TERRA FORMA

Towards Energy Autonomous Wireless Sensor Networks

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Univ Rennes, IRISA, équipe GRANIT

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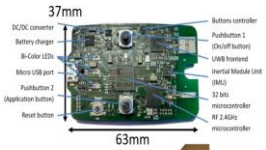
IRISA GRANIT Team in a nutshell

- **Green Radio and Adaptive Nodes for IoT**
  - Architecture department (D3) of IRISA
  - ~20 people from IUT and ENSSAT Lannion (UR1)
  - 7 permanent academic staff : 2PR and 5MCF (1 HDR)
    - ✓ O. Berder, A. Courtay, R. Gerzaguet, M. Gautier, R. Rocher, P. Scalart, B.Vrigneau
  - 3 research engineers, 2 administrative staff
  - 7 PhDs
- **From algorithms to platform implementation**
  - IoT and LPWAN
  - 5G/B5G
  - Optical communications
- **Strong partnership with industry**
  - Collaborative projects (+ 2 M€)
  - Direct grants (+ 300 k€)

Powwow IoT platform

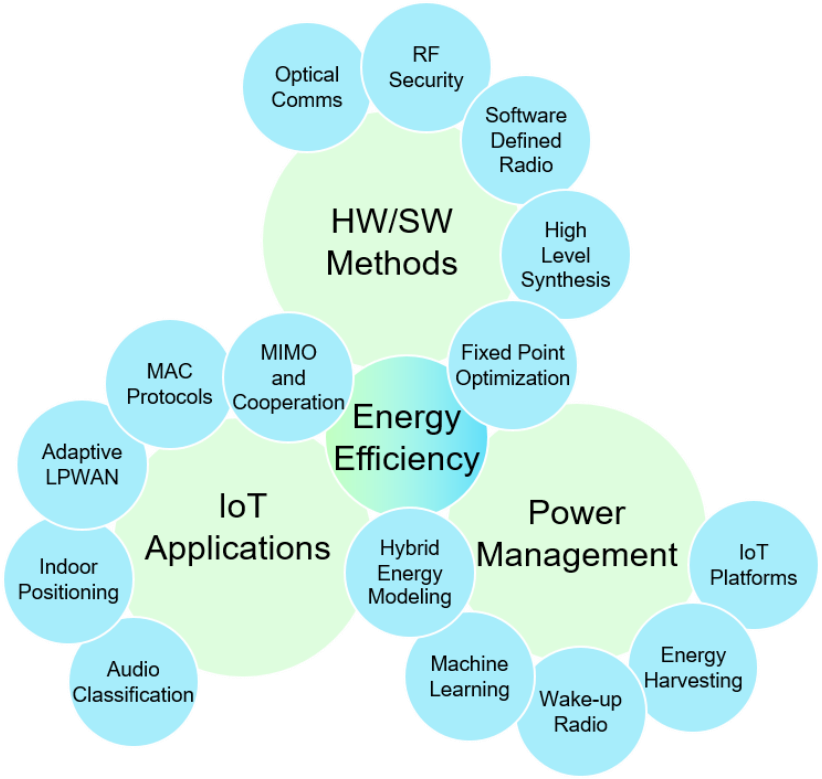


Zyggie platform

SENDATE board for optical communications

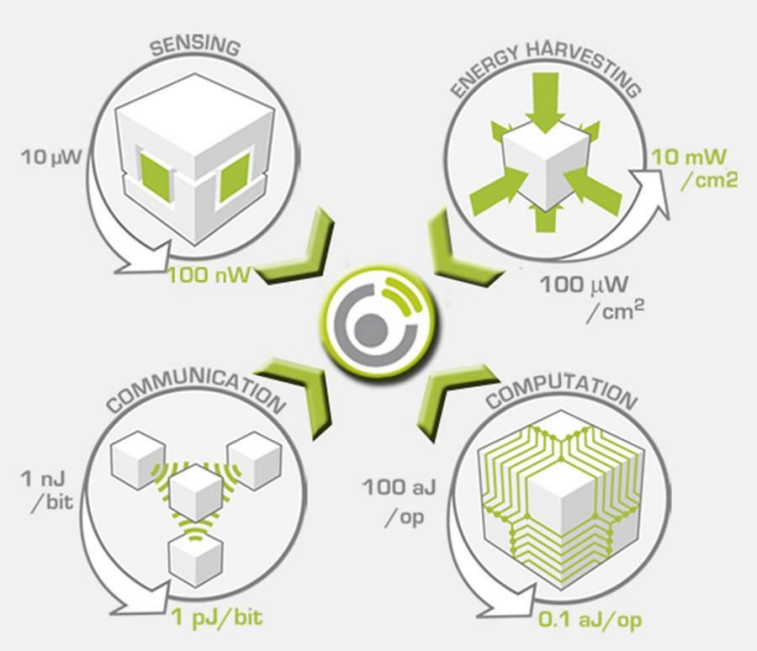
GRANIT Research topics

- **Focused on energy-efficiency**
- **3 main research areas**
  - HW/SW partitioning methods
  - IoT and WSN applications
  - Power management
- **Team emerging topics**
  - Software Defined Radio
  - RF and Hardware security
  - Wake-up radio and
    - ultra-low power nodes



How to design an energy efficient WSN platform?

