Chapter 1
Optical Network Optimization

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ABSTRACT
Optical networks form the foundation of the global network infrastructure; hence, the planning and design of optical networks is crucial to the operation and economics of the Internet and its ability to support critical and reliable communication services. This book chapter covers various aspects of optimal optical network design, such as wavelength-routed Wavelength Division Multiplexing (WDM) optical networks, Spectrum-Sliced Elastic (SLICE) optical networks. As background, the chapter first briefly describes optical ring networks, WDM optical networks, and SLICE optical networks, as well as basic concepts of routing and wavelength assignment and virtual topology design, survivability, and traffic grooming in optical networks. The reader is referred to additional references for details. Many optical network design problems can be formulated as sophisticated optimization problems, including (1) Routing and Wavelength Assignment (RWA) and virtual topology design problem, (2) a suite of network design problems (such as variants of traffic grooming, survivability, and impairment-aware routing), (3) various design problems aimed at reducing the overall energy consumption of optical networks for green communication, (4) various design optimization problems in SLICE networks that employ OFDM technologies. This chapter covers numerous optical network design optimization problems and solution approaches in detail and presents some recent developments and future research directions.

INTRODUCTION
Optical networking forms the foundation of the global network infrastructure, hence the planning and design of optical networks is crucial to the operation and economics of the Internet and its ability to support critical and reliable communication services. The optimal design and operation of optical core networks therefore lie in the heart of current and future Internet. Many optical network design problems can be formulated as sophisticated optimization problems.

In this book chapter, we will provide a detailed coverage on the design optimization of optical networks, such as wavelength-routed Wavelength
Division Multiplexing (WDM) optical networks, Spectrum-Sliced Elastic (SLICE) optical networks. As background, the chapter first briefly describes ring networks, WDM optical networks, and SLICE optical networks, as well as basic concepts of routing and wavelength assignment and virtual topology design, survivability, and traffic grooming in optical networks.

We will then present a host of network optimization formulations and, whenever applicable, optimal solutions, to a suite of network design problems, such as virtual network topology design, protection and restoration, traffic grooming, energy/impairment-aware routing, and optical layer multicasting. In particular, we will cover some recent developments that deal with solving the Routing and Wavelength Assignment (RWA) problem in large networks with a large number of wavelengths using a decomposition technique which results in computationally efficient formulation for the RWA problem and scalable optimal solutions.

In spite of the fact that optical networks continue to be a critical component of future networks due to their high capacity, low transmission loss, transparency to signal rate and format, and resilience to noise and harsh environmental conditions, less attention has been focused on investigating energy-efficient optical networks. Optical networks consist of components such as optical switches, amplifiers, transponders, regenerators, and wavelength convertors, all of which require considerable energy, and thus maintenance cost, to operate. Furthermore, physical impairments of transmitted optical signals, such as attenuation, dispersion, and cross-talk, can have an adverse impact on the overall system power consumption by increasing the need for equipments to address these impairments. This chapter will cover design optimization problems of new optical network architectures and protocols, aimed at reducing the overall energy consumption in optical core networks, for example, innovative energy efficient optical grooming routing, traffic grooming, and survivability techniques.

The fixed-size frequency allocation in WDM networks has drawbacks in its coarse granularity, less flexibility and spectral efficiency. Instead of using a single carrier and fixed channel assignment, Spectrum-Sliced Elastic optical path (SLICE) networks (Jinno, Takara, & Kozicki, 2009; Jinno, et al, 2009; Sone, et al, 2009; Takara, et al, 2010) employ OFDM technologies to accommodate traffic more efficiently and alleviate the increase in the cost of capacity in the backbone networks. SLICE networks enable flexible sub-wavelength and super-wavelength accommodation with high spectral and energy efficiency. Power consumption can be reduced by unique features from SLICE networks such as optical sub-carriers bypassing and partial spectrum path shutdown. This chapter will summarize a number of design optimization problems in SLICE networks such as elastic routing and spectrum allocation (RSA) to determine how traffic requests can be best accommodated, virtual networks mapping over SLICE to determine how joint optimization of RSA and virtual network mapping can be achieved, sub-carrier failure recovery, and energy-efficient design in SLICE networks to determine how best constrained network resources can be used in an energy-efficient manner.

**OPTICAL NETWORKS AND DESIGN OPTIMIZATION PROBLEMS**

Optical fiber transmission has played a key role in increasing the bandwidth of telecommunications networks, especially in recent two decades as the Internet penetrates our daily lives. The evolution of optical communication systems has gone through several generations. In the first-generation of optical networks, optical fibers were used purely as a
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