Les défis des systèmes de calcul verts et durables: de la récupération et gestion de l'énergie au traitement d'information adapté

Les énergies renouvelables et décarbonnées, IJL, Nancy

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le 18 avril 2024

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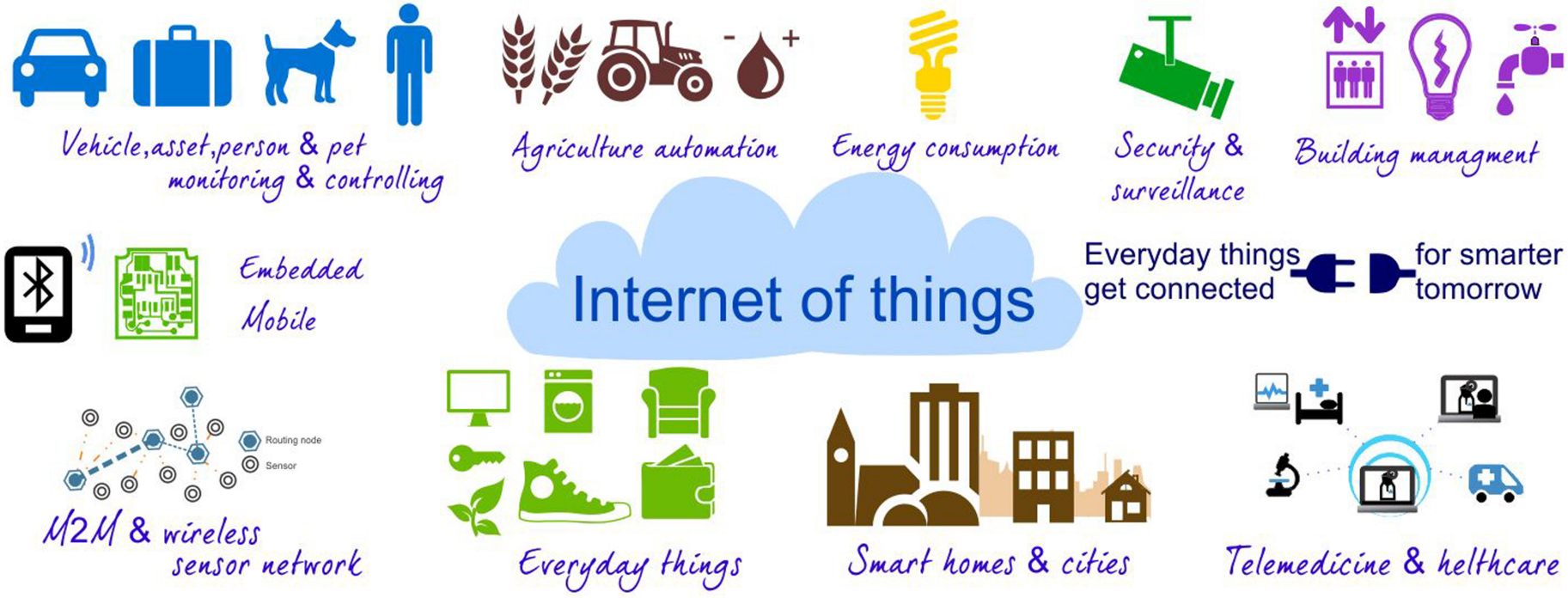
Summary

Introduction

Internet of things[1]

- Thing + HW/SW = Thing-based function + IT-based service



[1] *Internet of Things*. http://www.satiztpm.it/internet-things/?lang=en. Accessed: 2019-09-30.

Introduction

Internet of things

- From tens of isolated autonomous and disconnected devices (M2M) to billions of connections of `Things`

  → smart systems, sensors, devices, processes, industries, services, people, etc ⇒ *Internet of Everything (IoE)*
- Number of connected devices by 2025[2]

  → estimated at 41.6 billions
- Huge market opportunities[2]

  → huge revenues expected by IoT suppliers (2-6 trillions $)
- Growth in number of connected devices

  → unparalleled scale of generated data

  → huge amount of data to transmit (and process)

[2] Ibrahim Ali, Khaled Wassif, and Hanaa Bayomi. "Dimensionality Reduction for Images of IoT Using Machine Learning". In: *Scientific Reports* 14.1 (Mar. 2024), p. 7205. ISSN: 2045-2322. DOI: 10.1038/s41598-024-57385-4. (Visited on 04/07/2024).

Introduction

Internet of things → Big Data[5]

- Four salient features **4Vs** of **Big Data**
  → **V**olume, **V**ariety, **V**elocity, **V**alue
- **Goal**: Process all these data and extract actionable insights
- Traditional data processing not suitable anymore
  → AI-based methods
- *Context-aware computing*[3] → location, users, devices, etc
- *Cognitive computing*[4]: sense, predict, infer, learn tasks and environment