1. **Decrease Transmit Power**
   - Channel coding, cooperation
2. **Optimize radio activity**
   - MAC protocols, Wake-Up radio
3. **Reduce the amount of data**
   - Compression, features extraction
4. **Optimize hardware architecture**
   - Co-processing, DVFS, power-gating
   - Energy harvesting

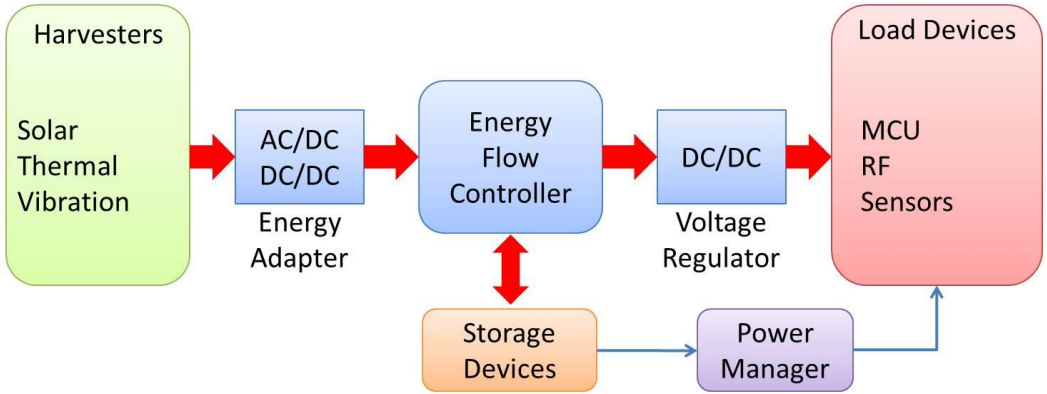


source: http://www.ga-project.eu/

Goal of future WSNs: reach energy autonomy!

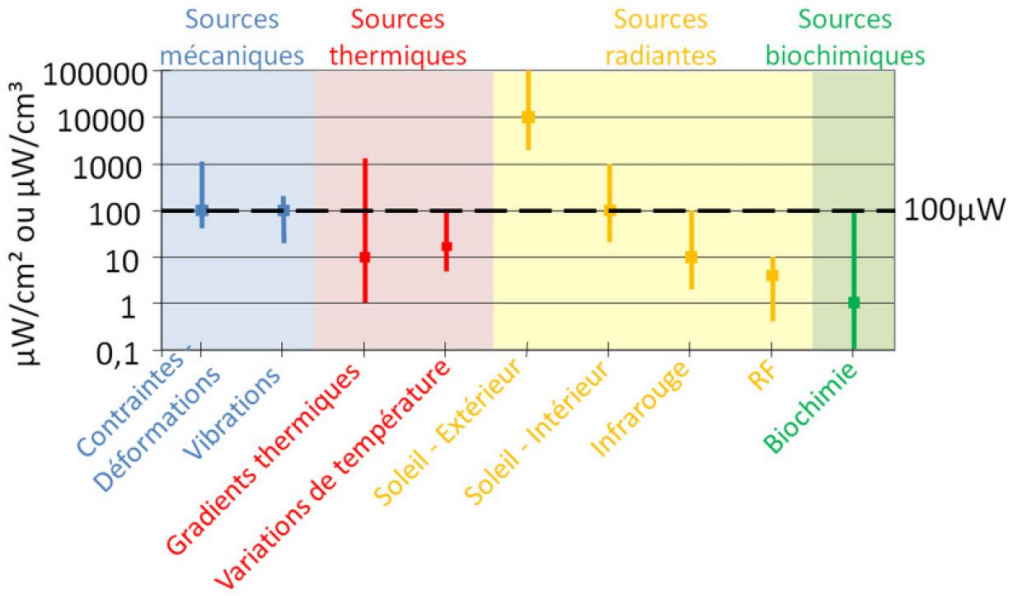
Towards autonomous sensor nodes

- **Energy manager design**
  - Multiple energy sources
    - Light, heat, moves, RF, bio…
  - Prediction algorithms… or not
  - Energy neutral operations (ENO)

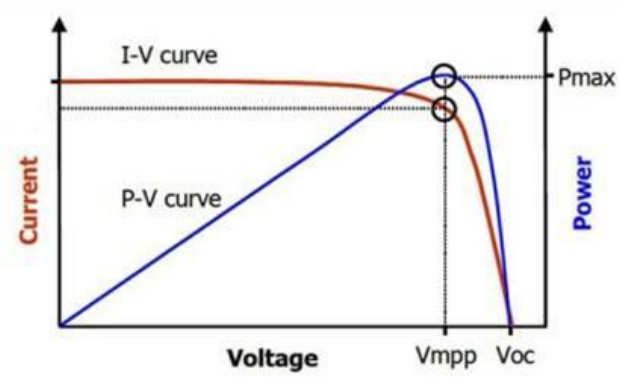


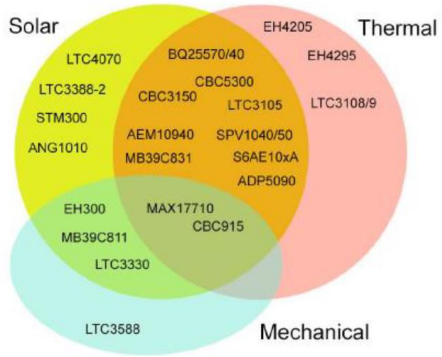
Ambient energy sources

- Typical battery-powered IoT devices are doomed to die…
  - …and changing the battery is not always feasible !
- What about ambient available energy to power IoT devices ?



Maximum Power Point Tracking

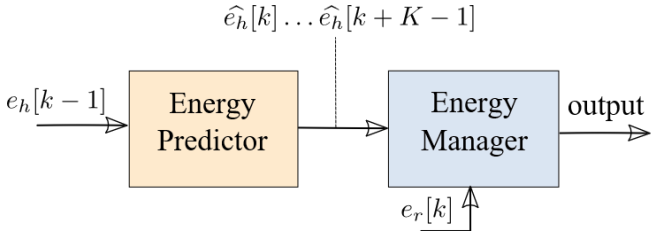




- Non ideal energy sources → there exists an optimal load
- Need to track the **Maximum Power Point**
- V_{MPP} is proportional to V_{OC}**:**
  - $V_{MPP} \approx 0.7 \times V_{OC}$ for solar panels
  - $V_{MPP} \approx 0.5 \times V_{OC}$ for TEG, windmills…
- Fractional Open Circuit Voltage method
  - measure V_{OC} to determine V_{MPP}
- Cheap and easy method to implement, used in power management IC (**PMIC**)

