Chapter 6

Energy–Efficient Optical Transport Networks with Mixed Regenerator Placement

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ABSTRACT

In this chapter, the authors first discuss the background and basic concepts of all-optical regeneration and translucent optical networks. Since all-optical regenerator is much more energy-efficient than traditional O/E/O ones, they investigate translucent lightpath arrangement that involves mixed placement (MRP) of optical inline amplifiers (1R), all-optical 2R regenerators, and O/E/O 3R regenerators for energy-saving. In order to make sure that the end-to-end transmission performance requirement can still be satisfied with this arrangement, the authors analyze the signal BER evolution through fiber links and different types of regenerators, and propose a theoretical model. They then develop search strategies based on exhaustive search and genetic algorithms, and discuss how to use them to optimize the energy-efficiency of lightpaths using MRP. Finally, the authors move to the network design using MRP, in which they considered both offline network design and online network provisioning.

INTRODUCTION

Over the last decade, Internet traffic has been growing at an annual rate of more than 70% (Odlyzko, 2003), and various network applications continue to require for more bandwidth. With the Dense Wavelength Division Multiplexing (DWDM) technology, over 10 Tb/s capacity can be provided over a single strand of fiber (Fukuchi et al., 2001).

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In order to facilitate efficient and flexible access to such a wide bandwidth, researchers are still looking for ways to automate and expedite bandwidth provisioning in the optical layer. These ongoing efforts indicate the inevitable trends of the development of more flexible, intelligent, and energy-efficient optical layer, especially for core and transport networks. While the remarkable growth of Internet bandwidth demands have spurred intensive research on efficient optical networking systems, the major technical difficulties are still
caused by the physical layer limitations, such as signal-to-noise degradation, fiber dispersions, crosstalk, and nonlinearities. In opaque optical networks, optical-electronic-optical (O/E/O) 3R (Re-amplification, Re-shaping, and Re-timing) regenerators overcome physical layer limitations at every switching node to increase transmission reach. However, since devices are usually expensive and power-hungry (Leclerc et al., 2003). For example, the state-of-the-art optoelectronic core router, a Cisco CRS-3 16-slot single-shelf system for 4.48 Tb/s aggregate switching capacity, has dimensions (H x W x D) of 213.36 x 59.94 x 91.44 cm, with a maximum power consumption of 13.2 kilowatts http://www.cisco.com/en/US/products/ps5763/prod_models_comparison.html. To support over 300 Tb/s throughput, it has to use a multi-shelf configuration that may consume more than one million watts. These factors limit the scaling of the transport network infrastructure. Therefore, network operators have to mitigate their network infrastructure from opaque to translucent, for reducing capital expenditures (CAPEX) and operational expenditures (OPEX) (Saradhi et al., 2010).

Translucent network design aims to minimize the number of O/E/O 3R, without compromising transmission performance. Recently, all-optical 2R (Re-amplification and Re-shaping) regenerators have been demonstrated for operation speed at 40 Gb/s and beyond (Leclerc et al., 2003), and commercially available devices have been released (Maxwell, 2008; Zhu et al., 2005). Compared to O/E/O 3R, these devices are much more energy-efficient and cost-effective, and can achieve wavelength conversion simultaneously with signal regeneration (Leclerc et al., 2003). Therefore, if we introduce all-optical 2R in translucent lightpath design, we can solve the signal quality and wavelength contention issues in optical networks with a more energy-efficient and cost-effective way. To explore these benefits, we will discuss on translucent lightpath arrangement that involves mixed placement (MRP) of optical inline amplifiers (1R), all-optical 2R regenerators, and O/E/O 3R regenerators. It is well known that the estimation of quality of transmission (QoT) in optical transport networks is usually time consuming, especially for the cases with mixed regenerator placements (Zhu, 2011). We will focus on search strategies based on exhaustive search and genetic algorithm, discuss how to use them to find the optimized solutions of MRP for lightpaths, and compare the performance of these strategies. By the end of this chapter, we move to network design with MRP, in which we will consider both offline network design and online network provisioning.

The rest of the chapter is organized as follows: Introduction discusses the background and basic concepts. The analytical model of signal transmission through translucent lightpaths with Mixed Regenerator Placement (MRP) is presented afterwards. We propose several regenerator location search algorithms to design energy-efficient translucent lightpaths. The MRP-based green translucent network design and provisioning methods are then discussed. Finally, we summarize this chapter and draw conclusions.

BACKGROUND AND BASIC CONCEPTS

All-Optical Regeneration

The major task of optical transport networks is to deliver high-speed data over long transmission distance across a large number of switching nodes. While the combination of wavelength division multiplexing (WDM), optical amplification and modulation techniques keeps pushing the fiber transmission capacity to heroic numbers (Beceuarn et al., 2004; Borne et al., 2006; Yoshikane et al., 2004), the main technical difficulties for improving the optical transport networks' scalability remain to be physical layer limitations from signal-to-noise ratio degradation, Chromatic Dispersion
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