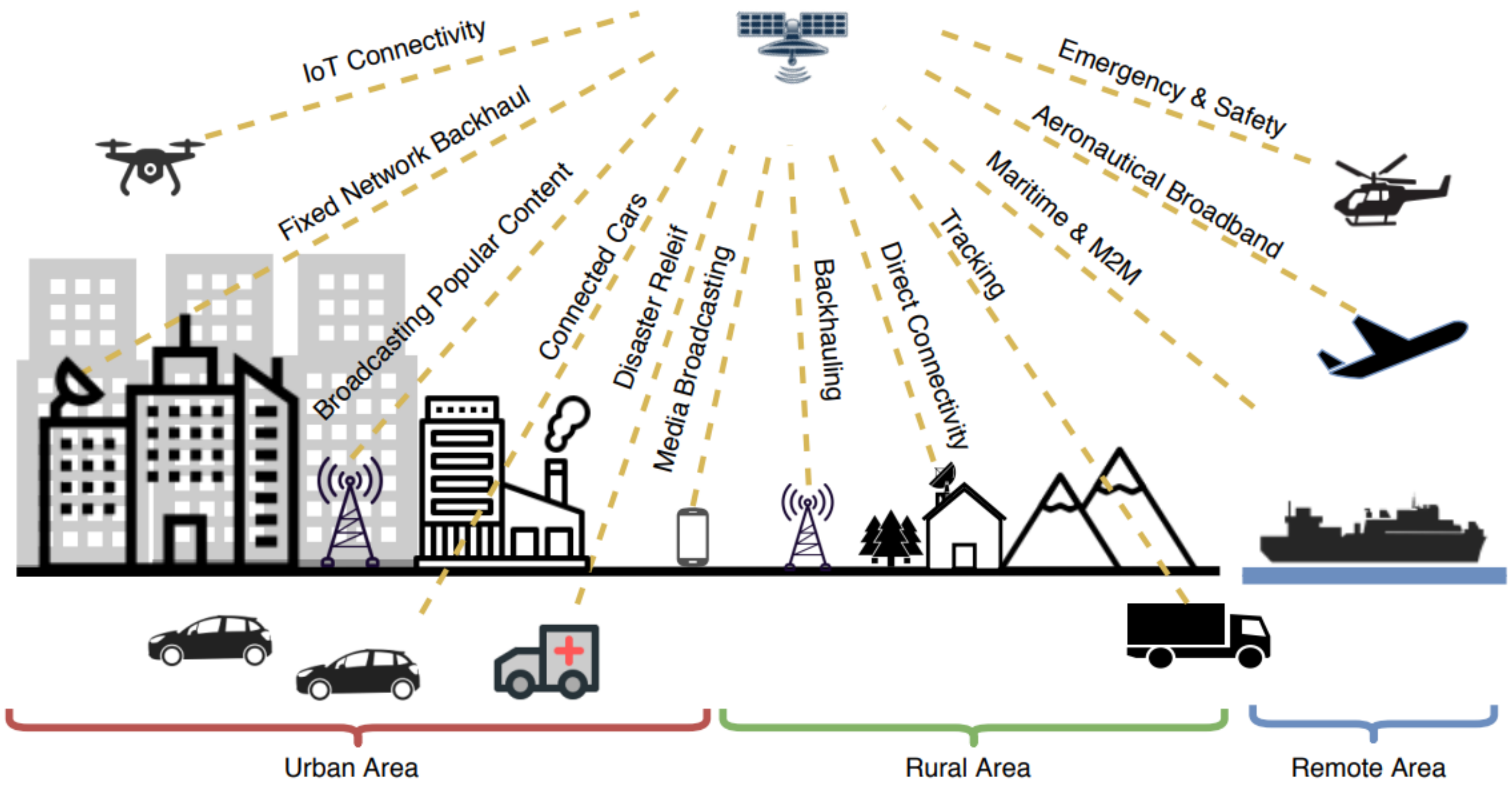
UNIVERSITÉ CÔTE D'AZUR

RF Things

space Lacuna

New space for IoT

CubeSat provide an “affordable” access to space



CubeSat applications

O. Kodheli *et al.*, "Satellite Communications in the New Space Era: A Survey and Future Challenges," in *IEEE Communications Surveys & Tutorials*, vol. 23, no. 1, pp. 70-109, Firstquarter 2021, doi: 10.1109/COMST.2020.3028247.