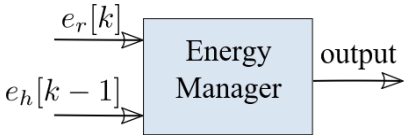
Energy Management for EH-WSNs: State-of-the-Art

- **Prediction-based EM**



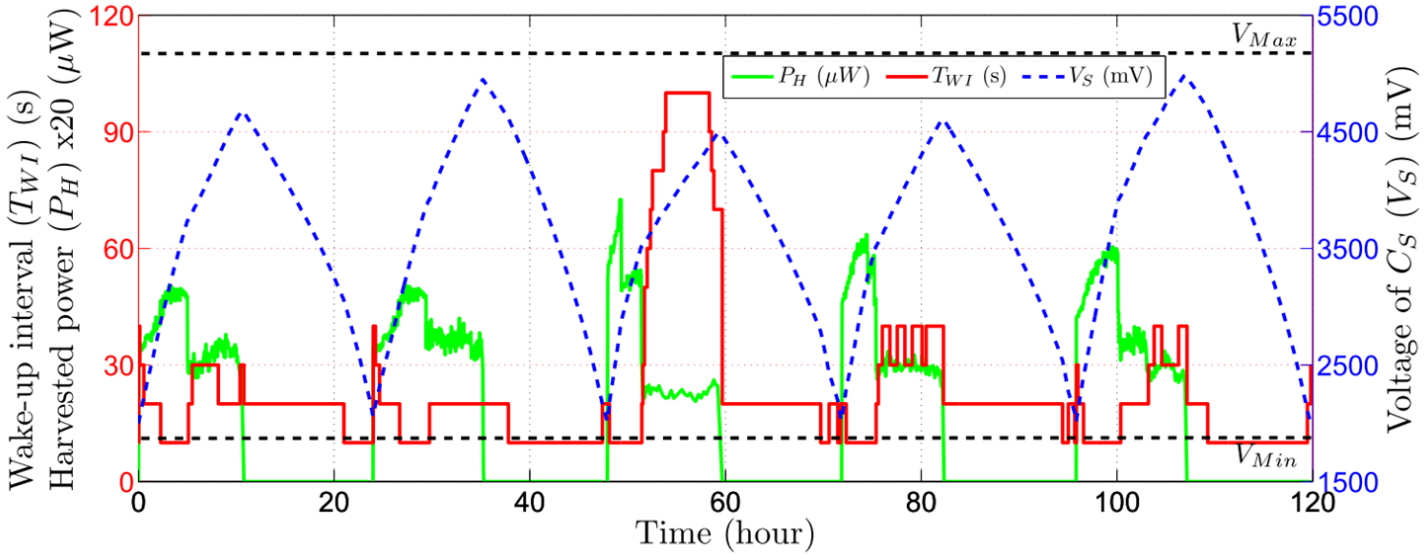
  - Specific algorithm [Kansal]
  - Linear programming [Moser]
  - Dual EM [Castagnetti]
  - Network level [Yang]
  - Kinetic energy [Gorlatova]

- **Model-free EM**



  - LQ-Tracker [Vigorito]
    - Linear Quadratic control
  - RLTDPM [Hsu]
    - Q-Learning
  - P-FREEN [Peng]
    - Set of "principles"

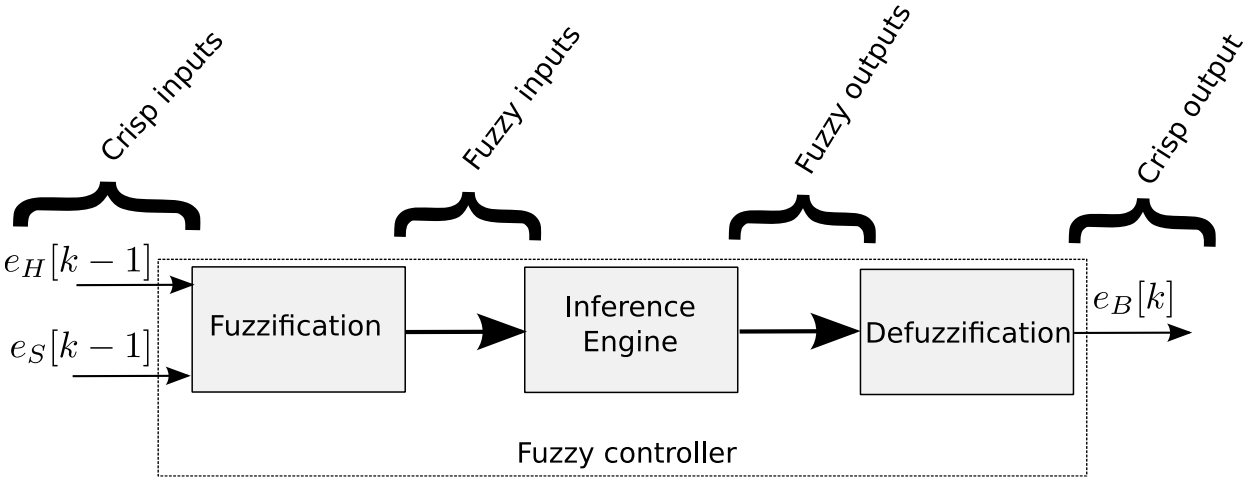
Design of generic energy harvesting



- Daily ENO
- No power failure
- Quality of services enhancement [le15acmjetc,le15ieeesj]

