

SONATA

SUSTAINABLE COMPUTING AND COMMUNICATION AT THE EDGE



PROJECTS SEMINAR 2022

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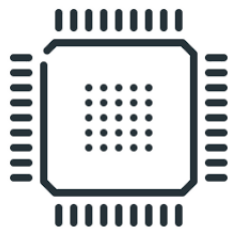
PROJECT ID CARD

- Call Topic: Towards Sustainable ICT (S-ICT), Call 2020
- Start date: 1 March 2022
- Duration: 36M
- Partners
 - CTTC (Spain)
 - Imperial College London (UK)
 - Bilkent University (Turkey)
 - Pázmány Péter Catholic University (Hungary)

SCIENTIFIC BACKGROUND

- Long term vision

- **Computation at the network edge** is key to supporting many emerging applications, from extended reality to smart health, smart cities, smart factories and autonomous driving
- Large scale adoption of edge intelligence technology, while benefiting human productivity and efficiency, will result in a surge of data and computation in mobile networks, which, in turn, will exacerbate their already **significant energy consumption**



MAIN OBJECTIVE

- To bring the **intelligence to data by exploiting the memory and computation capabilities of edge nodes** (routers, base stations, etc.) **and edge devices**, while at the same time maintain their **power consumption at the minimum level**



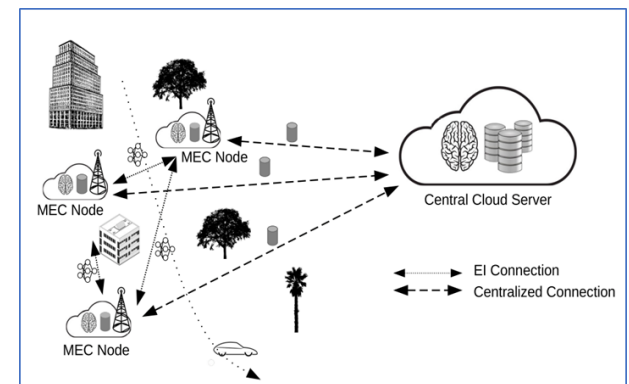
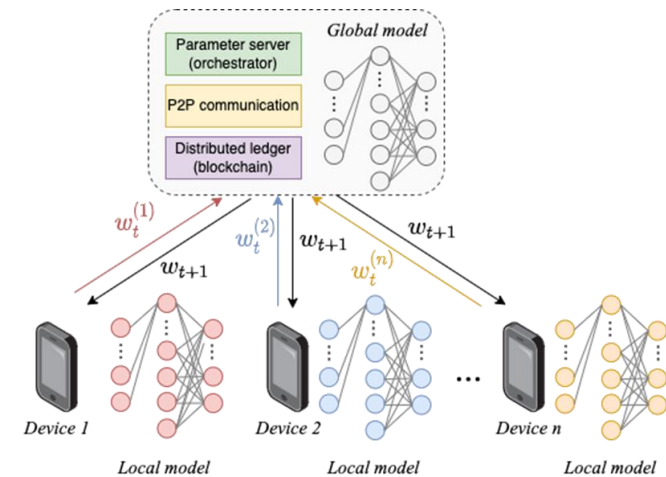
KEY CHALLENGES

- **Memristor devices** for energy efficient edge intelligence
- **Distributed ML across wireless devices**
 - exploit data and processing power of edge devices
- **Over-the-air computation (OAC)**
 - exploit air not only for communication but also for computation
- **Decentralized and server-less learning**
 - adaptive and efficient orchestration of learning algorithms for mobile edge devices
- **Incorporation of energy harvesting technologies** through the design of associated computing and communication protocols that are robust against stochastic availability of ambient energy

POTENTIAL IMPACTS

- Design and build **energy-efficient neuromorphic computing devices** for edge applications
- Employ **coding theoretic ideas to compensate for low accuracy** memristive devices both for in-memory computing and data storage
- Exploit **synergies between wireless communications, networks and distributed ML algorithms** to design energy-efficient distributed learning algorithms
- Consider **energy harvesting technologies** at the edge devices for prolonged network operations without battery replacement
- Design **adaptive communication, coding and computing protocols** to exploit the limited and stochastically available energy in the most efficient manner
- Evaluate the potential of developed techniques for **real use cases** that rely on energy-efficient sustainable networking paradigms

- **Decentralized federated learning**
 - Peer-to-peer (gossip learning)
 - Distributed Ledger Technology (Blockchain)
- **Energy efficiency, scalability and security**
- Orchestration of computing and communication resource in presence of **energy harvesting edge nodes**
- **Heterogeneous data and devices**
 - asynchronous implementations
- **Integration with over-the-air-computing**
- **Application to realistic use cases**
 - mobile traffic characterization
 - massive IoT deployment
 - smart cities
 - smart aquaculture



Miozzo, M., Ali, Z., Giupponi, L., & Dini, P. (2021). Distributed and multi-task learning at the edge for energy efficient radio access networks. *IEEE Access*, 9, 12491-12505

Wilhelmi, Francesc, Lorenza Giupponi, and Paolo Dini. "Blockchain-enabled Server-less Federated Learning." arXiv preprint arXiv:2112.07938 (2021).

