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Minimum cost dimensioning of ring optical networks

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Abstract

We consider the problem of traffic grooming of low-rate traffic circuits in WDM rings where circuits are associated with a set of heterogeneous granularities. While networks are no longer limited by transmission bandwidth, the key issue in WDM network design has evolved towards the processing capabilities of electronic switches, routers and multiplexers. Therefore, we focus here on traffic grooming with minimum interconnecting equipment cost. We first formulate the problem as an integer linear programming (ILP) or a mixed integer linear programming (MILP) problem depending on the design specifications: UPSR vs BLSR, fixed vs variable wavelength capacities, non-bifurcated vs bifurcated flows, wavelength continuity vs possible signal regeneration on a different wavelength. Considering the case study of the second SONET ring generation with MSPP like interconnection equipment, we define the cost by a function of the number of transport blades, taking into account that the number of MSPP transport blades makes up a significant portion of the overall network design cost. Using the CPLEX linear programming package, we next compare the optimal solutions of the ILP or MILP programs for different design assumptions, including the classical ring network design scheme with a single hub where the lightpaths directly connect the hub to all other nodes.

Keywords: Grooming; Routing; Wavelength assignment; Ring optical network; WDM; SONET; MSPP; OADM; UPSR; BLSR

1. Introduction

Rings have been and are still widely used in optical networks, and several papers have studied the GRWA (Grooming, Routing and Wavelength Assignment) problem for ring networks under various grooming or traffic assumptions. Traffic grooming is defined as the problem of how to pack different low-rate traffic streams into higher speed streams. In a WDM (Wavelength Division Multiplexing) network, the traffic grooming is often coupled with the RWA problem, i.e., the problem of routing and wavelength assignment of the higher speed streams so as to optimize some design objective or minimize the management cost. The resulting problem corresponds to the so-called GRWA problem.

Even if ring networks correspond to an elementary architecture, the ring GRWA problem is already an NP-complete problem, as it can be reduced to a bin-packing problem (Chiu and Modiano [1]). However, analytical solutions can be found under particular grooming or hub or traffic assumptions, see, e.g., Gertsel, Ramaswami and Sasaki [2], Gerstel, Lin and Sasaki [3], Zhang and Qiao [4,5].

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When it is not possible to find an analytical solution, various algorithms and mathematical models have been proposed, again under various grooming or traffic assumptions. An often used simplifying traffic assumption considers that client signals all possess the same capacity. Publications based on this assumption usually define a grooming factor which is the ratio of the capacity of the high-speed optical transport signals over the capacity of the client signals (Chiu and Modiano [1]). As an example of this single traffic granularity assumption, an OC-48 network, for which the capacity is 2.5 Gb/s on each wavelength, serving OC-3 client signals, with 155 Mb/s capacity, corresponds to a grooming factor of 16. This means that up to 16 client signals can be groomed to form a high-speed optical transport signal.

In order to solve the GRWA problem exactly, several mathematical models corresponding to integer linear programs (ILP) have been proposed for the ring grooming problem. Each of them considers particular cases. We review them below. Wang et al. [6,7] study the minimization of the number of ADMs for both unidirectional and bidirectional rings. They consider non-uniform traffic with a grooming factor and compare the cases of single-hop connections and multiple-hop connections where a hub node is used to cross-connect traffic between different wavelengths. Hu [8] proposed an ILP formulation for unidirectional rings assuming traffic under the simplifying assumption of a grooming factor for the minimization of the number of ADMs. Hu [8] showed that the ILP formulation can be reduced to a MILP (i.e., Mixed ILP) formulation that is much easier to solve in practice. Another formulation can be found in Liu and Tobagi [9] that generalizes Hu's formulation [8] to support multiple line speeds but under the same restricted assumptions (unidirectional rings, grooming factor).

While most linear programming relaxations of the ILP formulations can be used, when solvable, to get lower bounds, some studies have also focused on the computation of lower bounds, see, e.g., Wang, Liu and Frieder [10], Billah, Wang and Awwal [11] for bounds on the number of wavelengths, Bermond and Coudert [12] for unidirectional rings, and Chow and Lin [13] for uniform traffic.

As it is often difficult to solve exactly the integer linear programs of the various mathematical models, different heuristic schemes have also been proposed, but again under some restricted assumptions. We report below some of the studies that considered a cost objective, i.e., most often the minimization of the number of SADMs — SONET Add/Drop Multiplexers. First greedy heuristics were proposed by Gerstel, Lin and Sasaki [14] and later improved by Li, Scott and Deogun [15]. Zhang and Qiao [16] proposed an extension of their analytical solution for uniform traffic with circle construction to non-uniform traffic and derived lower bounds for either minimizing the number of wavelengths or of SADMs. Wang et al. [6,7] designed a Simulated Annealing heuristic for non-uniform traffic with single-hop connections in unidirectional and bidirectional rings. Battiti and Brunato [17] proposed a reactive local search heuristic for all-to-all uniform traffic with various grooming factors. Ghafouri, Zhu and Fei [18] proposed various optimization algorithms, based on full or partial circle constructions, that aim at minimizing the number of SADMs while optimizing the number of wavelengths. Calinescu, Frieder and Wan [19] proposed two polynomial-time approximation algorithms, with some performance guarantees close to 1.5. Other approximation algorithms can be found in Li and Simha [20]. Zhang and Ramamurthy [21] proposed a greedy and a Tabu Search heuristic for dynamic traffic grooming that they also experimented with success for static traffic grooming with the grooming factor assumption. Finally, although not limited to ring networks, let us cite the work of Zhu et al. [22] that investigated the GRWA problem with OXCs (optical Cross Connect) of different bandwidth granularities and proposed an auxiliary graph model heuristic scheme to solve it.

In this paper, we consider the general ring GRWA problem where client signals have different capacities. Consequently, multiple traffic granularities are involved and no grooming factor is therefore defined. Moreover, we do not assume any specific hub design constraints as we want to study a distributed design scheme in terms of interconnecting equipment (i.e., MSPP – MultiService Provisioning Platform – available at each node with a limited, but not necessarily identical, number of transport blades). Indeed, we want to find the minimum cost GRWA design, with the cost defined as a function of the number of transport blades. Such a distributed design offers more flexibility in addition to some cost reduction in exchange of a slight increase in the complexity of network management.

The paper is organized as follows. In Section 2, we present a brief introduction to SONET and WDM architectures with a particular focus on the cross-connect equipment that plays a critical role in the amount of optical bypass and consequently on the grooming efficiency in order to reduce the design costs. In Section 3, we set a mathematical formulation that encompasses different design scenarios and many of