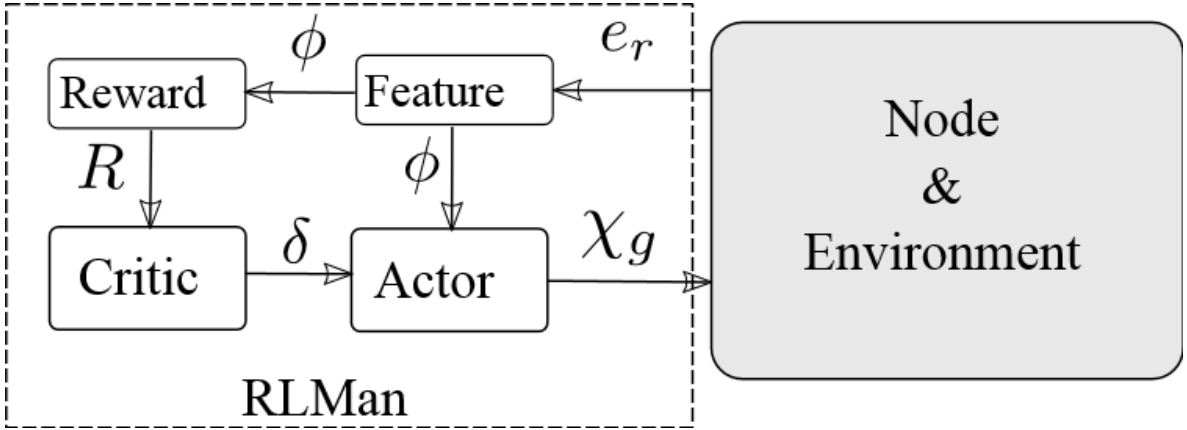
Design of generic energy managers

- **Fuzzyman: Based on fuzzy logic [aitaoudia16icc]**
  - Unstable and hard to predict energy sources and network behaviors
  - Energy harvesting systems difficult to model



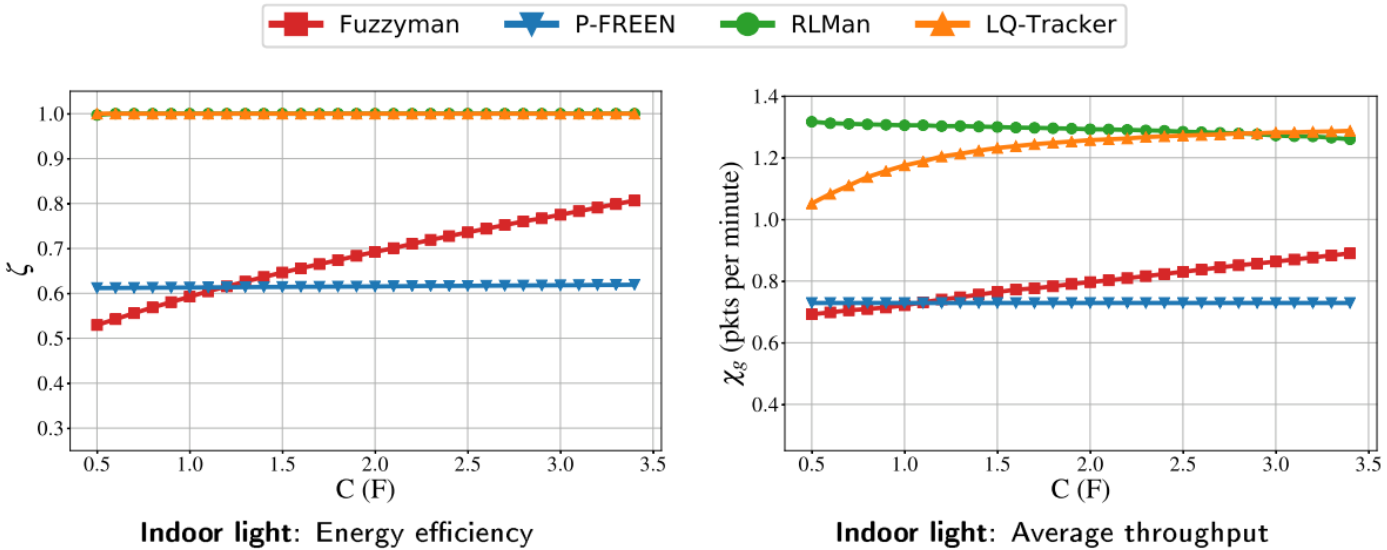
Design of generic energy managers

- **RLMan : Reinforcement learning for EM**
  - Learn the behavior of both source and sensor node



