Chapter 7
Future Networks:
Overview of Optimization Problems in Decision-Making Procedures

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ABSTRACT
This chapter gives an insight into some challenging combinatorial optimization problems that have to be tackled to deliver efficient and appropriate decision algorithms to manage future networks. The first part of the chapter is dedicated to variants of routing optimization problems in future IP networks, and the second part is dedicated to two optimization problems related to network virtualization and 5G network slicing, the virtual network embedding problem and the service function chaining problem. Each of these optimization problems is described along with the main challenges to overcome, and a recent and extensive related state of the art is given, so as to highlight the most recent and promising approaches to solve them.

INTRODUCTION
With the emergence of the Software Defined Networking (SDN) and virtualization techniques, future networks are expected to be more flexible, dynamic, open, and service-oriented. However, this evolution brings new challenging problems to design and manage networks. The virtualization of network functions and the programmability of the control plane will lead to architectures composed of several virtual

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network layers on top of a shared physical infrastructure, in many network segments. Although a key rule in the administration of large networks is to avoid complexity, mainly so that human administrators can stay in charge, the complexity of the tasks on the one hand, and the constantly improving efficiency and reliability of software on the other hand, will undoubtedly to rely more and more on automated processes. Thus, on the road towards automated networking, many challenging optimization problems have first to be tackled to deliver efficient and appropriate decision-making algorithms.

In this chapter, the authors present some of these optimization problems, essential to deliver and operate robust services on top of the future network architectures. Our purpose is to provide a State-of-The-Art (SoTA) of the optimization and decision-making challenges such as efficient routing and forwarding, physical and virtual resource allocation, and virtual network function placement. Along with the SoTA, an insight on the complexity of the underlying optimization problems is provided.

The chapter is divided into two main parts associated to two major optimization challenges: first, the routing policies in software-defined networks, second the optimization challenges that arise with the emergence of 5G and more generally virtualized networks: the virtual network embedding onto a physical infrastructure and the virtual network function placement and routing in the context of Service Functions Chaining.

**ROUTING OPTIMIZATION IN SOFTWARE-DEFINED NETWORKS**

In spite of the promises of the MPLS forwarding scheme, most IP networks still heavily rely on shortest-path rules where weights are assigned to links by network administrators and the routers are then able to compute shortest routing paths. It has been acknowledged for a long time that this indirect control (by setting administrative weights only) on the overall routing scheme makes the TE (Traffic Engineering) tasks very difficult to execute. On the contrary, MPLS-based mechanisms allow network administrators to deploy almost any possible routing pattern. However, the introduction of such a powerful tool shifts the problem from “how do I set weights so that traffic uses (more or less) the routes I want?” to a new kind of problem, namely “how do I find the best set of routes?” Indeed, if traffic between any o-d (origin-destination) pair can be forwarded along any combination of paths, deciding the routes for all o-d pairs at the same time seems an intractable problem.

Fortunately, such problems are extremely well solved using sophisticated optimization techniques and powerful algorithmic tools. The rise of SDN is a major opportunity to wisely combine all these optimization approaches in order to derive efficient routing and forwarding policies.

**Some Building Blocks**

Most of the problems requiring somehow the computation of optimal routes within a telecommunication network can be closely related to well-known and intensively studied problems in optimization and graph theory. The shortest-path problem is one of the most studied problems in graph theory and hundreds of extremely powerful algorithms have been designed in the past to address almost every possible variant (Schrijver, 2002). The so-called multi-commodity flow problem consists in deciding how to send flows in a graph between various pairs of end-nodes (called commodities) and without exceeding the edge capacities (Minoux, 2008). This problem is obviously particularly well-suited to model traffic demands routed within a telecommunication network.
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