Internship proposal — 6 months

GREEN-FED: Federated Learning for Energy-Efficient Orchestration with SDN Control in Multi-Domain 6G Networks

Fetia Bannour

SAMOVAR Lab, NeSS team, ENSIIE.

Contact: fetia.bannour[at]telecom-sudparis.eu, fetia.bannour[at]ensiie.fr

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Context: The evolution toward 6G networks promises ubiquitous connectivity, immersive services, and pervasive intelligence, but also raises a critical sustainability challenge. ICT infrastructures already consume nearly four percent of global electricity, and this figure is projected to rise sharply unless energy efficiency becomes a built-in feature of future orchestration mechanisms [1, 2]. Achieving sustainability in 6G requires moving away from static, centralized approaches toward **AI-native and energy-aware orchestration**.

At the heart of 6G, **end-to-end slicing** is the fundamental mechanism that enables the provisioning of highly heterogeneous services such as ultra-reliable low-latency communications, extended reality, connected vehicles, and industrial IoT. Each slice must dynamically span RAN, transport, and core domains, with guaranteed QoS and efficient resource utilization. Our recent work has demonstrated the potential of combining deep reinforcement learning with transformer architectures to deliver adaptive and context-aware slice management [3]. These approaches highlight that slicing should be understood not as a static configuration, but as a **continuous and dynamic orchestration process**, where decisions are revisited in real time as traffic, mobility, and service demands evolve.

Conventional orchestration relies on centralized controllers to decide on the placement and scaling of VNFs and slice resources. While effective in limited environments, this model is unsuited for 6G as it introduces scalability bottlenecks, latency, and privacy risks in multi-domain settings. **Federated Learning (FL)** offers an alternative paradigm. Each domain, whether edge, core, or cloud, trains a local slicing or orchestration model on its telemetry and contributes only model updates to a global aggregator, enabling collaborative intelligence while preserving data privacy [4, 5]. In parallel, **Software-Defined Networking (SDN)** provides the programmable control layer that can enforce slicing decisions through flow rule installation, VNF scaling, and resource allocation. Research on distributed SDN control confirms the importance of coordination between multiple controllers to enable scalable and consistent slicing in multi-domain contexts [6]. Recent white papers and architectural studies emphasize that the integration of distributed AI with programmable SDN control is a cornerstone for achieving **sustainable, zero-touch, AI-native slicing in 6G** [7, 8].

Energy Efficiency in Slicing and Orchestration

The GREEN-FED framework explores how federated learning can serve as an **energy-efficiency enabler** for orchestration and slicing. Energy optimization can be achieved by forecasting traffic evolution and service demand to consolidate slice workloads, scaling down idle or underutilized VNFs and slice components to reduce unnecessary server activity, and dynamically routing flows along energy-optimal paths through SDN-based traffic steering to minimize network energy usage while respecting QoS constraints. By capturing domain heterogeneity, FL policies can place latency-sensitive slices such as XR or V2X at the edge despite higher energy constraints, while offloading delay-tolerant slices to core or cloud infrastructures where large-scale processing is more efficient. Predictive slice management policies can enable selective activation of sleep modes in infrastructure supporting low-priority slices during off-peak hours. Finally, FL itself contributes to energy efficiency by reducing communication overhead, since only model updates are exchanged instead of large volumes of raw telemetry data [9].

To align with the most recent research trends, the project will also investigate several promising directions. **Hierarchical federated learning** can enhance scalability by allowing intermediate aggregators (e.g., at domain or regional levels) to combine models before global aggregation, reducing communication overhead and adapting to domain-specific conditions. **Split learning** may be introduced in contexts where edge devices or lightweight controllers lack the resources to train full models, offloading heavier layers to servers while preserving privacy. The integration of **multi-agent reinforcement learning** can allow distributed controllers to interact and learn cooperative slice management policies, thus capturing the dynamic interplay of multiple domains. Finally, **graph neural networks (GNN)** represent a cutting-edge way to encode slice and topology relationships, enabling policies that are inherently topology-aware and generalizable across different network configurations.

Objectives

The internship will design, implement, and evaluate a **federated learning-based framework for energy-efficient slicing and orchestration** in multi-domain 6G networks. It aims to show how federated learning can serve as the intelligence layer for slice placement, scaling, and dynamic adaptation, while SDN controllers provide the enforcement layer that applies these decisions in real time. The overarching objective is to demonstrate that federated slicing can significantly reduce energy consumption while maintaining SLA and QoS guarantees. Alongside the core implementation, the project will explore extensions involving hierarchical FL, split learning, multi-agent RL, and GNN-based models, positioning GREEN-FED in line with the most advanced 6G research directions.

Methodology

The work will begin with a state-of-the-art review of federated learning for networking [4, 5], intelligent slicing frameworks [3], and sustainability strategies for 6G orchestration [1, 2, 7]. Building on this foundation, the intern will model slice orchestration as a multi-objective optimization problem, balancing energy efficiency with latency, throughput, and reliability requirements.

For the implementation phase, a multi-domain emulation testbed will be developed using Mininet, Mininet-WiFi, or ns-3, combined with SDN controllers such as Ryu or ONOS. Each domain will operate as an FL client, training on local slice telemetry and contributing updates to a federated aggregator implemented with frameworks such as Flower [10] or PySyft. The global model will then produce slicing and orchestration policies that SDN controllers enforce across the network. The evaluation will benchmark centralized, local-only, and federated slicing approaches, with metrics including overall energy consumption in kWh, SLA satisfaction for multiple slice types, orchestration latency, and FL overhead. To ensure practical relevance, the evaluation may simulate use cases such as an immersive XR slice with stringent latency requirements, a V2X slice for connected vehicles with mobility dynamics, and an IIoT slice with massive device connectivity.

Expected Outcomes

The expected outcome of the internship is a **prototype slicing and orchestration framework (GREEN-FED)** that demonstrates how federated learning can drive energy-efficient slice management in multi-domain 6G networks. The evaluation should provide quantitative insights into the trade-offs between SLA compliance and energy savings, validating federated learning as a key mechanism for sustainable, AI-driven slicing. By exploring advanced directions such as hierarchical FL, MARL, split learning, and GNNs, the project will highlight the potential of GREEN-FED to evolve into a comprehensive research direction, and depending on results, the work may lead to a publication in a major networking or AI-for-6G venue.

Practical Information

The internship will last 6 months, starting in February or March 2025, and will be hosted at the SAMOVAR lab (Télécom SudParis) in Evry or Palaiseau. Supervision will be provided by Fetia Bannour (Associate Professor at ENSIIE & SAMOVAR), who works on AI/ML-driven approaches for the control and management of SDN/NFV-based future networks. The project will also benefit from collaboration with colleagues in the RMS team of the LTCI (Télécom Paris).

References

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