- **Trade-off between exploit and explore** **[aitaoudia18ieeetgcn]**

Results in terms of energy and QoS

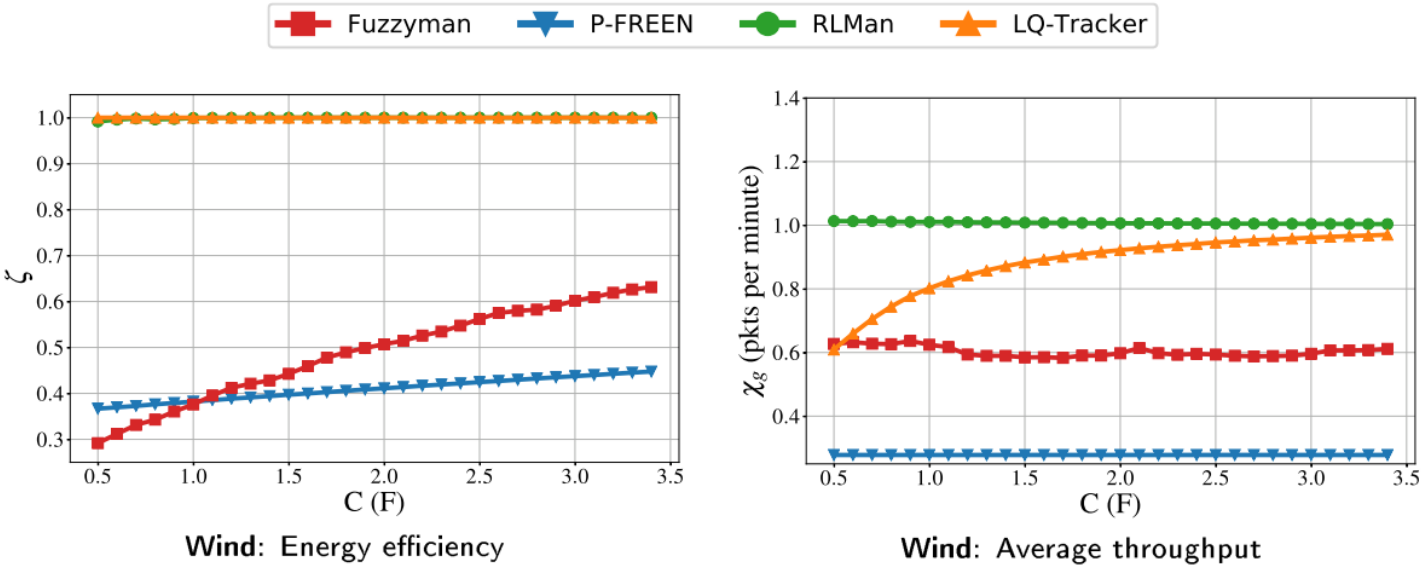


Indoor light: Energy efficiency

Indoor light: Average throughput

- Only RL Man and LQ Tracker do not waste anything
- RLMan has a better data rate
- Fuzzyman has to be parameterized according to material and source

Results in terms of energy and QoS



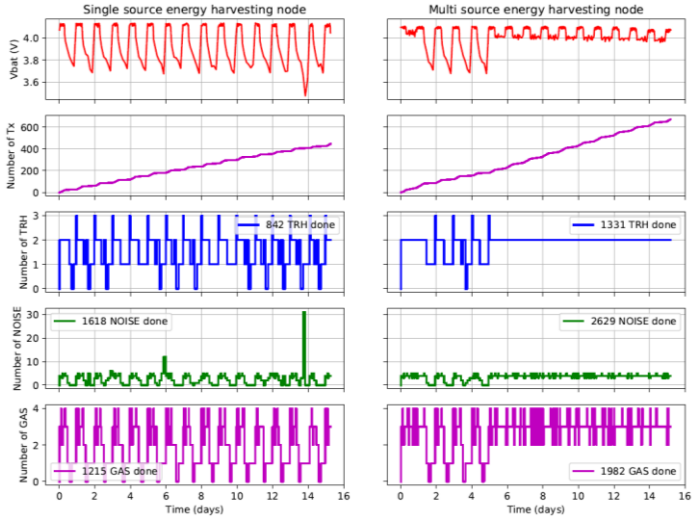
Wind: Energy efficiency

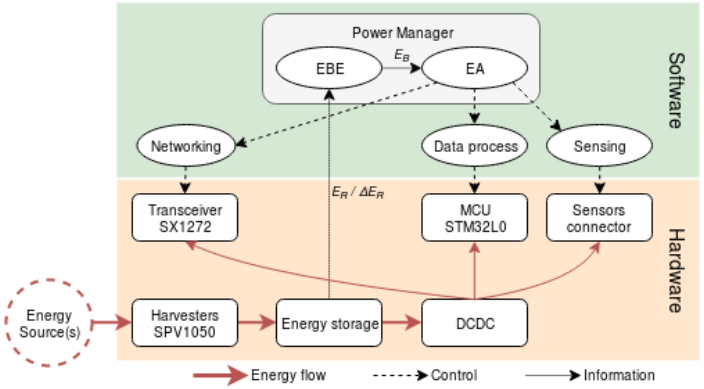
Wind: Average throughput

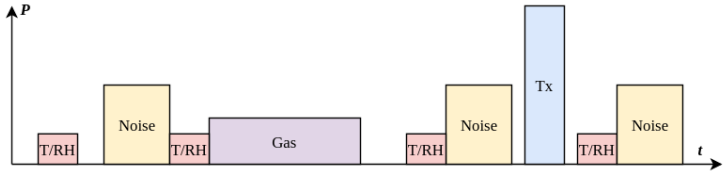
- Same results for wind
- No need to adapt RL Man between wind and indoor light : it learns!

Multi-sources energy harvesting and LoRa autonomous nodes

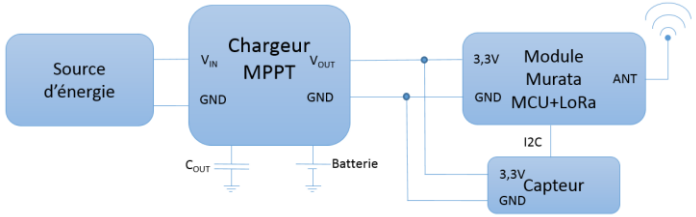
- CIFRE PhD with Wi6Labs (2015-2018)
- LoRa transmissions : energy hungry
- No need for too complex EM [gleonec18ict]
- Energy allocation



