CESI LINEACT

Title: **Computational efficiency of federated learning techniques on edge-cloud infrastructure.**

Scientific field: Computer science

Keywords: IoT, Distributed computing, Edge-cloud computing, Artificial intelligence, Federated learning, Energy efficiency, Buildings and cities of the future.

Supervision

Thesis director:

*M. Mourad ZGHAL, Habilité à Diriger des Recherches (*HDR)

Co-supervisor or co-supervisor(s):

- *M. Jean-François DOLLINGER, Associate professor*
- *M. Amine BRAHMIA, Associate professor*

Research work

Thesis project

Scientific background

The integration of digital technology in buildings is an opportunity to meet energy efficiency ambitions. The massive instrumentation of buildings by interconnected sensors and the aggregation of data measured by the sensors in the digital BIM mock-up opens the way to optimised energy management. The aim of the project is to process the data collected via a digital platform capable of reducing the energy consumption of buildings while guaranteeing the operability of infrastructures and the comfort of users. To achieve this, data are first collected and then processed on the terminals. Then they propagate to feed federated learning (FL) models trained on a distributed infrastructure. Based on these models, decision-making systems generate the appropriate local actions to optimise energy flows. In this project, we are interested in orchestrating the execution of operations to minimise the communication and computation times of the federated learning nodes.

Thesis subject

Collecting building data and making it available in the digital mock-up makes it possible to apply new energy-saving strategies. In particular, a system can use the information to predict energy consumption and usage to adapt the energy consumption of buildings without compromising comfort or functionality [1-3]. Furthermore, information from several buildings can be aggregated and consolidated to extend the models and exploit their complementarity. To use data sources collaboratively and ensure that processing scales up, we propose to implement a distributed architecture in order to distribute the computing load.

The hierarchical topology of an edge computing infrastructure [4] makes it a suitable candidate for deploying this type of processing. By integrating computing resources at the edge of the network, close to data-generating devices and upstream of *cloud* datacentres, it is possible to establish continuity of computing resources across the network. In practical terms, the sensor transmit data to servers close to the data source, to feed local learning models. Distributed training algorithms consume raw information to refine the models. Once the models have converged, they are sent to remote servers where they are consolidated to predict the energy requirements of buildings. The models propagate on local servers to ensure automatic control of the buildings. Because of the heterogeneity of the resources available and the limited computing power, the system orchestrates processing to make efficient use of edge-cloud resources [5-7], but also to partition sensitive data. For example, care will be taken to find the most suitable resources [8] and to distribute the load in such a way as to minimise computing times. In particular, we will design the proposed platform to reducing the system's energy footprint [9].

During the course of the thesis, the candidate is going to study two complementary elements to achieve a high-performance system. The aim is to establish a predictive model of energy consumption in buildings that is both reliable and requires very little computation and information exchange. Secondly, the aim will be to spread the computing load over heterogeneous, potentially massively parallel and distributed resources in order to minimise execution times.

Work schedule

1. Produce a comprehensive state-of-the-art report on the use of federated learning in the context of edge computing.
2. Distribute processing on an edge-cloud architecture.

   a. Propose a federated learning model with a balance between execution time and prediction accuracy.
   b. Design a robust federated learning model distributed on *edge-cloud* architectures.
3. Assess the performance of the proposed algorithms in an energy-saving context.

Expected scientific/technical output

The work carried out as part of this thesis will lead to publications in leading international conferences and journals. The candidate will design and implement a platform capable of automating the energy management of a building.

Context

Presentation of the laboratory

CESI LINEACT (UR 7527), the Digital Innovation Laboratory for Business and Learning at the service of Regional Competitiveness, anticipates and supports technological change in sectors and services linked to industry and construction. CESI's historical proximity to companies is a determining factor in our research activities, and has led us to focus our efforts on applied research close to companies and in partnership with them. A human-centred approach coupled with the use of technology, as well as the regional network and links with training, have enabled us to build a cross-disciplinary research approach; it puts people, their needs and their uses at the centre of its issues and approaches the technological angle through these contributions.

Its research is organised into two interdisciplinary scientific teams and two application areas.

