Offer #2023-06353

PhD Position F/M Big Data and Machine Learning Methods for Direct-to-Satellite Internet of Things

Contract type : Fixed-term contract

Level of qualifications required : Graduate degree or equivalent

Fonction : PhD Position

Level of experience : From 3 to 5 years

About the research centre or Inria department

The Inria research centre in Lyon is the 9th Inria research centre, formally created in January 2022. It brings together approximately 300 people in 16 research teams and research support services.

Its staff are distributed at this stage on 2 campuses: in Villeurbanne La Doua (Centre / INSA Lyon / UCBL) on the one hand, and Lyon Gerland (ENS de Lyon) on the other.

The Lyon centre is active in the fields of software, distributed and high-performance computing, embedded systems, quantum computing and privacy in the digital world, but also in digital health and computational biology.

Context

The doctoral program will occur within the Inria Agora research group at the La Doua Campus in Lyon. The Space-Terrestrial Integrated Internet of Things (STEREO) ANR project (Projet de recherche collaborative- entreprise, or PRCE) (ANR-22-CE25-0014-01 managed by Inria) provides and funds the position. The candidate will collaborate with four group members: Dr. Hervé Rivano (director), Dr. Juan Fraire (encadrant), Dr. Oana Iova, and Prof. Fabrice Valois. Some remote work may be possible. The Ph.D. candidate will utilize pre-existing software tools, including simulators and optimizers provided by the Agora group. There is no requirement for regular travel associated with this position.

Assignment

Context: The Ph.D. candidate will investigate the Direct-to-Satellite IoT (DtS-IoT) communication paradigm under the guidance of Dr. Hervé Rivano and the assistance of Dr. Juan Faire, Dr. Oana Iova, and Prof. Fabrice Valois. DtS-IoT offers a promising solution for providing data transfer services to IoT devices in remote areas where deploying terrestrial infrastructure is impractical or unfeasible. The project aims to establish a Space-Terrestrial Integrated Internet of Things (STEREO), enabling seamless connectivity for IoT devices to terrestrial gateways or directly to low-Earth orbit (LEO) satellites when no network infrastructure is available. Consequently, satellites can serve as passing-by IoT gateways, allowing devices to offload buffered data. The applications of DtS-IoT encompass various areas, including international asset tracking, cross-border environmental monitoring, and global data collection. These applications extend to remote regions that lack low-cost, power-efficient terrestrial IoT connectivity, such as poles, deserts, and oceans. The project aligns with the current trend in the space industry known as the "new space" paradigm, characterized by reduced costs and the emergence of new players exploring space technologies and business opportunities, such as nano-satellites. Despite the favorable context and compelling applications, DtS-IoT poses significant challenges due to transmission distances, dynamic channel conditions, and the resource limitations of ground-based devices.

Challenges: The primary challenge of DtS-IoT stems from its inherent characteristics. DtS-IoT aims to establish a direct device-to-gateway connection within a highly dynamic low-Earth orbit (LEO) environment without additional infrastructure. In such conditions, existing IoT medium access control (MAC) schemes must be supplemented with advanced informatics mechanisms to handle the potential simultaneous connection of millions of devices within the LEO coverage area. Furthermore, the challenges are amplified by limited energy availability and latency issues resulting from the extended channel range of approximately 600 kilometers. This poses difficulties in employing negotiation approaches reliant on extensive handshakes, underscoring the necessity of accurate predictions supported by machine learning techniques in DtS-IoT. DtS-IoT offers a unique opportunity to enhance machine learning predictions by leveraging the predictable nature of orbital mechanics, the tolerance for delays, and the learning derived from frequent revisits of satellites to service areas. These aspects necessitate novel Big Data approaches to effectively manage the numerous parameters required for modeling modern large-scale constellations, commonly called satellite mega-constellations. However, deploying DtS-IoT systems still needs to be improved. The private sector often drives it, resulting in challenges in accessing real-world data for research and development purposes. Overcoming these challenges requires concerted efforts to make DtS-IoT systems more widely available, reduce deployment size, and establish collaborations with private entities to facilitate access to relevant data.