- **Distributed ML algorithms** for energy efficient learning over wireless networks

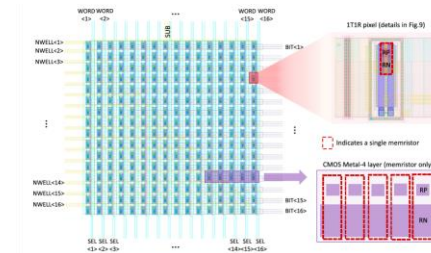
- **Over-the-air computation**

- imperfect alignment
- Computation of arbitrary functions
- In memory computing with OAC

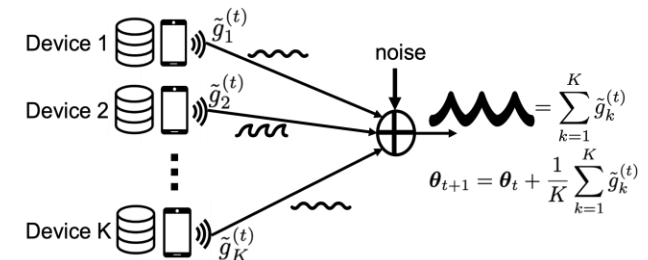
- **Memristive device technology**

- **Analog storage technology using neural networks**

- Store signals (image, audio) on memristors in an analog fashion
- Store neural network coefficients on memristors

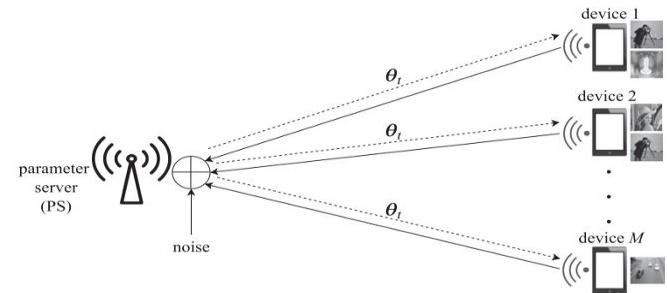


Memristors array in a 16×16 1T1R crossbar structure.



- **Federated Edge Learning (FEEL) with Over the Air Computation (OAC)**

- OAC benefits from interference (instead of avoiding it) and seamlessly combines learning and communication tasks

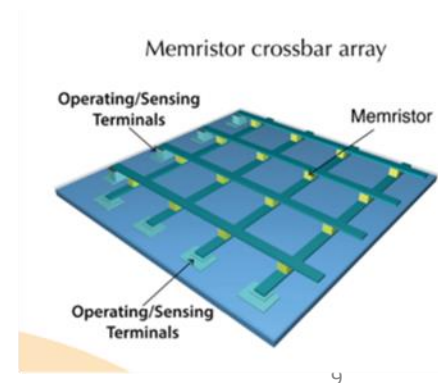


- **FEEL with Energy Harvesting Devices**

- energy-efficient solution for training large networks (also lowers the carbon emission)

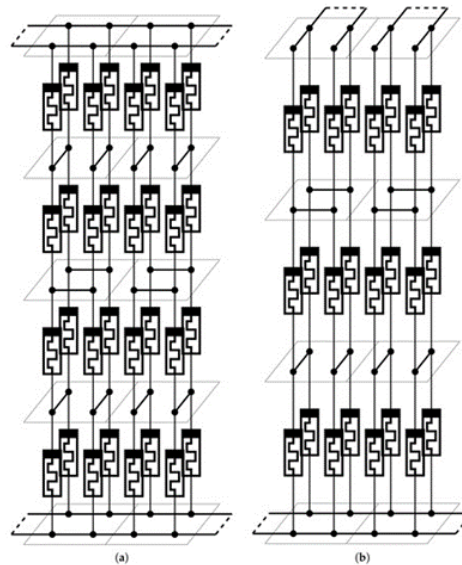
- **Information Decoding with In-Memory Computing**

- Memristive devices, e.g. PCM, ReRAM and MRAM are suitable for in-memory computing
- Efficient decoding of channel codes by crossbar arrays



Reference: A. Mehonic et al. "Memrisors- From In-memory computing", *Advanced Intelligent Systems*, Vol. 2, Nov. 2020.

- **Memristor grid solution** capable of effectively increasing device yield and parameter robustness at the cost of device size
- A **3D grid design** can be implemented with many-layer manufacturing technologies
- The resulting device has **increased reliability and parameter uniformity** and achieves **faster switching speed**.



EXPECTED IMPACTS

- **Scientific impact**

- **Distributed / Decentralized ML** will foster novel mission critical applications at the network edge, thus far limited to the cloud
- Opening of **new research directions** in the intersection of communications, networking, coding theory and ML
- **Instrumental in shaping next generation wireless systems and verticals** such as robotics and autonomous systems

- **Economic, industrial and societal impact**

- Bringing **intelligence to IoT and other edge devices** and technologies
- **Enabling new technologies and applications**, that can only be implemented centrally today using powerful computing resources.
- Helping **democratize AI/ML, protect privacy, and spearhead several verticals** and domains such as medicine

EXPLOITATION OF RESULTS

- **Academic dissemination**, scientific results will be published in top-tier journals and conferences (IEEE/IEE, EURASIP as well as various top venues for ML research). Open access
- **Invited talks, demos, organization of conferences** and special sessions/workshops, and visits will further increase the dissemination potential
- **Participation in standardization** efforts related to project topics. In particular, contributing to the O-RAN Alliance, ITU (AI for Good)
- Booth at **Mobile World Congress** (MWC)
- **Participation in technological platforms** (e.g., SNS JU)
- Enhance the **course curricula** at our institutions in neuromorphic computing, wireless networks, distributed systems, ML, and service creation
- **Technology transfer and intellectual property generation** activities through our technology transfer and innovation offices

Thanks for your kind attention!



“The world has enough for everyone’s need, but not enough for everyone’s greed.” M. Gandhi

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