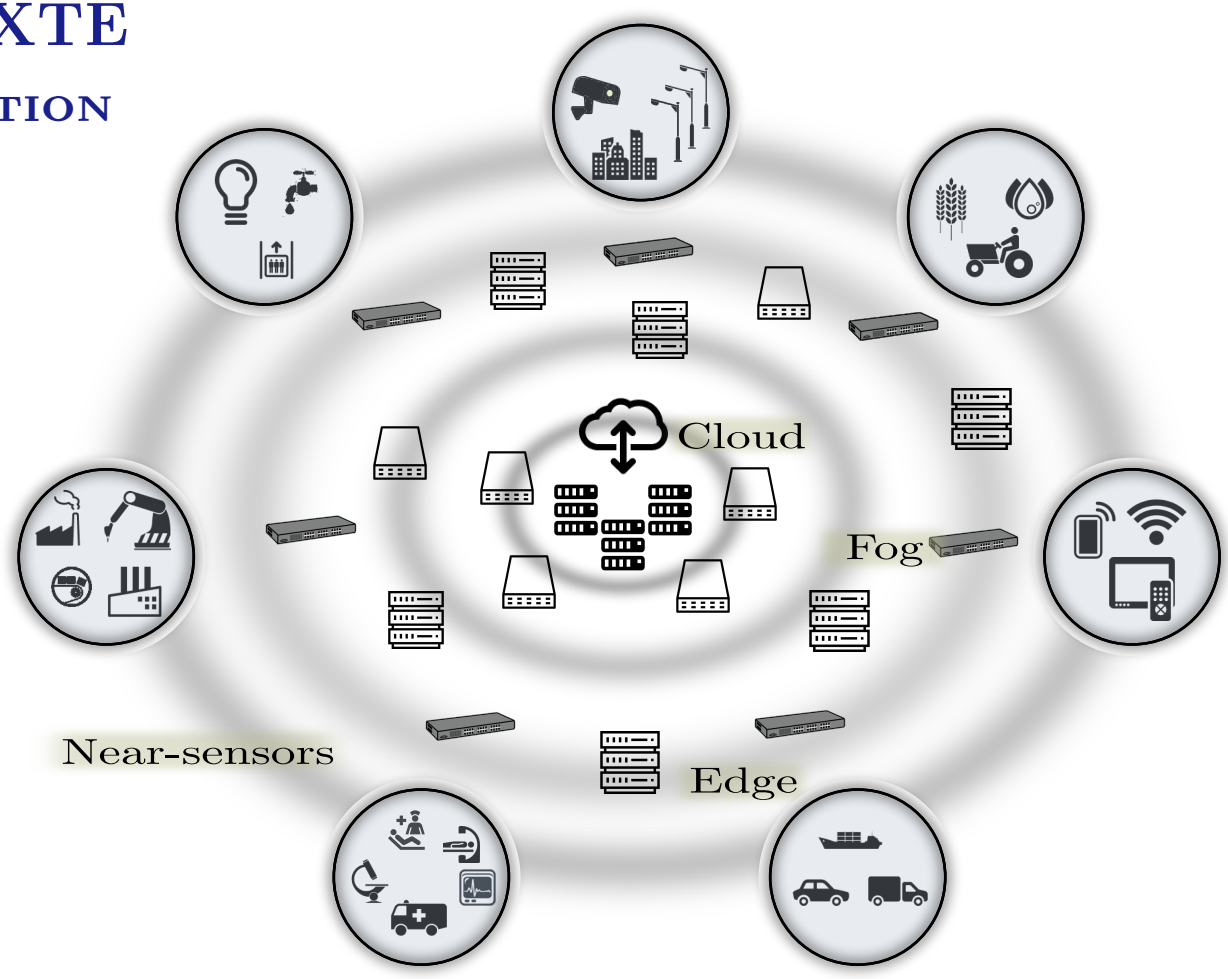
[3] Omer Berat Sezer, Erdogan Dogdu, and Ahmet Murat Ozbayoglu. "Context-Aware Computing, Learning, and Big Data in Internet of Things: A Survey". In: *IEEE Internet of Things Journal* 5.1 (Feb. 2018), pp. 1–27. ISSN: 2327-4662. DOI: 10.1109/JIOT.2017.2773600. (Visited on 04/14/2024).

[4] Shivam Gupta et al. "Big Data with Cognitive Computing: A Review for the Future". In: *International Journal of Information Management* 42 (Oct. 2018), pp. 78–89. ISSN: 02684012. DOI: 10.1016/j.ijinfomgt.2018.06.005. (Visited on 04/14/2024).

[5] Amina Adadi. "A Survey on Data-efficient Algorithms in Big Data Era". In: *Journal of Big Data* 8.1 (Jan. 2021), p. 24. ISSN: 2196-1115. DOI: 10.1186/s40537-021-00419-9. (Visited on 04/14/2024).

Contexte

Introduction



- *Power Trio: AI, Big Data and IoT*[a]

[a] Yinong Chen. "IoT, Cloud, Big Data and AI in Interdisciplinary Domains". In: *Simulation Modelling Practice and Theory* 102 (July 2020), p. 102070. ISSN: 1569190X. DOI: 10.1016/j.simpat.2020.102070. (Visited on 04/14/2024).