Objective: This project aims to investigate methods and algorithms in the fields of Big Data and Machine Learning that can effectively address the challenges posed by DtS-IoT. As a sub-objective, the project will focus on developing suitable simulator tools capable of generating synthetic and realistic datasets for research purposes. This development will be based on the existing FLoRaSat tool, previously developed by the Agora team. Furthermore, the solutions derived from this research will be utilized as inspiration, mapped, and applied to the existing Low-Power Wide Area Network (LPWAN) technologies. These adapted solutions are being considered for various public and private DtS-IoT projects to provide connectivity in areas with limited terrestrial infrastructure.

The main **research questions** that will be addressed in this Ph.D. project are:

1. How can Big Data mechanisms be leveraged to support the analysis of future DtS-IoT systems? There is an increasing need to efficiently handle and extract insights from vast amounts of data generated by connected devices combined with the telemetry streams from the orbiting fleet. By effectively analyzing and utilizing the massive volumes of data generated by DtS-IoT systems, valuable insights can be obtained, leading to improved decision-making, optimized resource allocation, and enhanced overall performance. Furthermore, exploring integrating Big Data techniques with orbital mechanics, delay-tolerance, and machine learning in DtS-IoT systems opens up new opportunities for advancements in both fields.
2. How can Machne Learning mechanisms be leveraged to support the operation of future DtS-IoT systems? Machine learning offers a powerful approach to tackling the DtS-IoT challenges by enabling devices and gateways to make intelligent decisions based on patterns, predictions, and data-driven insights. Machine learning algorithms can optimize resource allocation, manage power constraints, and improve communication efficiency while enabling adaptive and self-learning capabilities to adapt autonomously to changing environmental conditions. Furthermore, integrating machine learning with orbital mechanics and delay-tolerance specific to DtS-IoT systems opens up exciting possibilities. Machine learning models can accurately predict connection availability, optimize transmission scheduling, and improve overall system performance by leveraging the predictable nature of orbital mechanics and learning from frequent satellite revisits. Furthermore, integrating machine learning with orbital mechanics and delay-tolerance specific to DtS-IoT systems opens up exciting possibilities.

Bibliography:

1. Fontanesi, G., et al. "Artificial Intelligence for Satellite Communication and Non-Terrestrial Networks: A Survey." arXiv preprint arXiv:2304.13008 (2023).
2. Fraire, Juan A., Oana Iova, and Fabrice Valois. "Space-Terrestrial Integrated Internet of Things: Challenges and Opportunities." IEEE Communications Magazine (2022).
3. Fraire, Juan A., et al. "Direct-To-Satellite IoT-A Survey of the State of the Art and Future Research Perspectives." International Conference on Ad-Hoc Networks and Wireless. Springer, Cham, 2019.
4. Fraire, Juan A., et al. "Sparse Satellite Constellation Design for LoRa-based Direct-to-Satellite Internet of Things." GLOBECOM 2020-2020 IEEE Global Communications Conference. IEEE, 2020.
5. Centenaro, Marco, et al. "A survey on technologies, standards and open challenges in satellite IoT." IEEE Communications Surveys & Tutorials 23.3 (2021): 1693-1720.
6. Routray, Sudhir K., et al. "Satellite-based IoTt for Mission-Critical applications." 2019 International Conference on Data Science and Communication (IconDSC). IEEE, 2019.
7. Cluzel, Sylvain, et al. "3GPP NB-IoT coverage extension using LEO satellites." 2018 IEEE 87th Vehicular Technology Conference (VTC Spring). IEEE, 2018.

Main activities

The main expected activities are:

1. **Survey** and qualitatively compare the existing implementation of Big Data and Machine Learning to space-based networks, specifically, DtS-IoT architectures.
2. **Develop** a simulator toolchain by extending existing simulators (FloRaSat: https://gitlab.inria.fr/jfraire/florasat) to generate synthetic data sets suitable for Big Data and Machine Learning models.
3. **Investigate** new Big Data and Machine Learning methods to process and exploit the generated data sets. Methods should consider network and protocol management as well as use-data treatment.
4. **Evaluate** the developed methods in the same simulator tool considering the data's drift in realistic deployments (e.g., varying the orbital parameters, artificially adding errors to the data, etc.).
5. **Write** and prepare conference and journal papers targeted to high-impact international venues.