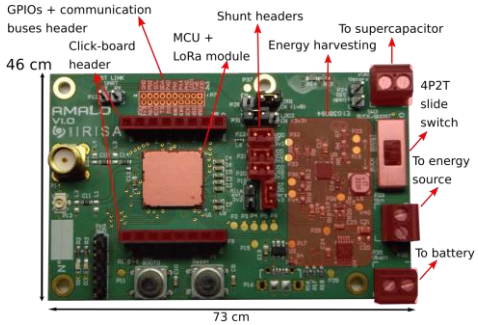




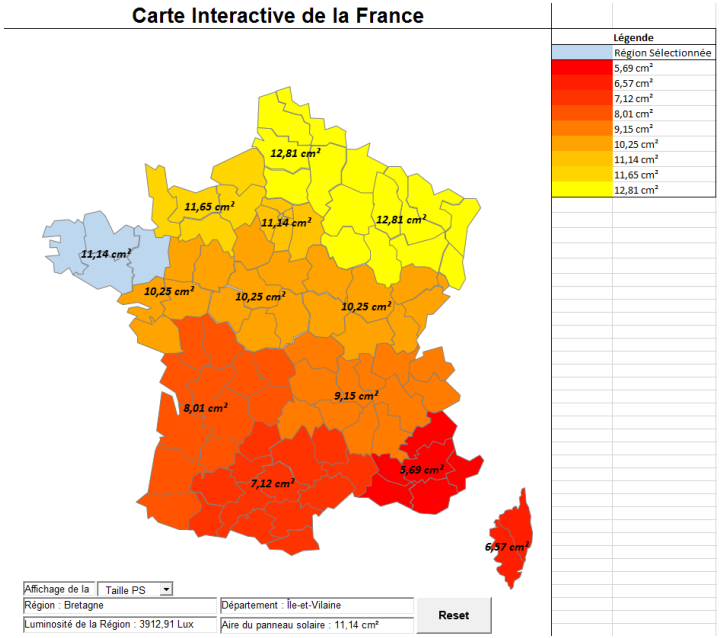
Autonomous node design



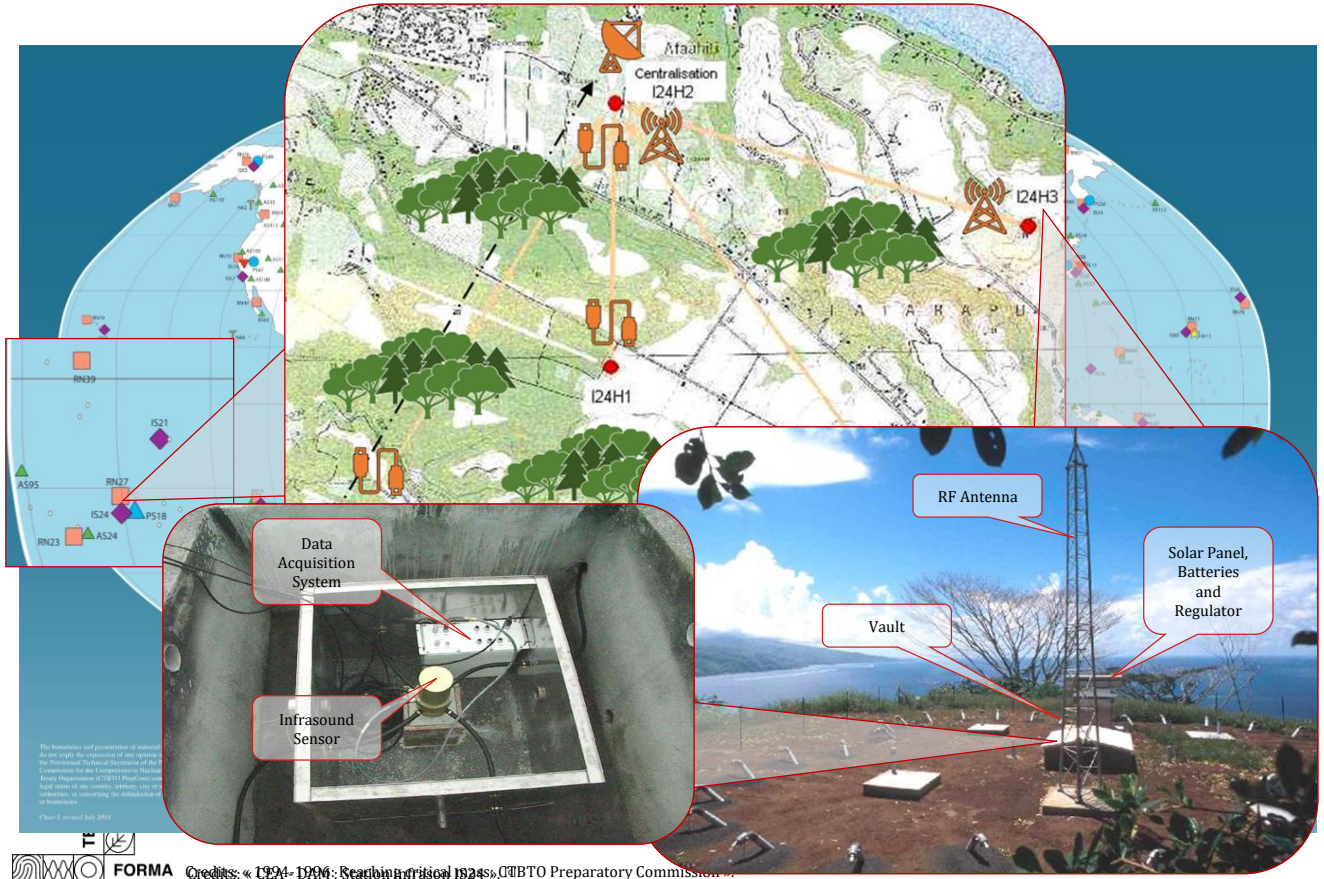
- Tool for dimensioning
  - Photovoltaic panel
  - Energy storage
- [mabon19wcmc]



SF12, BW : 125kHz, CR : 4/5, Payload 20 o, TOA : 1,319s, Pt : 14dBm



Example of infrasound sensors station



Credits: « I24H1 : Station infrason IS24 » CTBTO Preparatory Commission

State-of-the-art Application

→ Focus on IS24 station in Tahiti-Polynesia (FRA)

