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Computational intelligence in photonics technology and optical networks: A survey and future perspectives

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Abstract

The continuous growth of broadband communications, multimedia services and Internet is absolutely related to the deployment and operation of optical networks. Despite optical fibers' enormous physical bandwidth the development of optical networks for today's advanced, reliable and guaranteed-type services, require an efficient management of the bandwidth together with an orthological and careful use of optical components given their high manufacturing cost. These requirements have lead to the need for sophisticated photonic devices and to optical networks' implementations of increased functionality and associated thus complexity. For the efficient consideration of those problems different design and optimization techniques have been applied to date. However, as the complexity increases, the use of computational intelligence (CI) in those problems is becoming a unique tool of imperative value. In this paper we review in a unified approach the applications of CI starting from the physical layer and ending to services layer, given that here there is a strong relation and unique interplay between components' technology and network issues, being sharing the common target of physical bandwidth's efficient utilization. The applicability of different CI classes (genetic algorithms and evolution strategies, fuzzy systems, and artificial neural networks) in optical wavelength division multiplexing (WDM) networks is identified and evaluated. Furthermore specific optical networks' optimization problems are categorized. Being a rapidly growing area, new trends, such as evolutionary game theory, in understanding and design of large scale Optical Network are also identified and discussed. The paper seeks to review the aforementioned areas, identify new problems and trends, triggering this way new research efforts for interdisciplinary cooperation between researchers.

Keywords: Computational intelligence; Evolution strategies; Genetic algorithms; Neural networks; Fuzzy systems; Optimization; Optical networks; WDM; Photonic components

1. Introduction

Optical networks form undoubtedly the core technology for the construction and operation of today's and next generation's broadband communications and multimedia services, such as video on demand, videoconferencing,

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real time telemedicine etc. Few years ago optical fibers were simply and inefficiently used as a transmission medium with huge bandwidth, for point to point transmission of information. The evolution and development of the photonics technology together with the increased need for an internetworking broadband communication environment pushed to the direction of the development of more sophisticated optical networks. Those networks are now interconnected and cooperated with other network technologies such as wireless, satellite etc, and have also expanded from the transport layer to the access layer as fiber to the home (FTTH) applications [64].

The future challenge for the optical technology is the development to the form of all-optical networks in order to fully exploit the available optical fibers' bandwidth. The obvious and current approach toward the development of all-optical networking is the wavelength division multiplexing (WDM) technology [123], where hundreds of wavelength channels can be established in a single fiber link. Transmission capacities of Tb/s have been already demonstrated in optical test beds and so WDM technology is expected to dominate next generation backbone transport networks.

The paper is focusing on the applications of computational intelligence (CI) – evolution strategies, genetic algorithms, neural networks, and fuzzy logic – into this rapidly growing area of optical networks. Computational intelligence is an area of fundamental and applied research [89,131] involving numerical information processing in contrast to the symbolic information processing techniques of artificial intelligence (AI). The main theoretical characteristics of a computational intelligent system are mainly the following [108]: it deals only with numerical (low level) data, has a pattern recognition component, it exhibits computational adaptability, computational fault tolerance, speed approaching human – like turnaround. CI's major advantages like broad applicability, robustness to dynamic environments, self optimization capability, established its role as an optimization and design tool in modern telecommunication networks [89,108,131]. As complexity of technology and networks' services increase new challenging multi-combinatorial problems are emerging and consequently the CI applications are expected to be further enhanced.

The scope of this survey paper is to comprehensively review CI applications in the design, optimization and operation of optical networks and their underlying photonic components technology. This integrated approach for the review is judged as a necessity given that optical networks technology form a special case of a uniquely strong and unidirectional relation between physical and network layer. Today's WDM networks rely almost exclusively on the development of optically intelligent components for wavelength recognition and all optical processing. The functionality and performance of those components affect drastically the design and the operation of the network.

Despite the focus of the survey on the single technological area of optical networks, we demonstrate the extended frontiers of this technology ranging from physical aspects of light manipulation to purely networking issues such wavelength routing, traffic grooming, restoration techniques and QoS routing. By this way the extended applicability of CI in such a broad area of problems is also demonstrated. Furthermore given that all these different layers' optimization problems are closely related and becoming almost indistinguishable as the evolution of all-optical network is progressing, the optimization problem will become more challenging for CI in this new multi combinatorial environment.

The paper is organized in the following sections. Section 2 gives a brief introduction in the main optical components used in optical telecommunication systems and networks. Characteristic applications of computational intelligence in the design of optical components are presented for different categories of those devices, such as integrated optics, grating based devices, photonics crystals, optical amplifiers etc. Section 3 gives a brief presentation of the evolution and current status of optical networks, in order to support the following discussion in Section 4 where the main design issues of WDM optical networks are discussed. Section 5 presents the optimization issues in Optical Networks. These optimization problems are categorized in a few main classes such as physical and logical topology, routing and wavelength assignment, optimal placement of components, traffic grooming, and services provision optimization. Section 6 contains the discussion and concluding remarks.

2. Optical components

Photonic components are based on fundamental physical mechanisms of light propagation or manipulation but today they have been evolved in quite complex systems that are usually multifunctional devices. Photonic components for all-optical networks cover a quite broad range of technologies, since the optical technology