PhD proposal on
Parameterized Algorithms for Future Networks Optimization Problems

Supervised by

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Context: The arrival of 5G and beyond (5G+) networks and, with it, new disruptive network technologies such as *software-defined networking* (SDN) and *network virtualization*, enable greater flexibility in the deployment and management of future networks. Using SDN, manual network interfaces can be replaced with programming interfaces to automate tasks such as configuring and managing flow control policies, and to allow the network to dynamically respond to application needs. Consequently, these new technologies offer greater flexibility in terms of programmability, and it is possible to deploy and execute decision-making algorithms directly from network controllers (SDN controllers). This approach is the converse of the current trend that consists of executing the optimization algorithms offline and then implementing the output solutions in the network (such as creating new MPLS tunnels or changing metrics for shortest path based routing protocols). These new paradigms provide a more fine-grained way to manage the network and make it more responsive in case of undesirable event such as network equipments failures. However, this flexibility comes at the price of a substantial increase in the complexity of managing these future networks. Hence, artificial intelligence (AI) appears as a key enabler for 5G+ networks and will ultimately pave the way toward network automation [10]. The technical board of 5G-PPP even recommends the replacement of traditional approaches for network optimization by automated AI methods [1]. Despite the fact that classical AI techniques are generally seen as a tool for decision-making in complex environments for many areas including telecommunication networks, assessing if they provide solutions that can be explainable and trustable is still an open question as noted in the 5G-PPP whitepaper [1, Section 4.4.2]. Here, an algorithm is explainable and trustable if it is theoretically proven having structural properties and performance guarantees (like upper and lower bounds over the optimal solutions). A promising approach for palliating this issue is to combine conventional network optimization and AI to get reliable and scalable algorithms. In this thesis, we are particularly interested in studying the contribution of the parameterized complexity theory in that matter.

State of the art & expected work: The theory of parameterized complexity is a theoretical framework which provides a more fine-grained complexity analysis of NP-hard optimization problems. The central notion is fixed-parameter tractability (FPT) which refers to the idea of confining the inevitable combinatorial explosion to some problem-specific parameters such as the number of traffic flows to route in an IP network or the maximum number of virtual network functions (VNFs) to deploy. The objective is to identify a parameter that has "small" values in practice so that the running time of the FPT algorithm grows smoothly with the size of the problem. In the context of future telecommunication networks, several complexity results, approximation algorithms and FPT algorithms were established for problems related to Virtual Network Embedding (VNE) [11, 7], network design [6] and traffic engineering [9]. For example, a problem related to segment routing, called waypoint routing, is proved NP-hard in [3] and FPT with respect to the parameter treewidth [12]. The objective of this thesis is then to follow the same line of research by exploring new directions such as

- Determining relevant network-specific structural parameters. Telecom networks have specific architectures (sparsity, resiliency, hierarchical structures,...) which may be exploited in the design of efficient heuristics [4] and/or scalable FPT algorithms.
- Finding reduction rules to reduce the size of the input instances. Pre-processing (also called kernelization) is a central notion in parameterized complexity, and many techniques have been developed to design reduction rules that may dramatically reduce the size of an instance while keeping the quality of the solutions [2].

- Investigate parameters that measures the complexity of implementing a solution. [8]. Network manager are often reluctant to modify the network configuration and prefer a solution that incurs the least possible number of modifications (in the context of shortest path routing protocols, this corresponds to the maximum number of weights to change)
- Design parameterized algorithms for building resilient networks [5]. Network managers are interested in solutions that are not only good in the nominal case, but also good in case of multiple failure scenarios. This dramatically increases the combinatorial aspect of the problem at stake. Hence designing efficient procedure that detects the most network critical equipments (i.e those that induce the highest impact in case of failure) is essential.

The designed algorithms will be integrated into the C++ library `networktools` currently being developed in the team and which is used as the algorithmic backend of an end-to-end 5G+ digital twin platform.

Conditions: The PhD candidate is expected to have a Master's degree or equivalent in computer science with the following skills:

- Strong background in combinatorial optimization methodologies and algorithms, mathematical programming and graph theory.
- Programming experience in one or more of the following languages : Python, C, C++.

Additional informations:

- Expected starting date: October 1st, 2023
- Application deadline: May 15th, 2023
- Annual gross salary before taxes: 33848€, 38480€ (3rd year) + profit-sharing
- More information available at https://orange.jobs/site/en-theses

The thesis is fully funded by Orange. The PhD candidate will join the MORE team (*Mathematical Models for Optimization and peRformance Evaluation*) located at Orange Gardens, Châtillon. The team is composed of researchers, PhD students and software engineers. The team has a strong expertise in mathematical programming, exact and approximation algorithms, graph theory and artificial intelligence.

Any interested candidate is invited to email his/her application (including CV, letter of motivation, academic record during the last two years and possibly the name and email of reference persons) to morgan.chopin@orange.com and cristina.bazgan@dauphine.fr

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