Chapter 9
Applications of Computational Intelligence to Impairment–Aware Routing and Wavelength Assignment in Optical Networks

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ABSTRACT
Computational intelligence techniques have been used to solve hard problems in optical networks, such as the routing and wavelength assignment problem, the design of the physical and the logical topology of these networks, and the placement of some high cost devices along the network when it is necessary, such as regenerators and wavelength converters. In this chapter, the authors concentrate on the application of computational intelligence to solve the impairment-aware routing and wavelength assignment problem. They present a brief survey on this topic and a detailed description and results for two applications of computational intelligence, one to solve the wavelength assignment problem with an evolutionary strategy approach and the other to tackle the routing problem using ant colony optimization.

INTRODUCTION
The computational intelligence field has experienced an amazing growth in the last years. Beyond the well known techniques, such as Genetic Algorithms (GA) and Multi-Layer Perceptron Artificial Neural Networks (MLP ANN), many novel paradigms have been proposed to tackle different types of problems, such as combinatorial permutation problems in high dimensionality, multimodal optimization and many-objective optimization. In general, these approaches were inspired in nature. Some examples of these novel algorithms are Evolutionary Strategies (ES), Differential Evolution (DE), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Immune Systems (AIS), Artificial Bee Colony Optimiza-
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These algorithms have been frequently applied to solve complex problems in many scientific areas since the mid nineties. Furthermore, many researchers have proposed to tackle networking problems with bio-inspired techniques. Dressler (Dressler, 2010A) presented an overview of some key concepts and methodologies of these techniques when applied to solve network problems, addressing some capabilities and their practical relevance. Most of the examples given in (Dressler, 2010A) addresses applications for wireless networks. It shows that these techniques have not been proposed solely to solve problems in optical networks, but in transmission systems and networks in general. A special edition of a renowned journal was dedicated to bio-inspired networking (Dressler, 2010B).

Recently, some efforts have been carried out to demonstrate that these techniques can be useful to tackle tough problems in optical networks, such as to solve the Routing and Wavelength Assignment (RWA) problem, to design the physical and the logical topology of these networks and to properly place some high cost devices along the network when it is necessary, such as regenerators and wavelength converters.

In this chapter we will concentrate on the application of computational intelligence to solve the impairment-aware routing and wavelength assignment problem. We will present a brief survey on this topic and detailed description and results for two applications of computational intelligence, one to solve the wavelength assignment problem with evolutionary strategy and the other to tackle the routing problem using ACO.

BACKGROUND

Wavelength routed optical networks have been considered as the most reliable and economic solution to achieve high transmission capacities with Quality of Service (QoS). In these networks, the signal remains in the optical domain between the edge nodes, i.e. the signal propagates along the core of the optical network without any optical-electrical-optical conversion. One of the main challenges in these optical networks is to define an appropriate RWA algorithm in order to obtain a low blocking probability with an acceptable Quality of Transmission (QoT) for every established lightpath. A suitable impairment-aware RWA algorithm has to find a route and select a wavelength between the source-destination nodes that provides a minimum QoT for every network request, taking into account the impairments imposed by the physical layer. Besides, the RWA algorithm needs to consider the efficient utilization of network resources and the optimization of the network performance (Rahbar, 2011; Azodolmolky, 2009; Martinez, 2006).

In general, the routing problem and the wavelength assignment are treated separately. Several solutions were already proposed for the static problem and for the dynamic problem. Some approaches based on evolutionary computation were proposed for static routing in the past, however we believe the next generation of optical networks will have to deal with dynamic provisioning of resources. Some recent approaches were proposed to tackle the dynamic problem using different computational intelligence paradigms, such as Hopfield Neural Networks (HNN) (Bastos-Filho, 2010), Power Series Routing trained by Particle Swarm Optimization (PSR) (Martins-Filho, 2008, 2012; Chaves, 2011), Ant Colony Optimization (ACO) (Triay, 2010; Pavani, 2010), Evolutionary Strategies (ES) (Bastos-Filho, 2011), among others.

Bastos-Filho et al. (Bastos-Filho, 2010) proposed a routing algorithm based on Hopfield Neural Networks for transparent optical networks. The HNN takes into account the matching of available wavelengths between adjacent links along the lightpath and the HNN parameters are selected by a Multi Objective Optimizer in order to both