IA on the Edge : Deployment on MCU

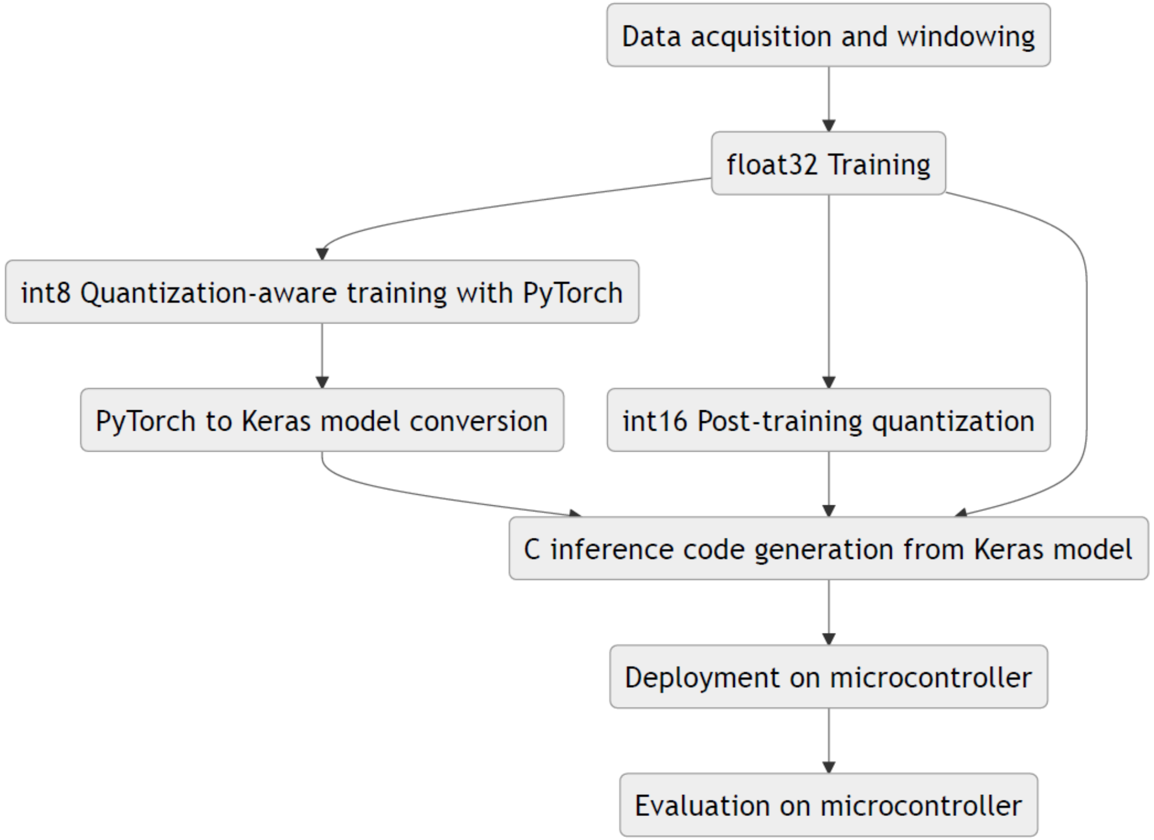
After the network has been trained and quantized it is deployed:

- **Export the weights** of the DNN and encode them into a format suitable for on-target inference
- **Generate the inference program** according to the topology of the DNN
- **Compile** the inference program
- **Upload** the program with weights onto the MCU's ROM

Pierre-Emmanuel Novac, Ghouthi Boukli Hacene, Alain Pegatoquet, Benoît Miramond, Vincent Gripon. Quantization and Deployment of Deep Neural Networks on Microcontrollers. *Sensors*, MDPI, 2021

IA on the Edge : Deployment on MCU

MicroAI General Flow



Pierre-Emmanuel Novac, Ghouthi Boukli Hacene, Alain Pegatoquet, Benoît Miramond, Vincent Gripon. Quantization and Deployment of Deep Neural Networks on Microcontrollers. *Sensors*, MDPI, 2021

Conclusion

- The combination of Edge AI and sensors
  - makes AI to the contact of the physics of the real world
  - Addresses the question of the energy consuption reduction of AI

- **By bringing AI closer to the sensor, the goal is**
  - **To reduce the amount of data to communicate**
  - **To lower the global energy consumption of the digital infrastructure**
  - **To reduce latency for decising making (close or open loop)**