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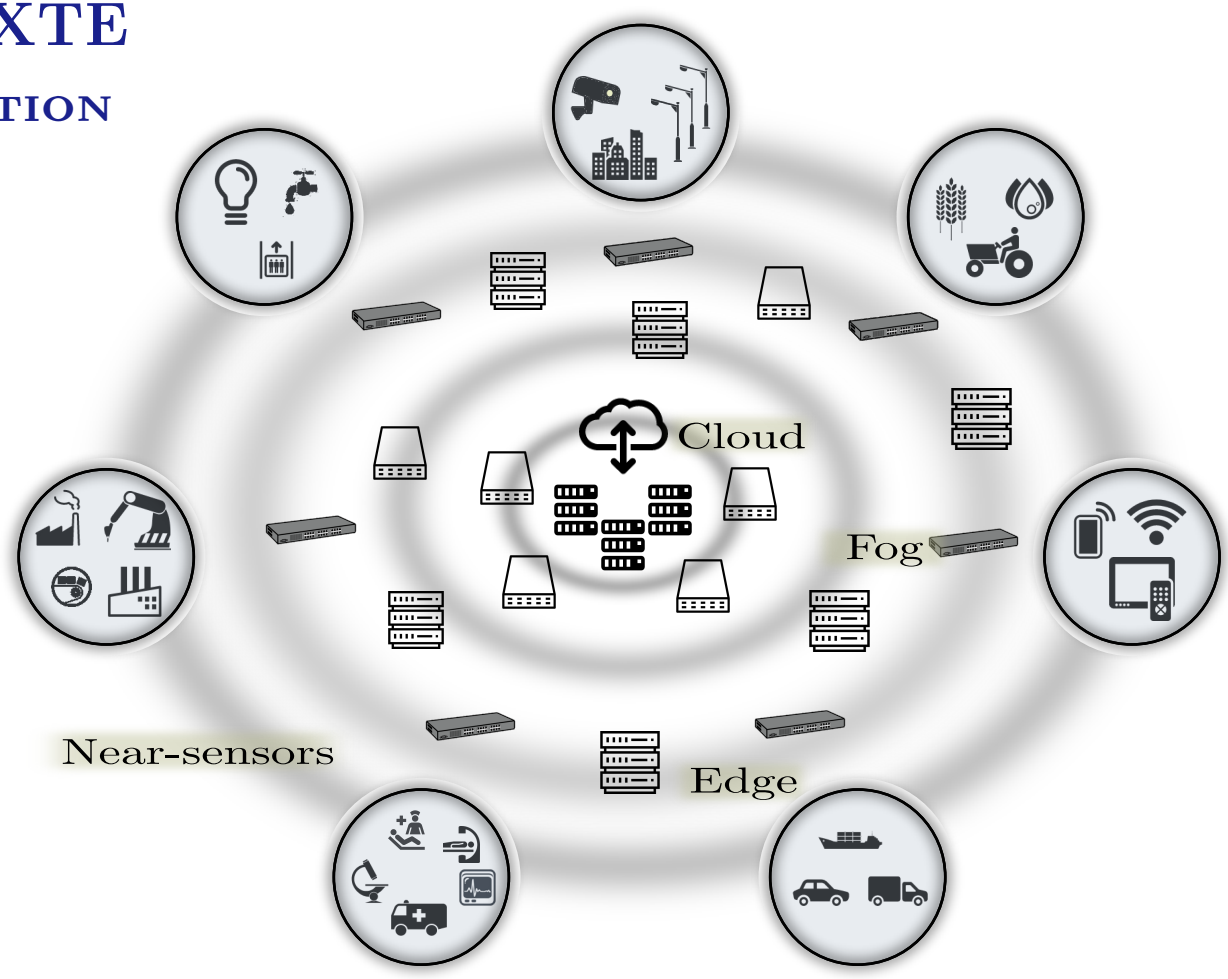
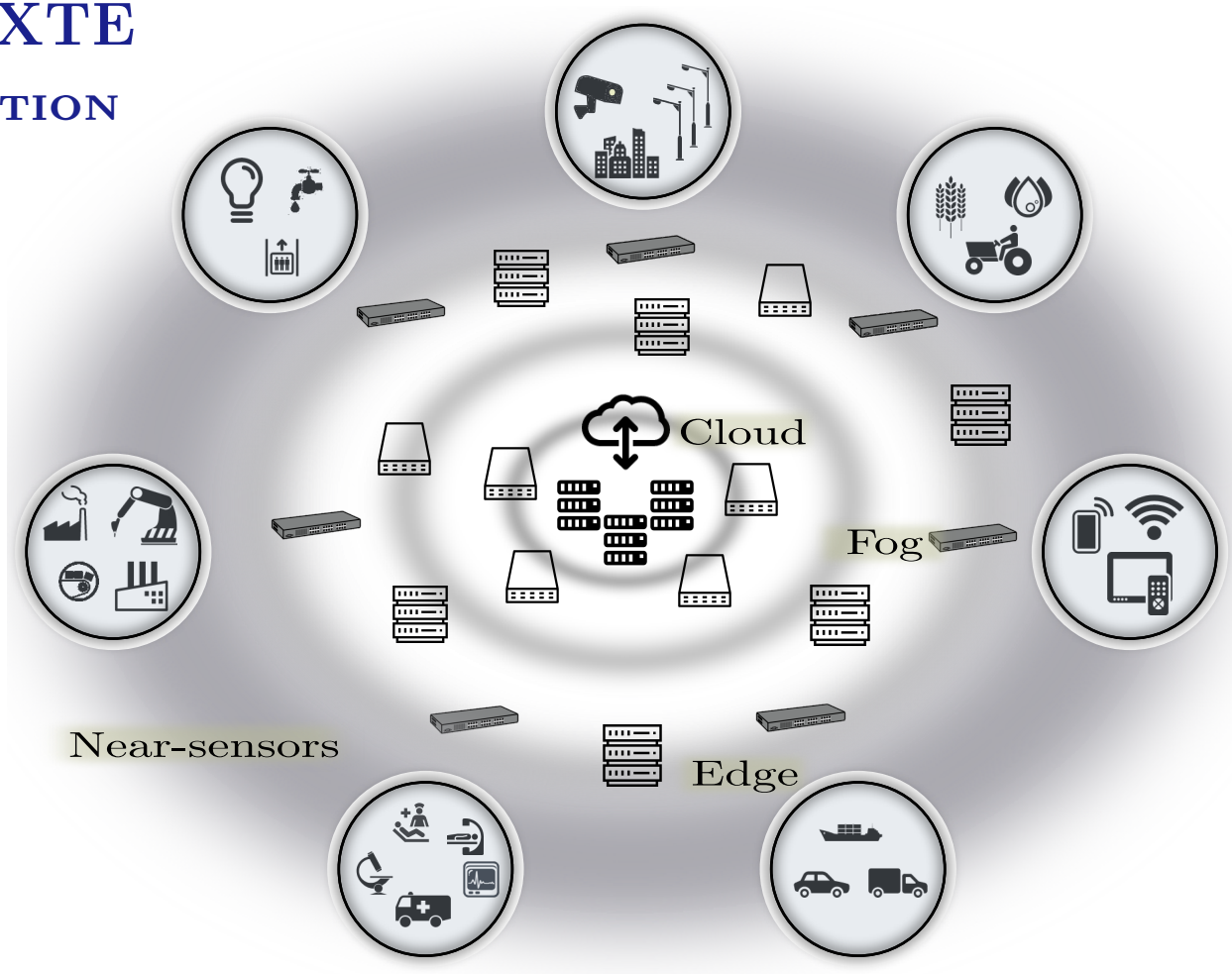


- *Near-sensors*
- *Edge*
- *Fog*
- *Cloud*

Contexte

Introduction



- *Near-sensors*
- *Edge*
- *Fog*
- *Cloud*

Introduction

Current challenges

Cloud computing:

- Inefficient
- Centralized processing
- High latency (no RT[6])
- Limited BW[6] for heavy loads
- Data privacy concerns
- Energy consum. (+20%/y.)[7]

IoT computing:

- Inefficient
- Huge amount of data generated
- High latency (request-update)
- Unnecessary BW for data sending
- Computation for data sending
- Limited lifetime

- **Solution**:

  → Pushing intelligence and processing capabilities downstream closer to where data generates

[6] RT- real-time; BW - bandwidth

[7] (Lynn H. Kaack et al. "Aligning Artificial Intelligence with Climate Change Mitigation". In: *Nature Climate Change* 12.6 [June 2022], pp. 518–527. ISSN: 1758-678X, 1758-6798. DOI: 10.1038/s41558-022-01377-7. [Visited on 04/09/2024])

Introduction

Sustanaibility - problem or solution?