- Team 1 "Learning and Innovation" is mainly concerned with Cognitive Sciences, Social Sciences and Management Sciences, Training Sciences and Techniques and Innovation Sciences and Techniques. The main scientific objectives are to understand the effects of the environment, and more specifically of situations instrumented by technical objects (platforms, prototyping workshops, immersive systems, etc.) on the processes of learning, creativity and innovation.
- Team 2 "Digital Engineering and Tools" is mainly concerned with Digital Science and Engineering. The main scientific objectives are the modelling, simulation, optimisation and data analysis of cyber-physical systems. Research work also focuses on the associated decision support tools and on the study of human-system interactions, particularly through digital twins coupled with virtual or augmented environments.

These two teams develop and cross-fertilise their research in the two application areas of the Industry of the Future and the City of the Future, supported by research platforms, mainly the one in Rouen dedicated to the Factory of the Future and those in Nanterre dedicated to the Factory and Building of the Future.

Integration within the laboratory research themes

The thesis project is part of the "digital engineering and tools" research theme of the CESI LINEACT laboratory. It targets the "Building of the Future" application domain and focuses on distributed processing and AI techniques with the aim of automating a building's energy management.

Thesis organization

Funding: Co-funded by CESI Région Est and Région Grand-Est.

Workplace: CESI LINEACT, Strasbourg (2 allées des Foulons, 67380 LINGOLSHEIM), FRANCE.

Start date: Starting from September 2023.

Duration: 3 years.

Your recruitment

Procedure: application and interview.

Please send your application to Dr Jean-François DOLLINGER (jfdollinger@cesi.fr) and Dr Amine BRAHMIA (abrahmia@cesi.fr) with the subject line:

« [Candidature] FL-EC performance »

Your application must include:

- **a detailed Curriculum Vitae of the applicant**. In the event of a break in the academic curriculum, please give an explanation;
- **a cover letter** to explain the reasons for pursuing a doctoral thesis;
- **university results** and corresponding report cards;
- any other documents you consider useful.

*Please send all the documents in a zip file entitled **NAME firstname.zip**. Applications will be processed in the order in which they are received, so this offer of a thesis will expire once a candidate has been selected.*

Your skills:

Scientific and technical skills:

- have a solid grounding in programming (C++, Python) and networks.
- have a good knowledge of parallelism and distributed computing.
- have a good knowledge of AI techniques.
- knowledge of federated learning techniques would be a plus.
- have good written and spoken English.

Soft skills:

- be autonomous, have initiative and curiosity,
- the ability to work as part of a team and good interpersonal skills,
- be rigorous.

References

[1] A. Abboud, A. Brahmia, R. Mazeranny, A. Abouaissa and A. Shahin, “A Hybrid Aggregation Approach for Federated Learning to Improve Energy Consumption in Smart Buildings”, In: International Wireless Communications and Mobile Computing (IWCMC), 2023.

[2] M. Savi and F. Olivadese. « Short-term energy consumption forecasting at the edge: A federated learning approach ». In: IEEE Access 9 (2021), p. 95949-95969.

[3] A. Taïk and S. Cherkaoui. «Electrical load forecasting using edge computing and federated learning». In: ICC 2020-2020 IEEE international conference on communications (ICC). IEEE. 2020, p. 1-6.

[4] A. Yousefpour et al. « All one needs to know about fog computing and related edge computing paradigms: A complete survey ». In: Journal of Systems Architecture 98 (sept. 2019), p. 289-330.

[5] L. Liu et al. « Dependent Task Placement and Scheduling with Function Configuration in Edge Computing ». In: Proceedings of the International Symposium on Quality of Service. IWQoS '19. Phoenix, Arizona: Association for Computing Machinery, 2019. isbn : 9781450367783.

[6] S. Wang et al. « Adaptive federated learning in resource constrained edge computing systems ». In: IEEE journal on selected areas in communications 37.6 (2019), p. 1205-1221.

[7] M. Abadi et al. « TensorFlow: A System for Large-Scale Machine Learning ». In: Proceedings of the 12th USENIX Conference on Operating Systems Design and Implementation. OSDI'16. Savannah, GA, USA : USENIX Association, 2016, p. 265-283.

[8] C. Peng. « Intelligent Device Selection in Federated Edge Learning with Energy Efficiency ». PhD thesis. 2021.

[9] Y. G. Kim and C.J. Wu. «Autofill: Enabling heterogeneity-aware energy efficient federated learning». In: MICRO-54: 54th Annual IEEE/ACM International Symposium on Microarchitecture. 2021, p. 183-198.