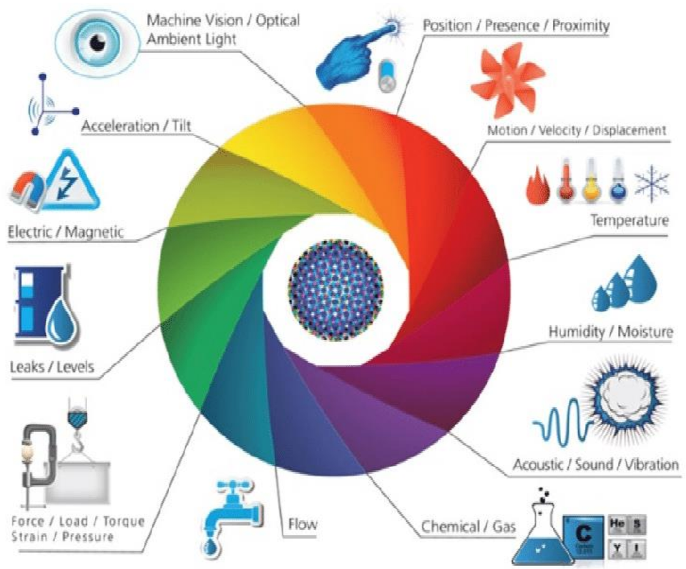
- Original approach and promising results on bio-inspired AI thanks to
  - Greater sparsity
  - Event-based processing (specific neuromorphic hardware)
  - Reduced power consumption
  - And a large amount of unexplored features in the brain

- Remaining challenges for EdgeAI / Neuromorphic architectures
  - **Training methods SNN are not so mature** compared to standard machine learning
  - A lack of european actors in the domain of Electronic manufacturers for **AI Chips**
  - **On-line/On-board training** is still an open question related to catastrophic forgetting in ML

  - Interested ? Join 3IA Côte d'Azur … join LEAT

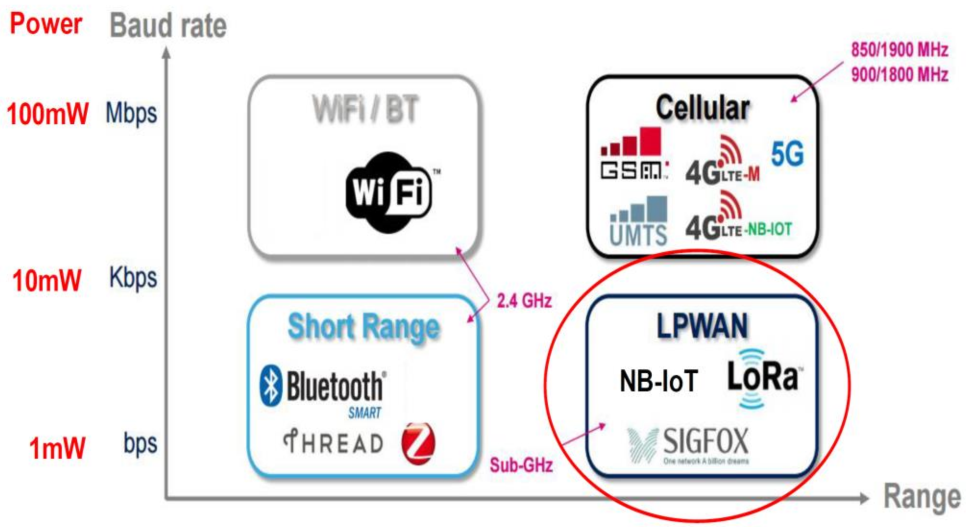
Key elements of IoT sensors

Sensors



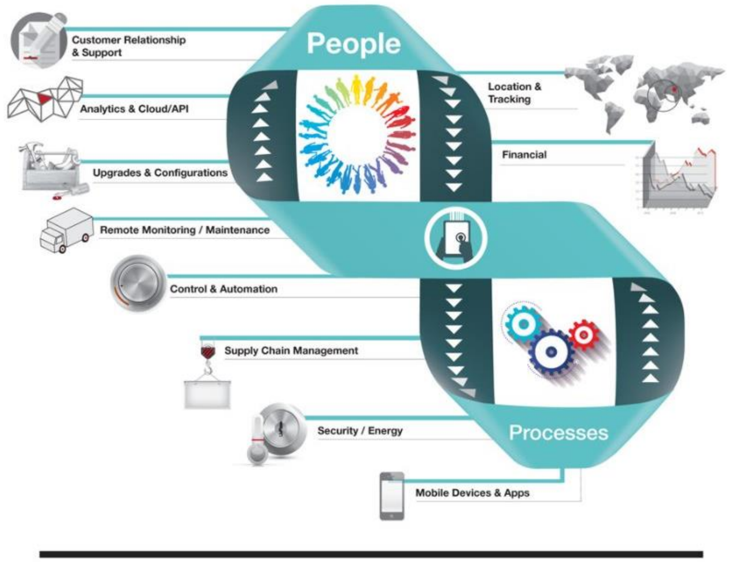
Captures a discrete representation of the dynamics of the physical world