- ICT energy consumption $\approx 6\%$[7] of GEC[8]
- Energy consumption of data centers $\approx 2\%$ of GEC
- IoT traffic will be preponderant in the next years[9]

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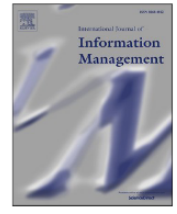

Opinion paper

Climate change and COP26: Are digital technologies and information management part of the problem or the solution? An editorial reflection and call to action☆

[7] World Bank and International Communication Union. *Measuring the Emissions & Energy Footprint of the ICT Sector - Implication for Climate Action*. Tech. rep. 2024. (Visited on 04/14/2024).

[8] GEC - Global Energy Consumption

[9] Hung Nguyen-An et al. "IoT Traffic: Modeling and Measurement Experiments". In: *IoT* 2.1 (Feb. 2021), pp. 140–162. ISSN: 2624-831X. DOI: 10.3390/iot2010008. (Visited on 04/09/2024).

[9] (Yogesh K. Dwivedi et al. "Climate Change and COP26: Are Digital Technologies and Information Management Part of the Problem or the Solution? An Editorial Reflection and Call to Action". In: *International Journal of Information Management* 63 [Apr. 2022], p. 102456. ISSN: 02684012. DOI: 10.1016/j.ijinfomgt.2021.102456. [Visited on 04/07/2024])

Introduction

Sustanaibility - problem or solution?

Powering the beast: why we shouldn't worry about the Internet's rising electricity consumption

13 Jan 2021 James McKenzie

Taken from the January 2021 issue of *Physics World*.

The Internet will use a fifth of all the world's electricity by 2025 – and that's no bad thing, says James McKenzie

- Internet: 20% of Global Energy Consumption by 2025 $\rightarrow$ (8% in 2012, 10% in 2020)
- 20% of renewable energy; 80% fossil fuels
- lot of efforts to decarbonize the data centers

[9] (James McKenzie. *Powering the Beast: Why We Shouldn't Worry about the Internet's Rising Electricity Consumption*. https://physicsworld.com/powering-the-beast-why-we-shouldnt-worry-about-the-internets-rising-electricity-consumption/. Jan. 2021. [Visited on 04/15/2024])

Introduction

Sustanaibility - ~~problem or~~ solution~~?~~

The Critical Role of Internet of Things (IoT) in Fighting Climate Change and Decarbonizing Our Planet

It's time to invest in solutions that reduce the global production of GHG.

Published Jun 03, 2022 at 10:08 AM EDT

10

- WEF identifies IoT as key technology for climate change[11]
- Impact of different topologies (centralized to distributed)[12]
- Influence of different protocols on the M2M communication[13]

[10] Newsweek. *The Critical Role of Internet of Things (IoT) in Fighting Climate Change An.* https://www.newsweek.com/critical-role-internet-things-iot-fighting-climate-change-decarbonizing-our-planet-1712448. June 2022. (Visited on 04/08/2024).

[11] World Economic Forum. *Future of the Connected World: A Roadmap for Mobilizing Global Action VISION, PROGRESS AND MEASURES OF SUCCESS.* Tech. rep. 2021.

[12] Ehsan Ahvar, Anne-Cécile Orgerie, and Adrien Lebre. "Estimating Energy Consumption of Cloud, Fog and Edge Computing Infrastructures". In: *IEEE Transactions on Sustainable Computing* 7.2 (Apr. 2022), pp. 277–288. DOI: 10.1109/TSUSC.2019.2905900.

[13] Chiara Caiazza, Valerio Luconi, and Alessio Vecchio. "Energy Consumption of Smartphones and IoT Devices When Using Different Versions of the HTTP Protocol". In: *Pervasive and Mobile Computing* 97 (Jan. 2024), p. 101871. ISSN: 15741192. DOI: 10.1016/j.pmcj.2023.101871.

Summary

IoT and Edge

Holistic approach - Sustanaibility at all levels[14]

- Sustainability by **design**
  → energy-efficient operation (comm., energy management, etc), adaptability, etc.
- Sustainable by **implementation**
  → energy- and material-efficient technologies (i.e. printed electronics)
- Sustainable by **use**
  → zero-energy (batteryless) IoT nodes with maintenance-free operation (reconfigurability, fault-tolerant, etc.)
- Sustainable **End-of-Life**
  → recycling (sustainable materials), repurposeability, circular economy cycling

[14] Marcos Katz et al. "Towards Truly Sustainable IoT Systems: The SUPERIOT Project". In: *Journal of Physics: Photonics* 6.1 (Jan. 2024), p. 011001. ISSN: 2515-7647. DOI: 10.1088/2515-7647/ad1c6a. (Visited on 04/07/2024).