→ Remote location to mitigate the noise of man-made activities

→ Vegetated area to mitigate the wind-generated noise

→ Array geometry with an aperture from 1 to 4 km

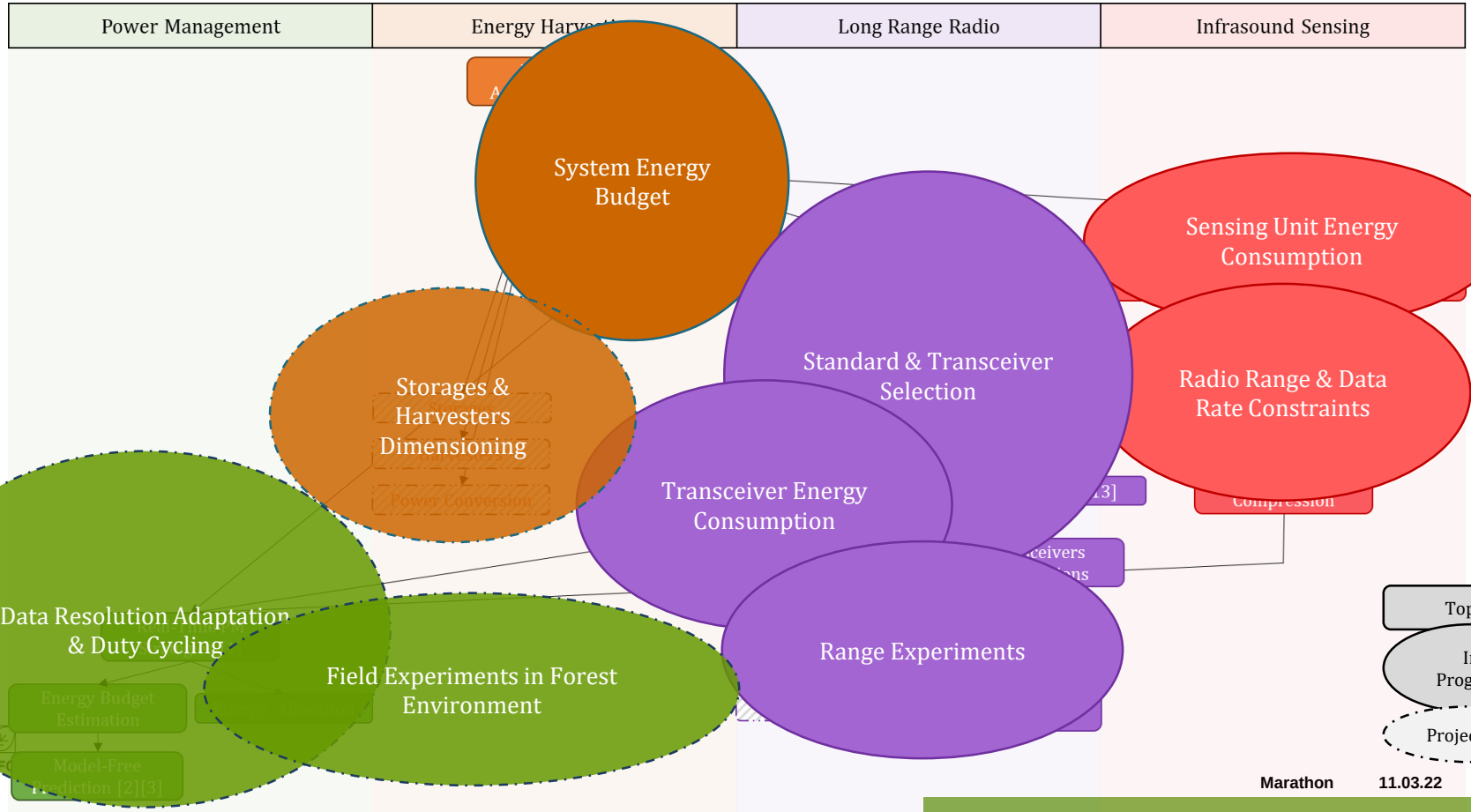
→ Number of elements from 4 to 12

→ One central recording facility

→ RF antenna or optic fiber, standalone photovoltaic systems or power grid

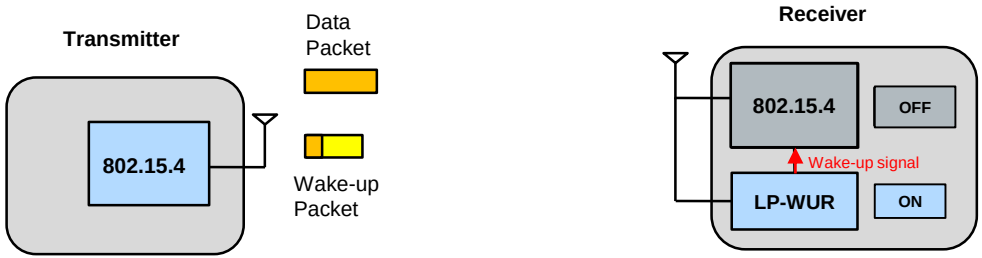
→ Analog infrasound sensor and a data acquisition system, GPS time-stamped

Example of infrasound sensors station



Wake-up radio principle

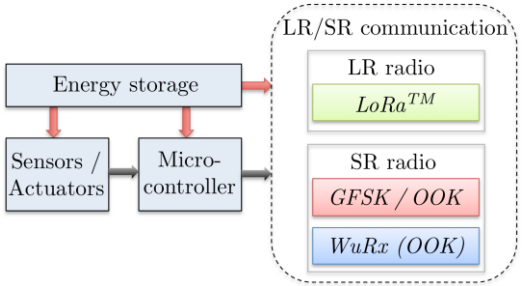
- **Revolution of IoT networks**
  - Exponential increase of IoT market, LPWAN emergence
  - The more you deploy nodes, the less you want to change batteries
  - Latency can be a problem for some applications
- **Towards a trade-off between energy and latency : wake-up radio**
  - Continuous listening with ultra low power consumption