Connectivity



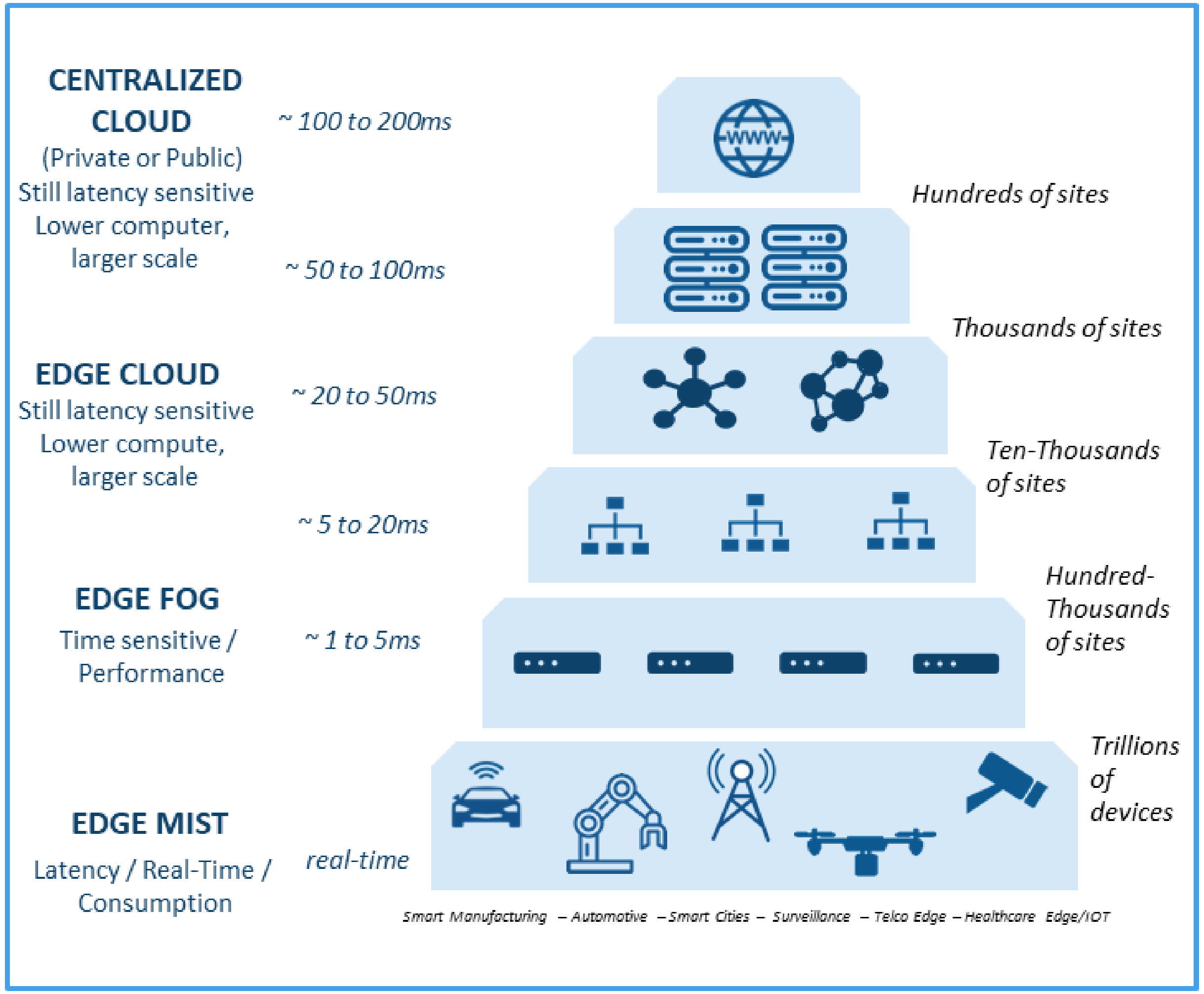
Transmits the sensors data through wireless communication