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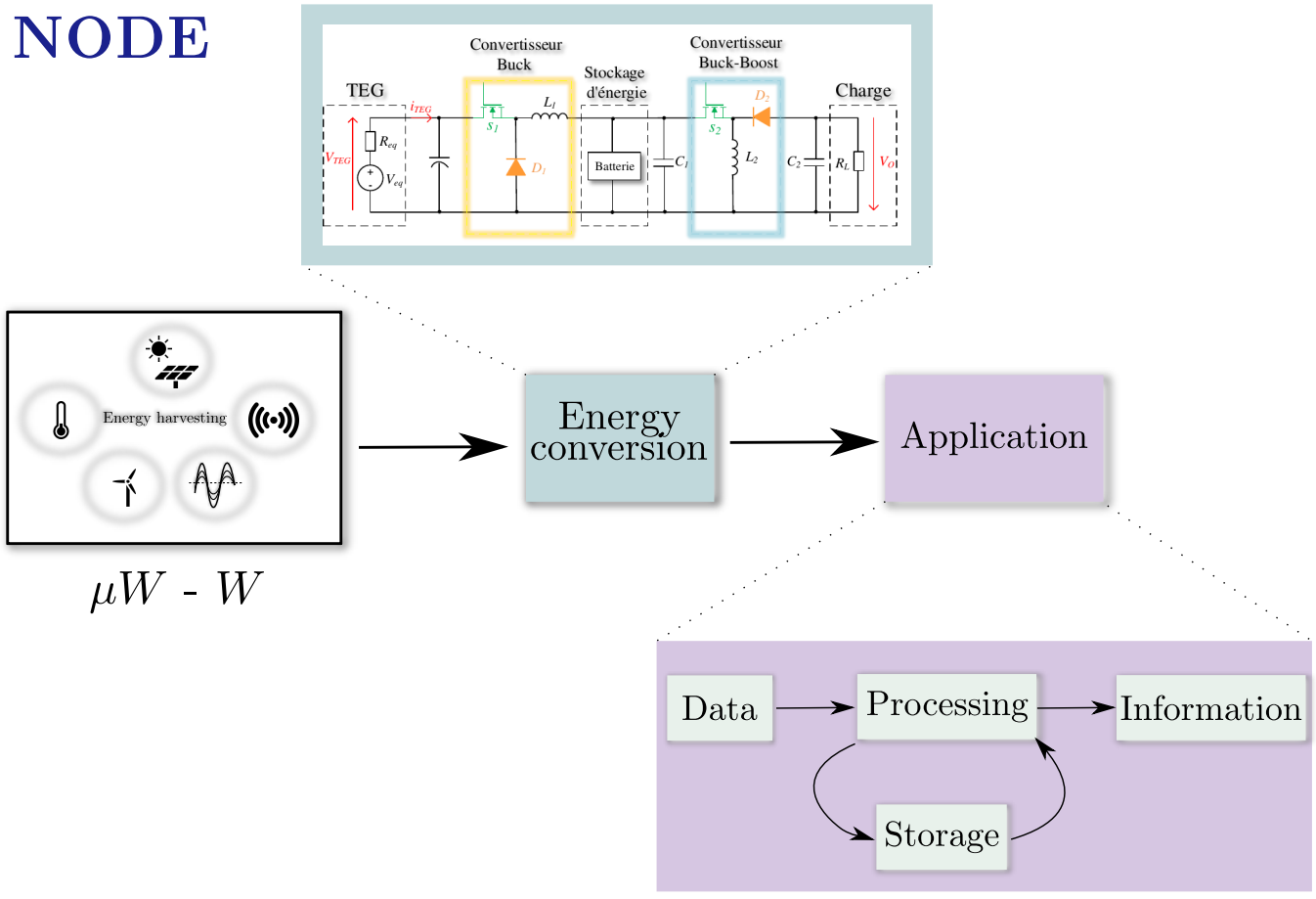
IoT node



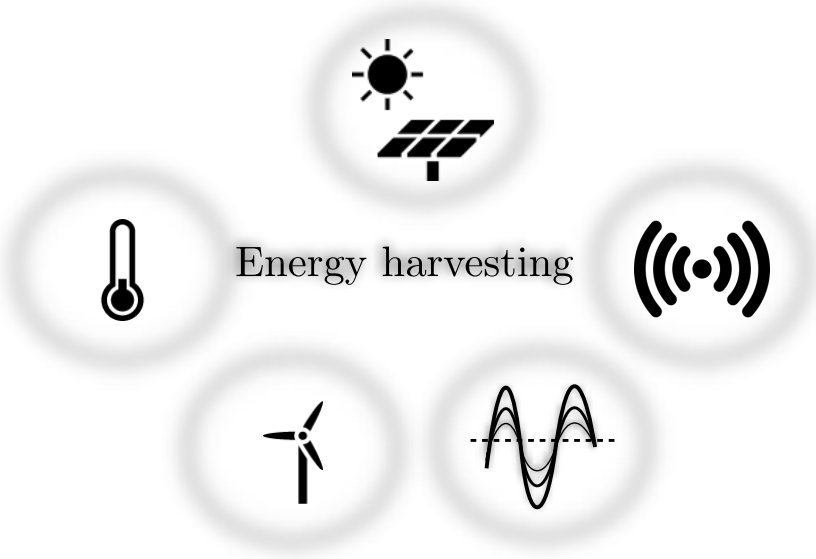
μW - W

- IoT node - **holistic design approach** :

  → source + energy management + use (computing)

IoT node

Energy harvesting



- Harvest ambient energy
- from μW to W

- Different energy sources (thermal, solar, RF, ...)
- Mono or multi-sources
- Hybrid solar-thermal energy sources

  → **ANR Hydres** (2022-26)

anr © Hybrid photovoltaic-thermoelectric systems for solar energy harvesting

- Thorough understanding for better use

IoT node

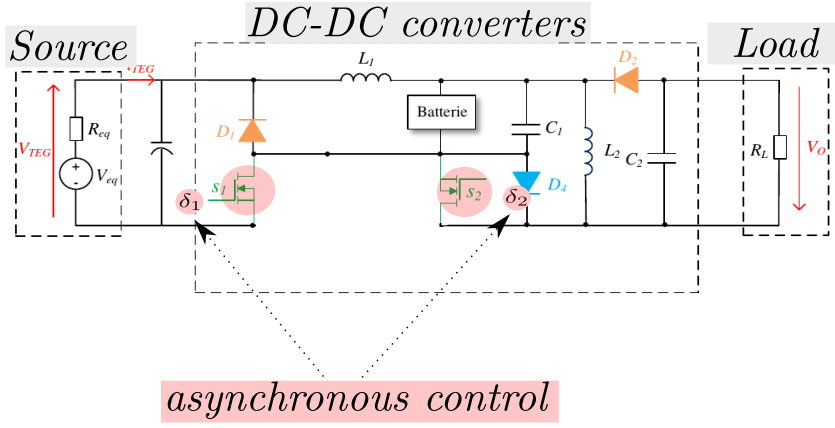
Energy Management

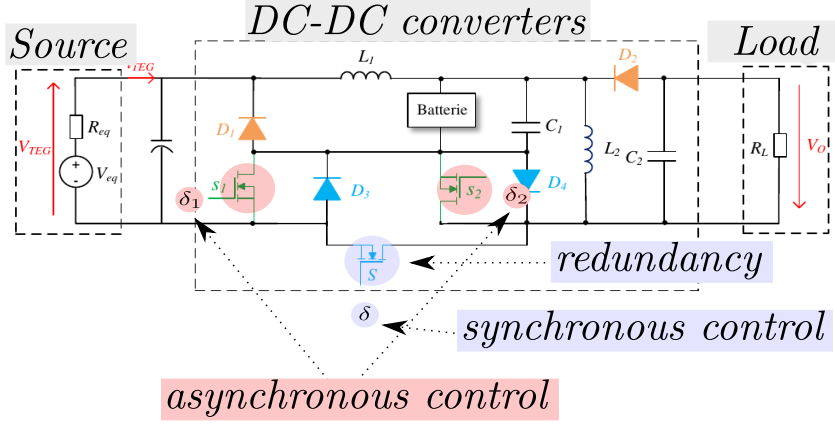
- *Ready-to-use* EM solutions (regulated voltage)
- Batteryless[a] solutions