Note: The prioritization and weight of the activities will be defined during the project.

Skills

Technical: The candidate must be at least in his/her last year of master studies (or equivalent) in Computer Science or Telecommunications. Good mathematical background, performance evaluation, wireless networking, and practical skills with programming languages (e.g., C/C++, Python) are required.

Languages: Fluent English level. Knowledge of the French language is not mandatory

Soft: Active listening, empathetic communication, the ability to tolerate and accept appropriate differences, proactive and self-driven.

Benefits package

- Subsidized meals
- Partial reimbursement of public transport costs
- Leave: 7 weeks of annual leave + 10 extra days off due to RTT (statutory reduction in working hours) + possibility of exceptional leave (sick children, moving home, etc.)
- Possibility of teleworking and flexible organization of working hours
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities
- Access to vocational training
- Social security coverage

Remuneration

- **1st and 2nd year:** 2 051 euros gross salary /month
- **3rd year:** 2 158 euros gross salary / month

General Information

- **Theme/Domain :** Networks and Telecommunications
  System & Networks (BAP E)
- **Town/city :** Villeurbanne
- **Inria Center :** Centre Inria de Lyon
- **Starting date :** 2023-10-01
- **Duration of contract :** 3 years
- **Deadline to apply :** 2023-08-31

Contacts

- **Inria Team :** AGORA
- **PhD Supervisor :**
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About Inria

Inria is the French national research institute dedicated to digital science and technology. It employs 2,600 people. Its 200 agile project teams, generally run jointly with academic partners, include more than 3,500 scientists and engineers working to meet the challenges of digital technology, often at the interface with other disciplines. The Institute also employs numerous talents in over forty different professions. 900 research support staff contribute to the preparation and development of scientific and entrepreneurial projects that have a worldwide impact.

The keys to success

Methods: The project's methodology is at the crossroads of engineering, computer science, and data science disciplines, a necessary equilibrium to deal with the aforementioned DtS-IoT challenges.

1. **Protocol Models** (Engineer approach): Detailed protocol models (i.e., physical, link, and network layers) will be implemented to study the expected performance and resource consumption of DtS-IoT using simulations in FLoRaSat. The model also includes a core network module for the architecture axis.
2. **Abstract Models** (Computer Science approach): System-level models will be developed to abstract the network elements and time-dependent resources to optimize decision-making based on Big Data and Machine Learning models.
3. **Simulation Models** (Software Development approach): Both protocol and abstract models will be materialized and evaluated in FLoRaSat, a discrete-event simulator developed and maintained by the Agora team.

Collaboration: The DtS-IoT topic is hot in the academic and industrial sectors. We foresee academic collaborations with IRIT / ENSEEIHT Toulouse researchers and foreign laboratories such as i2CAT in Barcelona and Universidad de Chile. Cooperation is ongoing with Semtech (the company that developed LoRa), and we are extending it to the DtS-IoT topic. Finally, several companies such as Lacuna, Kinesis, and Swarm are pursuing DtS-IoT activities and will be contacted as potential partners.

Warning : you must enter your e-mail address in order to save your application to Inria. Applications must be submitted online on the Inria website. Processing of applications sent from other channels is not guaranteed.

Instruction to apply

Defence Security :
This position is likely to be situated in a restricted area (ZRR), as defined in Decree No. 2011-1425 relating to the protection of national scientific and technical potential (PPST).Authorisation to enter an area is granted by the director of the unit, following a favourable Ministerial decision, as defined in the decree of 3 July 2012 relating to the PPST. An unfavourable Ministerial decision in respect of a position situated in a ZRR would result in the cancellation of the appointment.

Recruitment Policy :
As part of its diversity policy, all Inria positions are accessible to people with disabilities.