Persons & process



Provides the information to people or process the raw data into more abstract information

Edge Lines and their specific constraints



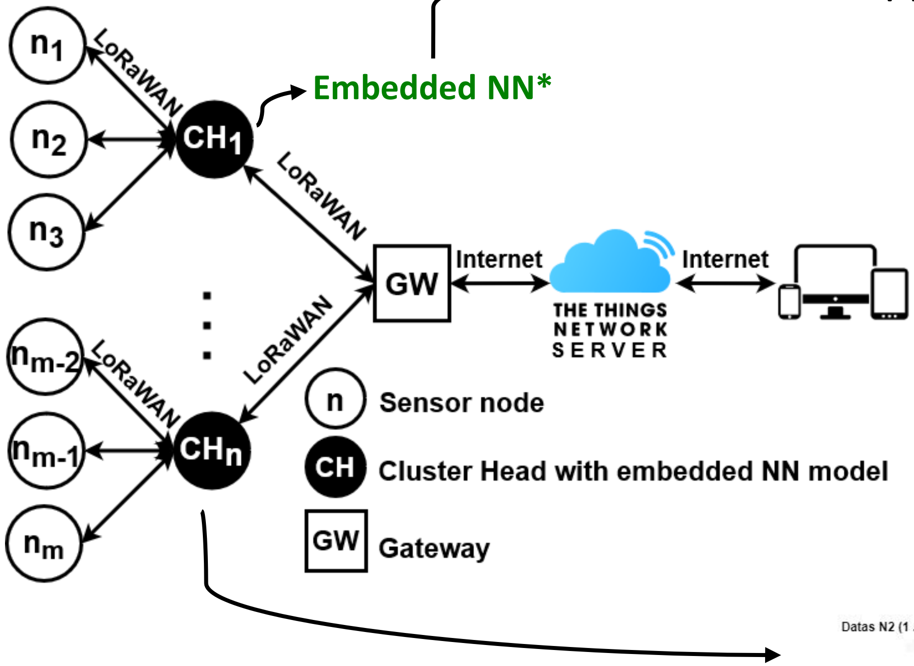
	Memory	Computation	Power	Efficiency
Edge Servers	GB	1 Tops	100 W	10 Gops/W
Gateway	MB	100 Gops	1 W	100 Gops/W
IoT Nodes	Hundreds of kB	1 Gops	1 mW	1 000 Gops/W