  → supercapacitors AMAP
- Fault-tolerant topologies[15]

  → reduced (no) maintenance costs
- Multi-source EM[16]

ANR Hydres (2022-26)





[a] related to computing

[15] (Saima Siouane, Slavisa Jovanovic, and Philippe Poure. "Open-Switch Fault-Tolerant Operation of a Two-Stage Buck/Buck–Boost Converter With Redundant Synchronous Switch for PV Systems". In: *IEEE Transactions on Industrial Electronics* 66.5 [May 2019], pp. 3938–3947. ISSN: 0278-0046, 1557-9948. DOI: 10.1109/TIE.2018.2847653. [Visited on 12/13/2020])

[16] (M Huq. "Critical Analysis of Optimized Energy Harvesting at Small-Scale by Thermally Coupled Photovoltaic-Thermoelectric Systems". In: *Renewable and Sustainable Energy Reviews* [2024])

IoT node

Computing

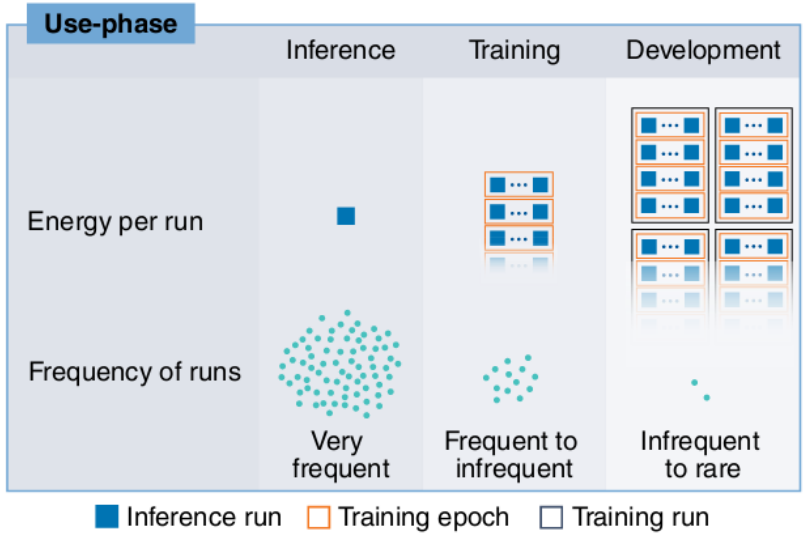
- sensing, processing, sending

  → cloud centric (heavy loads)

- sensing, AI-processing, sending

  → IoT or edge centric (light loads)

ANR Sorlahna (2023-27)



- AI-related energy consumption[17]
  - AI-processing: **energy** and **time consuming**

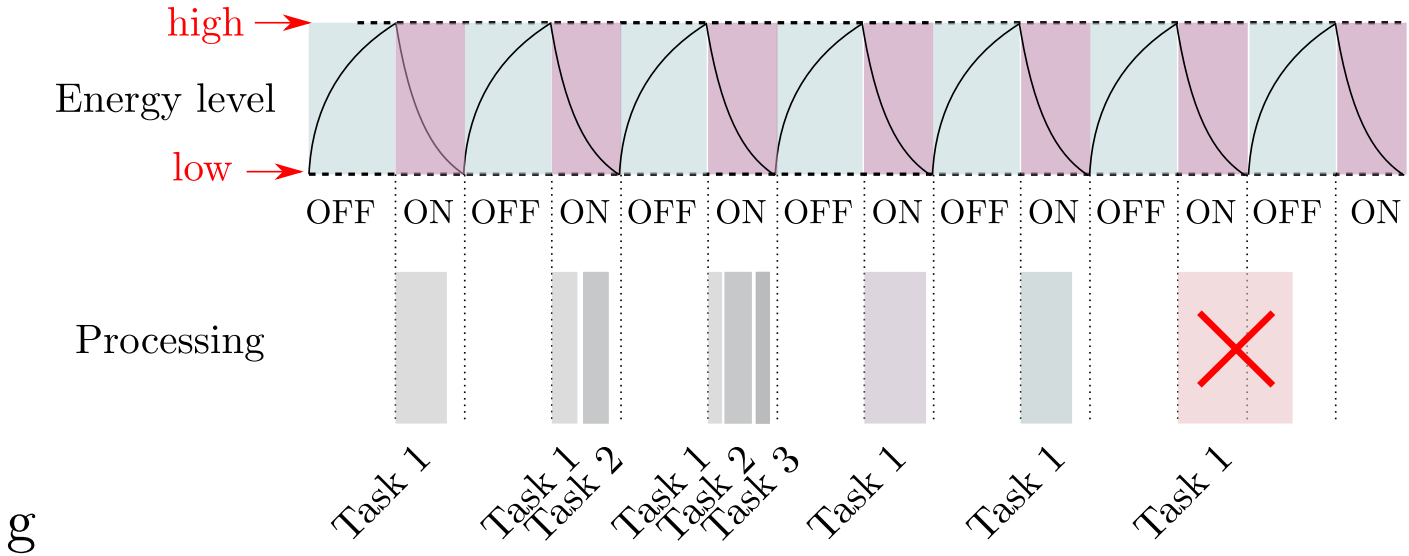
    → computation heavy tasks (even in inference)

    → time duration long tasks (uninterrupted processing needed)
  - How to reconcile heavy processing with uncertain energy?

    → **AI-processing** and **Energy harvesting**?

