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Review

Multi-objective routing and wavelength converter allocation under uncertain traffic

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ABSTRACT

Uncertain traffic plays an important role in the design of long-term optical networks. The performance of these networks is highly dependent on the way the wavelength converter allocation and routing problems are solved. In order to achieve a good performance for long time periods, both problems should be dealt with together, considering at the same time, uncertain traffic. To this aim, this work proposes a joint optimization approach where uncertainty is modelled through scenarios and the allocations of converters and paths for routing are simultaneously calculated. A multi-objective evolutionary algorithm is proposed to simultaneously minimize the number of wavelength converters, as well as the expectation and unfairness of the blocking probability. The proposed algorithm calculates an approximation to the optimal set of trade-off solutions called Pareto set. A benefit-cost study on the approximate Pareto set is proposed in order to help in the decision concerning the number of converters to be installed. The work also calculates the relation between the number of converters and the hyper-volume metric of expected blocking probability and the maximum unfairness through all scenarios, recommending that, the best number of converters to be strategically allocated ranges from 20% to 60% of the total number of nodes in a typical optical network.

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1. Introduction

Wavelength division multiplexing (WDM) network based on wavelength-routing has emerged as a feasible architecture for wide area networks (WANs) [1]. Optical networks consist of wavelength cross-connect nodes interconnected by optical fibres. Thus, the network provides all-optical communication between pairs of nodes by establishing circuit-switched connections called *light-path* [2].

Wavelength cross-connect nodes that interconnect pairs of optical fibres should use the same wavelength. This is known as the *wavelength continuity constraint* which forces to use just one wavelength for a complete light-path and it is the main cause of blocking in wavelength-routing networks [1,3].

Minimizing the blocking probability is possible using wavelengths converters [4] at cross-connect nodes, where a given wavelength may be converted into a different one when that conversion is convenient to maximize throughput or to minimize blocking.

The assumptions made in this work to study the impact of uncertain traffic in the multi-objective RWCA problem are as follows: a sparse-wavelength-conversion network architecture, a routing based on K-shortest paths [5], and a random wavelength assignment [6]. The uncertainty is modelled by means of scenarios as it is done by previous works dealing with optimization under uncertainty [7–9].

The minimization of system's blocking probability by an optimal selection of paths [10–12] and optimal wavelength converter allocation strategies [13–16] are the main focus of this work.[1]

Although the routing and wavelength converter allocation schemes are critical to get high performance, they can be dealt with separately, or sequentially in an *iterative-joint* optimization approach under dynamic traffic [5,6,24]. However, in high complexity topologies those approaches are not capable of finding good solutions considering the huge unexplored sub-set of solutions [3]. To overcome this issue, a recent work [4] proposed to solve the routing and wavelength converter allocation (RWCA) problem in a *full-joint* optimization approach. All works using iterative and/or full joint optimization [3–6,24], only consider one dynamic pattern traffic. Logically, the network performance may deteriorate when traffic changes pattern. In this new context of changing traffic patterns, of course, uncertain traffic issues must be taken into account. In addition, the minimization of cost and blocking probability are in conflict, so the problem must be modelled in a multi-objective context.

The main contributions of this work are as follows: (i) The design of a multi-objective evolutionary algorithm (MOEA) [25] which calculates simultaneously, for the first time, under a dynamic and uncertain environment, the best converter allocation and the best routing, minimizing the number of converters as well as the average blocking probability and the unfairness of blocking, in order to get a good trade-off among these three criteria [26]. (ii) In addition, studies on this trade-off are performed in order to quantify the benefits of introducing routing and converter allocation in sparse-wavelength-conversion network design.

The rest of this work is organized as follows: uncertain traffic, wavelength converter, and fairness concepts in optical networks are introduced in Section 2; the problem formulation in a multi-objective context is given in Section 3; the proposed evolutionary approach is presented in Section 4 while experimental results and discussion are given in Sections 5 and 6, respectively; finally, conclusions and ideas for future work are exposed in Section 7.

2. Preliminary concepts in optical networks

2.1. Uncertainty in traffic networks

Optical network design under uncertain traffic can be subject to the following basic aspects: (a) the model of uncertain traffic [7,9] and (b) the traffic dynamics [27]. In this context, the traffic model is analysed, then, approaches that consider uncertainty in traffic networks are studied.

2.1.1. Traffic models under uncertainty

Chekuri at al. [7,28] reported three dynamic traffic models: scenario-based model, hose model, and polyhedral model. In the scenario-based model, traffic is represented by a set of traffic matrices $\mathbf{T}=\{t_{sd}\}$ where t_{sd} is the traffic load from source node s to destination node d. Therefore, this model is called also pipe or discrete [29]. According to

[1] There are other schemes/strategies that can be viewed in [17–23].