Low-Power Architecture for WSNs

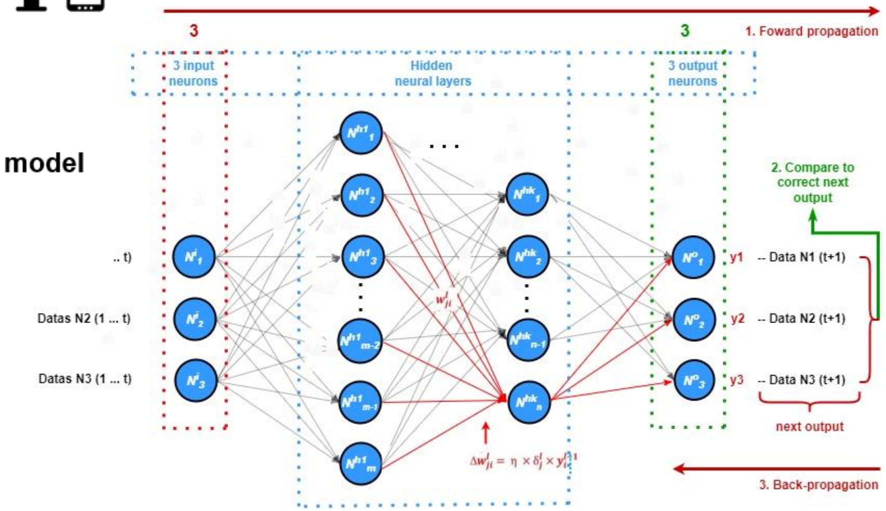
Overview of the global infrastructure

- Network Topology

Reduce the number of transmissions
Prediction of sensor data



MicroAI

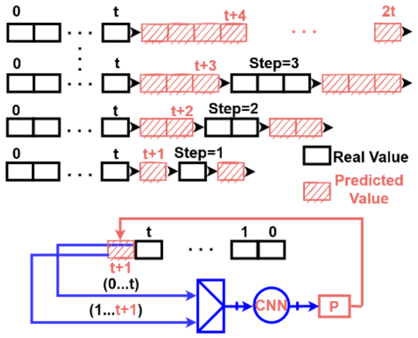


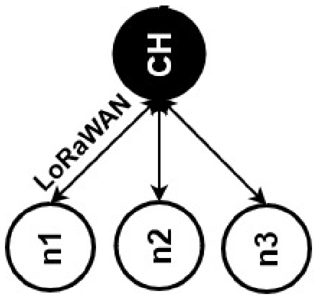
* Neural Network

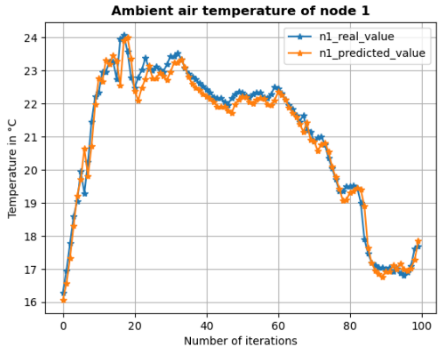
Experiments and Results

Results on different simulations

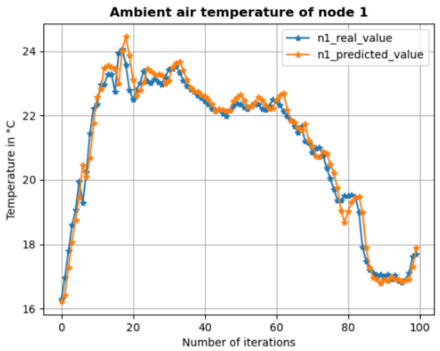
- Decision on change of rate





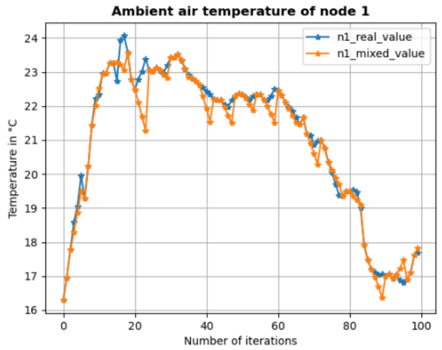


Structure A (MSE = 0,123)

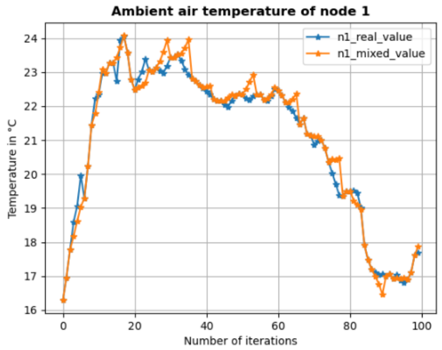


Structure B (MSE = 0,148)

Evolution of real and predicted data for sensor node 1.



Structure A (MSE = 1,637)



Structure B (MSE = 1,136)

Evolution of real and predicted data for sensor node 1 for a step of 3 for the decision on change of rate.

EdgeAI, let's play !