[17] (Lynn H. Kaack et al. "Aligning Artificial Intelligence with Climate Change Mitigation". In: *Nature Climate Change* 12.6 [June 2022], pp. 518–527. ISSN: 1758-678X, 1758-6798. DOI: 10.1038/s41558-022-01377-7. [Visited on 04/09/2024])

IoT node



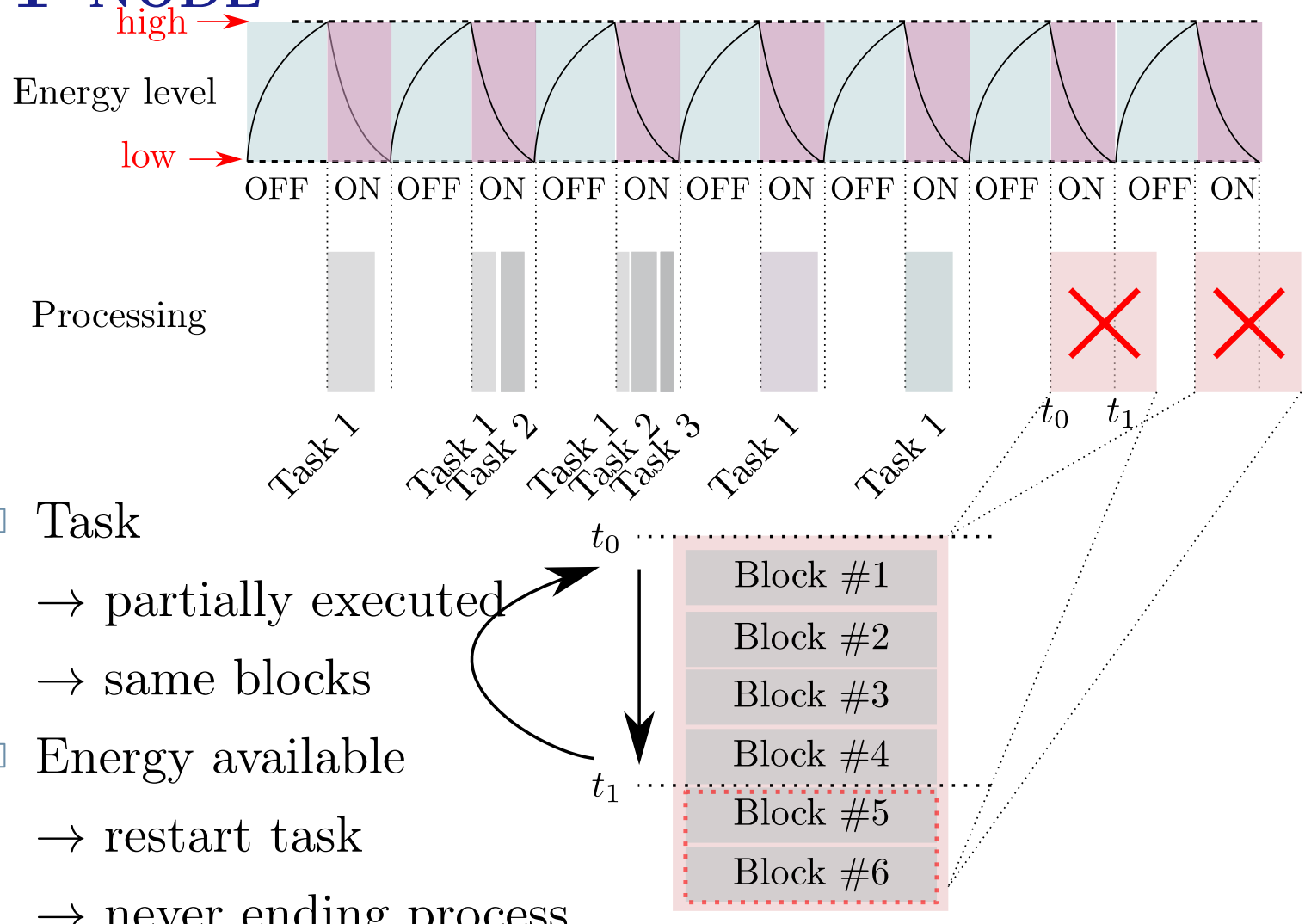
g

- Task execution as a function of available energy levels
- Light tasks → suited ✓
- Heavy task → unadapted ✗