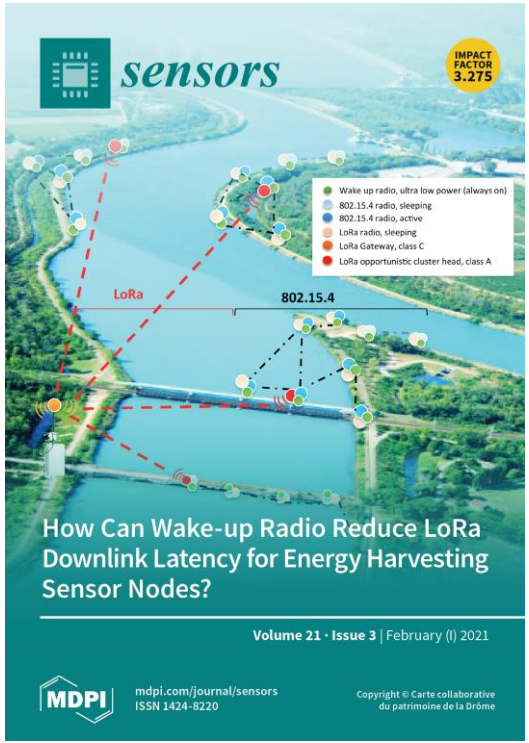
- **Change in networks paradigm**
  - WUR is a matter of trade-off (range, latency, data rate, addressing)

Heterogeneous LR/SR networks

- **ANR Wake-Up Project (2018-2022)**
  - Need to find a trade-off between latency and energy efficiency
  - Emergence of both LPWAN and Wake-up
  - Clustered network [djidi21sensors]



  - Heterogeneous node design [magno17ieeedate]

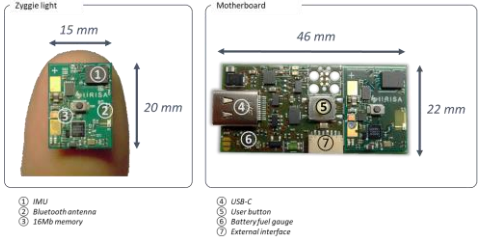


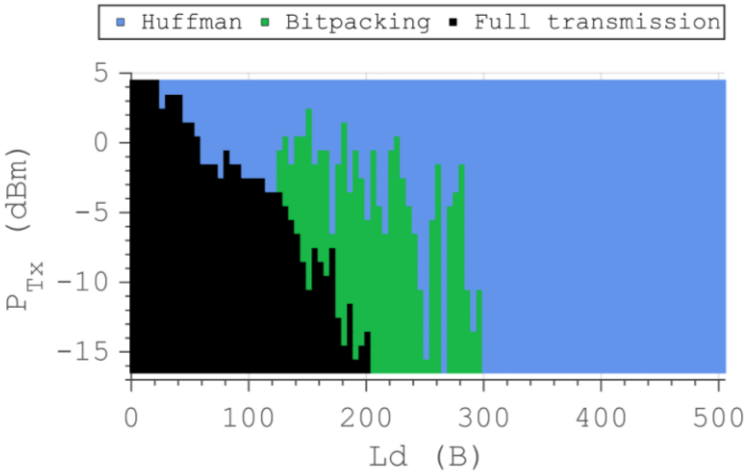
Why to reduce the amount of data. . . and when to do it?

- **Energy consumption in WSN context is a critical point**
  - 45 µJ to send one byte with 802.15.4 (3.5 dBm)
    - Equivalent to 45000 multiplications on Igloo FPGA
    - Equivalent to 760 µs on an ARM Cortex M4 (floating point computation)
  - 22 µJ to send one byte with 802.15.4 (-14 dBm)
- **Need for a methodology to reduce data overhead and adjust Tx power**
  - Trade off between computation and communication
- **How to do it?**
  - Source coding : compression algorithms
  - Feature extraction to feed classifiers
  - At the network level : data fusion and aggregation

Adaptive data compression

- **The best choice depends of**
  - Distance between nodes
  - Data length
  - Data type

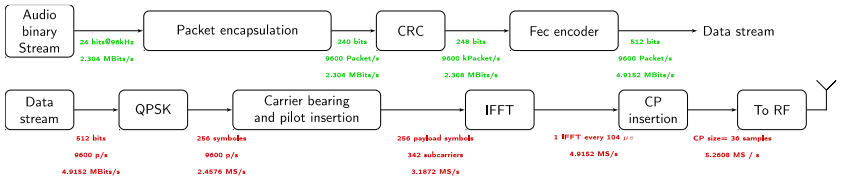


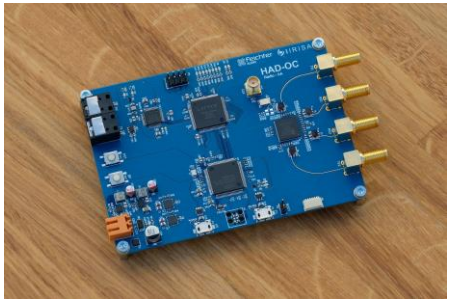


- **Necessity of an adaptive algorithm**
  - Use the architecture characteristics (CPU and radio energy consumption)
  - Estimate the consumption of each method (computation time + radio transmission)

Low Power Software Defined Radio

- **Low power SDR**
  - Custom wireless communications
    - Projet PME with Feichter electronics
    - High quality, high data rate, low latency 3D audio wireless transmission
    - Custom low power SDR based on micro-controller





- **Multistandard IoT**
  - EIT Digital thesis of Jules Courjault (with CG Wireless)
  - Adaptive LPWAN with RL

Conclusions

- **Complete energy autonomy is now possible**
  - Various energy sources
  - Efficient energy managers to reach energy neutrality
- **Emergence of low power radio techniques**
  - Wake-up radio : consumes quasi-nothing while continuously listening
  - LPWAN : long range but low power
  - New network paradigms
- **Near sensor computing**
  - Trade-off between local processing and data transmission
- **Energy efficiency needs cross layer design**
  - Impact of both hardware and protocol stack to consider
- **RF energy harvesting**
  - Simultaneous Wireless Information and Power Harvesting
  - Backscatter
- **Security energy cost? Confidentiality?**

Selected bibliography

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