The field of possibilities is only limited by your imagination

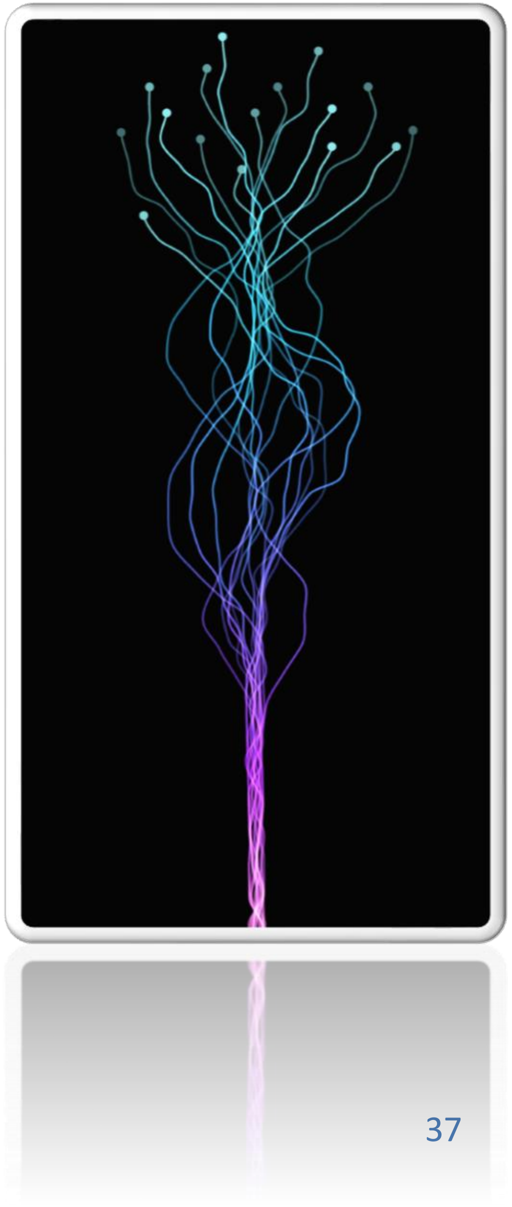
Plug

Train

Embed

Play

Repeat …

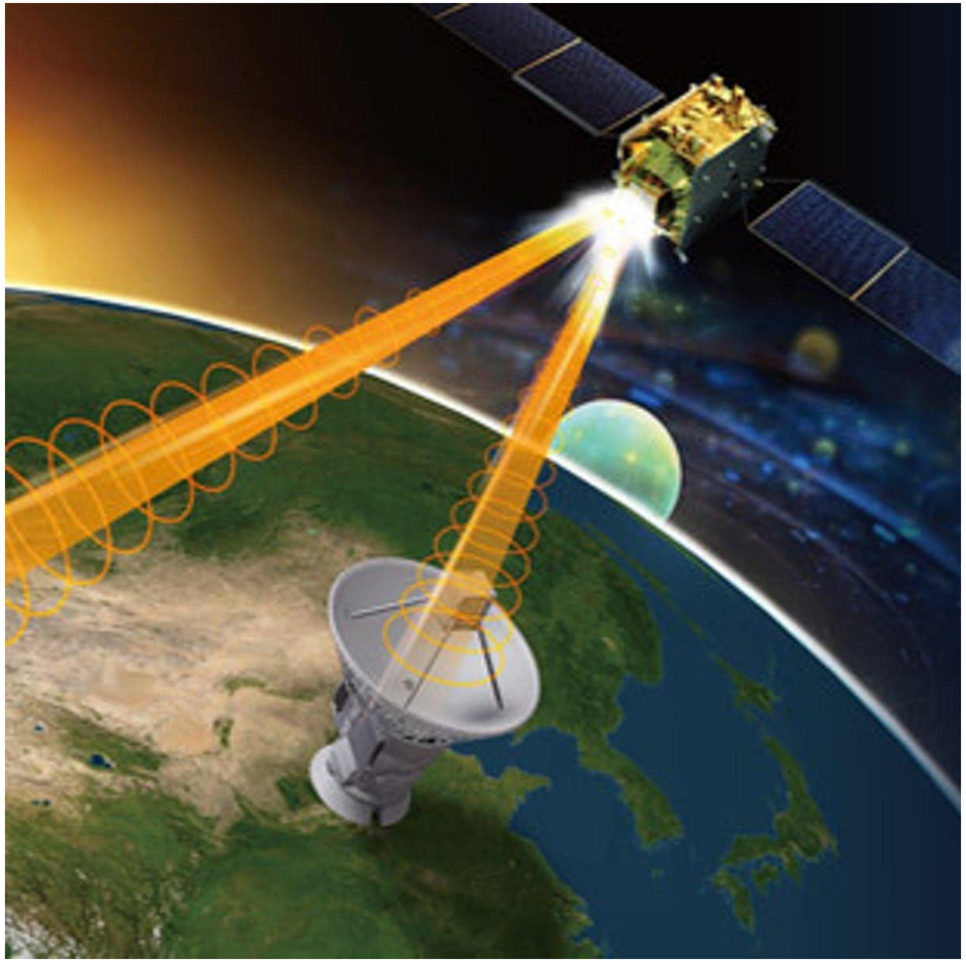


IDEX <u>**Sith**</u> project, F. Ferrero, L. Rodriguez, B. Miramond

Example of near-sensor classification

THALES

CIAR



Send the entire image

1

VS.

Send only the images without clouds, fire, …

2