  → task offloading to cloud

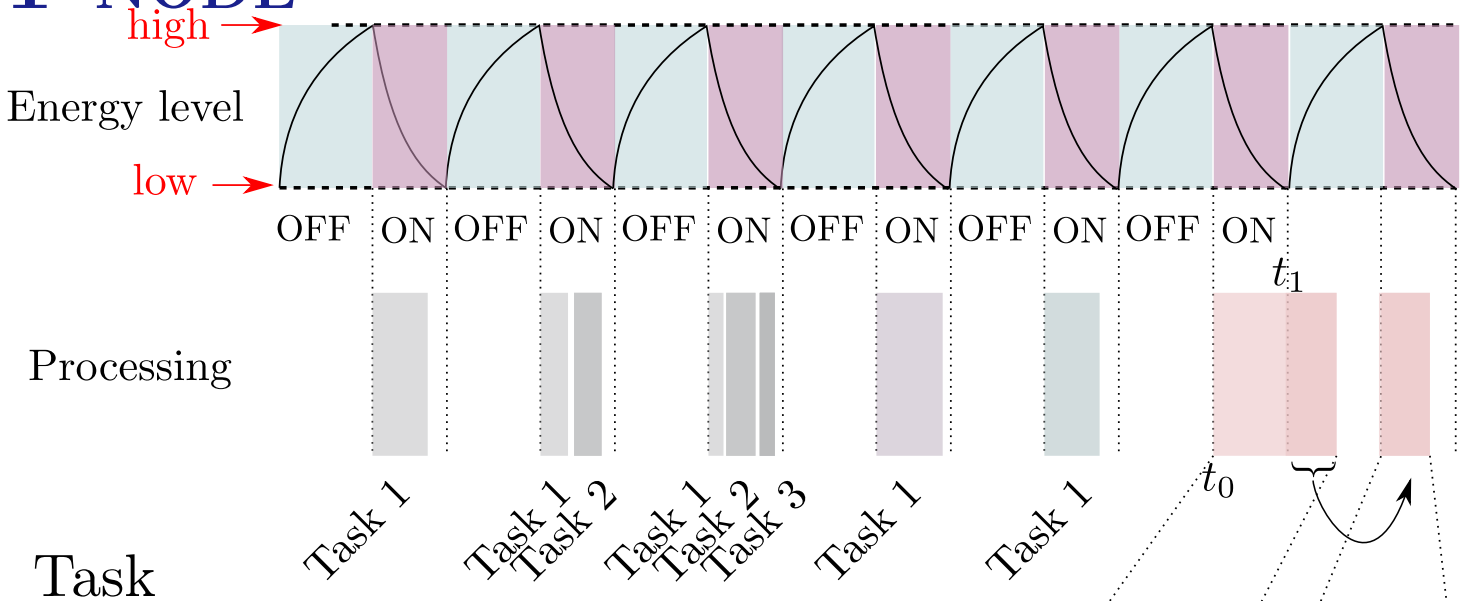
  → sending data in several bursts

IoT node

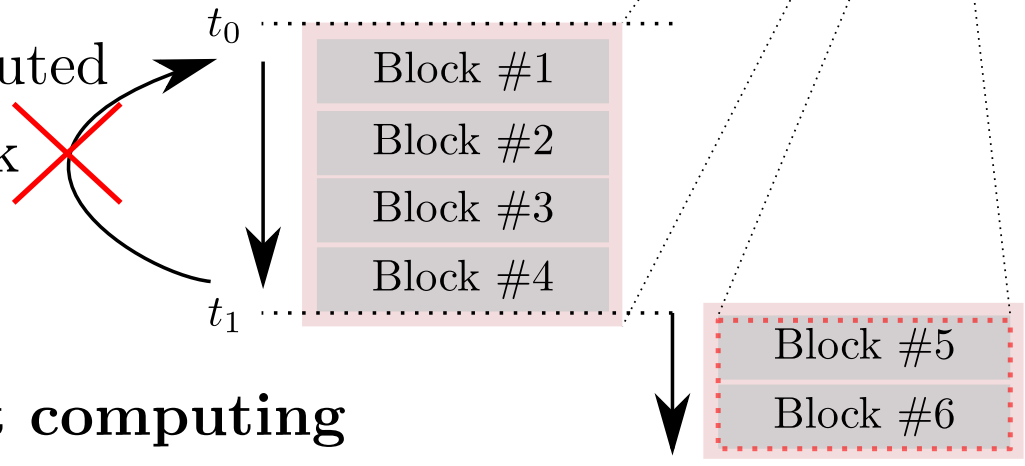


- Task
  - → partially executed
  - → same blocks
- Energy available
  - → restart task
  - → never ending process

IoT node



- Task
  - → partially executed
  - → block by block
- Energy available
  - → resume task
  - → **intermittent computing**
    - = computing as a function of available energy



IoT node

Intermittent computing[16]

- Computing paradigm shift
  → energy ≠ `const`
  → energy is a variable
- Intermittent computing: how?
  → existing technologies (✓)
  → very limited HW[a] (✗)[17]
  → adapted SW layers (✓)
  → transparent use (✗)

- Emerging technologies
  - ▷ computing capabilities
  - ▷ non volatile
    → to keep state(s)

  → spintronics[18] PEPR SPIN,
  → meta-materials[19] MetInfo,...
- New computing paradigms
  - ▷ physics-inspired AATLAS
  - ▷ processing in memory
  - ▷ stochastic computing, ...

[a] HW - hardware; SW - software

[16] (Brandon Lucia et al. "Intermittent Computing: Challenges and Opportunities". In: [2017], 14 pages. DOI: 10.4230/LIPICS.SNAPL.2017.8)

[17] Patent in progress

[18] (Zongxia Guo et al. "Spintronics for Energy- Efficient Computing: An Overview and Outlook". In: *Proceedings of the IEEE* 109.8 [Aug. 2021], pp. 1398–1417. ISSN: 0018-9219, 1558-2256. DOI: 10.1109/JPROC.2021.3084997)

[19] (I. T. Vidamour et al. "Reconfigurable Reservoir Computing in a Magnetic Metamaterial". In: *Communications Physics* 6.1 [Aug. 2023], p. 230. ISSN: 2399-3650. DOI: 10.1038/s42005-023-01352-4)

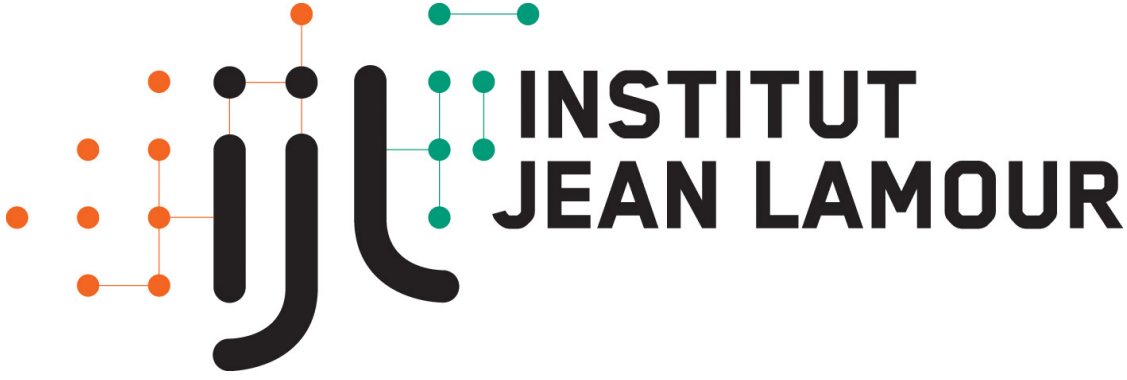
Summary

Conclusion and perspectives

Takeaways

- **Current technologies** allow to build **net-zero IoT** nodes
  → Sustainability by design and by usage is possible
- **Paradigm shift** in the traditional system design approaches
- Significant reduction in usage carbon emissions
- Associated with sustainable manufacturing technologies
  → **truly sustainable IoT and Edge nodes**
- Benefits from both:
  → most advanced digital technologies and
  → environmental friendly systems

Merci de votre attention



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