Master 2 Internship proposal — 6 months

Energy-efficient Green VNF-FG placement and chaining for softwarized 5G/6G mobile networks

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Context: Recent years have witnessed a surge in a variety of network services and innovative applications that impose a broad range of stringent service requirements in terms of QoS/QoE. In particular, the energy-efficiency of network systems has raised serious concerns, given the dramatic increase in energy cost and CO2 emissions. The 5G/6G mobile networks which shape the next-generation Internet, pledge to meet the different needs of current network services and reduce the carbon emissions of data centers and telecommunication infrastructures. They rely on network softwarization to overcome the limitations of traditional networks, and create new opportunities for effective and zero-touch network management. The transformation of telecommunication networks through softwarization has been driven by key technologies like Software-Defined Networking (SDN), Network Function Virtualization (NFV) and Cloud Computing (CC). SDN [1] **separates/abstracts** network control functions from the forwarding hardware of network devices with the purpose of centrally managing networks in an automated, programmatic, efficient, and innovative way. The NFV [2] network architecture concept **virtualizes** network services, such as routers, firewalls, and load balancers, that have traditionally been run on proprietary vendor-specific hardware. It allows service providers to run their networks on industry-standard servers rather than dedicated ones. NFV thus improves scalability and agility by allowing service providers to deliver new network services on demand without requiring additional hardware resources. Besides, NFV drives technology changes like model-driven, cloud-native, and DevOps practices.

In particular, network elements in 5G/6G mobile networks are provided as software implementations of network functions, or Virtual Network Functions (VNFs), which are elastically orchestrated with the help of an SDN controller in the form of Service Function Chains (SFC) to meet dynamic service demands and energy-efficiency purposes.

Although NFV and cloud-native service orchestration ease the management and automation of network services, their deployment requires the allocation of Virtual Network Function - Forwarding Graphs (VNF-FG). Accordingly, the network service becomes a request for running a set of VNFs that are orchestrated in the form of a VNF-FG, and that should be deployed and embedded on the substrate network. That said, the efficiency and management cost of a network are highly dependent on the optimization of the VNF-FG Embedding (VNF-FGE) problem [3], which should not only take into account the constraints of the underlying infrastructure and the fulfillment of the service's requirements in terms of QoS/QoE, but also implies an efficient allocation that reduces energy consumption, carbon footprint, and operational cost of their 5G/6G mobile infrastructures.

Although the VNF-FGE topic has been well-studied in existing literature, there is still much to explore since the energy-efficiency aspect has been quite overlooked in many research works. Motivated by this observation, we propose an intelligent energy-efficient algorithm using a multi-agent deep reinforcement learning technique [4] for VNF-FG placement and chaining in NFV/SDN-enabled infrastructures.

Internship objective: The main goal of this proposal is to define a proof-of-concept for building an intelligent energy-efficient approach to address Virtualized Network Function Forwarding Graph (VNF-FG) placement and chaining with VNFs shared across multiple tenants to optimize resource usage, reduce energy consumption, and increase provider revenue in the context of 5G/6G mobile networks.

Below we summarize the tasks that will be carried out by the selected candidate :

1. Study the state-of-the-art to understand the current works on energy-efficient VNG-FG placement and chaining problems, and their proposed algorithms and approaches.

2. Propose a green multi-agent deep reinforcement learning VNG-FG placement algorithm. The main idea is that agents learn how to cooperate and make decisions on the VNF-FGE by learning a *centralized policy* that leads to a *decentralized execution* [5] resulting in the allocation of the required resources to the virtual nodes and links. That cooperation between agents should improve energy savings without degrading performance and scalability.

3. Formulate the proposed VNF-FGE multi-agent deep reinforcement learning optimization problem [4, 2], and investigate the required placement metrics, with a special focus on energy consumption metrics.

4. Implement the proposed approach using a PyTorch framework and apply it to our specific use case which consists in optimizing the network slicing (with VNF-FG) of the 5G/6G core network [3].

5. Study/analyze the obtained results, and evaluate the gain in terms of energy savings of our method as compared to relevant state-of-the-art approaches.

Advisors' information:

Fetia Bannour (ENSIIE/SAMOVAR) and **Omar Houidi** (SAMOVAR) work on *the control and management of SDN and NFV-based future networks.*

We also plan to further investigate this topic with our colleagues and collaborators from the RMS team of the LTCI (Laboratoire de Traitement et Communication de l'Information) Telecom Paris research lab.

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